Analysis and Improvement of Security Concerning Light Commercial Vehicles

PFC
Enrique Garcia Orte
Supervisor: Adrian Gomila
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Analysis and Improvement of Security Concerning Light Commercial Vehicles
Abstract
Statistics confirm that there is a need to study the safety of vans with a permissible maximum laden mass between 2000 and 3500 kg. as well as develop strategies for improvement. The number of fatalities in accidents involving vans has been constant during the last 10 years, not following the diminishing tendency shown by the general accidents. Not only efficient, but also safer road freight transport is required.

This report analyses the security of the light commercial vehicles across the study of the influence from load distribution and the effectiveness of ESC (Electronic Stability Control). Through the medium of simulations made with Pc-Crash software, it has been analysed if the implementation of ESC in vans can at some extent compensate the influence of inaccurate load distributions.

Furthermore, due to van’s relatively high centre of gravity and its load, vans may have less avoidance properties than a passenger car. Also (in addition) the differences of braking and dynamic properties between passenger cars and light commercial vehicles have been studied.

Neither through literature review nor through own tests, the widespread opinion that vans have much worse active safety systems (brakes, driving stability when negotiating a turn) than passenger cars could not be verified.

Effectiveness of ESC implementation was proved just on specific load configurations, highlighting the importance of proper load distribution. On the other hand, Cost-Benefit analysis considering the installation of the ESC shows positive Social benefits for both countries, Denmark and Spain.
# Analysis and Improvement of Security Concerning Light Commercial Vehicles

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Chapter 1. Introduction

1.1 Origin of the project

Worldwide traffic is increasing with more and more vehicles on the road. With further economical growth (after the global crisis), it will be possible to see more increase in mobility and in traffic density throughout the world. This will require efforts to furthermore enhance the road safety. Thus, these changes are having a serious effect on one specific type of vehicle, the delivery van with a maximum allowed weight between 2-3.5 tons.

The statistics for the European Union demonstrate alarming results. In 2001, in the UE died 976 occupants of vans. Since that date, this figure fall to 795 deaths in 2005, this means a decrease of 18.5%. However, this is still far from the reduction achieved on passenger cars, where the difference between 2005 and 2001 is 25.6% less. A further study has been carried out comparing the two specific countries where this thesis has been done, Denmark and Spain.

1.1.1 Statistics from Denmark and Spain

- Spain

From the data of 2007 that has been obtained from the Dirección General de Tráfico DGT, in Spain there is a total of 2,435,706 which means an increase of 50% from 1999. Figure 1 shows a positive tendency on the number of registered vans per year.

![Figure 1: Vans registered in Spain per year](image)

On the other hand, by analysing the accident data it can be concluded that the general decrease on accidents and fatal injuries produced on the last years have not been translated to the light commercial vehicles

<table>
<thead>
<tr>
<th>Source: DGT</th>
<th>Victim role</th>
<th>Total</th>
<th>Dead</th>
<th>Total</th>
<th>Severe</th>
<th>Slight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>3,534</td>
<td>154</td>
<td></td>
<td>3,380</td>
<td>526</td>
<td>2,854</td>
</tr>
<tr>
<td>Passenger</td>
<td>2,679</td>
<td>81</td>
<td></td>
<td>2,598</td>
<td>380</td>
<td>2,218</td>
</tr>
<tr>
<td><strong>Total 2004</strong></td>
<td><strong>6,213</strong></td>
<td><strong>235</strong></td>
<td></td>
<td><strong>5,978</strong></td>
<td><strong>906</strong></td>
<td><strong>5,072</strong></td>
</tr>
<tr>
<td>Diver</td>
<td>3,543</td>
<td>133</td>
<td></td>
<td>3,410</td>
<td>597</td>
<td>2,813</td>
</tr>
<tr>
<td>Passenger</td>
<td>2,452</td>
<td>72</td>
<td></td>
<td>2,380</td>
<td>398</td>
<td>1,982</td>
</tr>
<tr>
<td><strong>Total 2005</strong></td>
<td><strong>5,995</strong></td>
<td><strong>205</strong></td>
<td></td>
<td><strong>5,790</strong></td>
<td><strong>995</strong></td>
<td><strong>4,795</strong></td>
</tr>
<tr>
<td>Diver</td>
<td>4,030</td>
<td>153</td>
<td></td>
<td>3,877</td>
<td>618</td>
<td>3,259</td>
</tr>
<tr>
<td>Passenger</td>
<td>2,954</td>
<td>77</td>
<td></td>
<td>2,877</td>
<td>451</td>
<td>2,426</td>
</tr>
<tr>
<td><strong>Total 2006</strong></td>
<td><strong>6,984</strong></td>
<td><strong>230</strong></td>
<td></td>
<td><strong>6,754</strong></td>
<td><strong>1,069</strong></td>
<td><strong>5,685</strong></td>
</tr>
</tbody>
</table>

Table 1: Van victims in Spain 2006
During 2006 there were 15% more drivers of vans dead, while in the same period there was a general decrease of 8%. No further data for years 2007 and 2008 has been found in relation with drivers and passenger of vans.

- **Denmark**

Figure 4 shows, as happened in Spain, an increase of the number of vans registered. On 2008 there are a total of 485,786 vans in Denmark. Obviously, the population in Spain is bigger (44,708,964) than in Denmark (5,447,084) so also the total number of registered vans. Proportionately, this represents a fatality rate of $9.44 \times 10^{-5}$ dead person per van in Spain, while in Denmark the number decrease to $4.94 \times 10^{-5}$. This may show that it is safer to drive a van in Denmark, but in both countries the same problem has been found. Van fatalities do not diminish or even increase not following the tendency shown by the general accidents.

<table>
<thead>
<tr>
<th>Source: statisk banken</th>
<th>Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Victim role</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>Driver</td>
<td>20</td>
</tr>
<tr>
<td>Passenger</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total 2005</strong></td>
<td>352</td>
</tr>
<tr>
<td>Driver</td>
<td>21</td>
</tr>
<tr>
<td>Passenger</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total 2006</strong></td>
<td>330</td>
</tr>
<tr>
<td>Driver</td>
<td>22</td>
</tr>
<tr>
<td>Passenger</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total 2007</strong></td>
<td>305</td>
</tr>
</tbody>
</table>

Table 2: Van victims in Denmark 2006
The data provided by CARE (EU road accidents database) in figures 5 and 6 for Denmark, lead us to different conclusions but to the same target. While in Spain the general fatalities have decreased, in Denmark has increased from 306 fatalities in 2006 to 406 in 2007. On the other hand, it is possible to observe a decrease tendency between 2003 and 2006. Finally, the number of dead persons inside a van remains almost constant between 2005 and 2007 with a value close to 24.

1.2 Motivation of the project

The origin of this project has been the increasing concern and the relative small number of studies that have been carried out regarding vans. Statistics confirm that there is a need to study the safety of light commercial vehicles, as well as develop strategies for improvement.

The aim is to examine vans security by simulating the most common accidents suffered by light commercial vehicles. Often, van accidents begin with a dangerous sliding, ending with a rollover, crashing against a roadside barrier or colliding against moving vehicles in the opposite direction. With the Electronic Stability Control (ESC), it would be possible to avoid such accidents, or at least significantly mitigate their effects. The main problem is that there is a low percentage of currently available models of vans equipped with ESC.

1.2.1 Euro NCAP valuation of ESC

By using the data provided by Euro NCAP it is possible to analyse de availability of the ESC for new cars in Europe. This has been calculated as follows: In each country, e.g. car model is available with two different body, two engines and five different specification level – this means twenty alternatives available to the public. The ESC is incorporated in two series (10 percent) of these variants, as an option on ten (50 percent) and is not available in eight (40 percent) [1]. The proportion of the ESC as standard equipment is shown in green, optional equipment in yellow and if it is not available in red. Figure 7 shows the total of vehicles while figure 8 shows the proportion of the type of vehicles with closer properties to light commercial vehicles.
Figure 7: ESC availability total of vehicles [RACC]  
Figure 8: ESC availability big Minivan [RACC]

There is a big difference between countries. Denmark appears as the first country with 76% of the vehicles with ESC as standard equipment, whereas Ireland has just 51%. Spain is in the tenth position with 63%. Furthermore, it has been found the availability of the ESC for the most common van models in both countries.

Contrary to what happens on passenger cars, it has been found that regarding vans, availability of the ESC is common for every version of each model. The only difference between countries has been found on the Iveco Daily. This poor availability of such important system for security as the ESC has also served as motivation for the study of this project.

Finally, it has been also a motivation to involve a human factor on the study of vans security. Different load configurations and how different positions may aggravate collision consequences have been studied. In fact, is the driver or the personal related with that decides how the load must be positioned.

1.3 Objectives and structure of the project
Paying particular attention to active and passive safety, several tests have been done in order to understand the potential improvements that could be achieved with the introduction of driver assistance systems (ESC mainly), a correct load distribution or the study of unsecured load. This has been done by following those steps:
- Technical description of the vehicle studied. Opel Movano.
- Comparison between the dynamic behavior of a Van and a Passenger car.
- Study of how ESC can prevent an accident or mitigate the consequences for different cargo configurations.
- Analysis of the consequences of unsecured cargo.

First of all, it has been described the most relevant parameters and characteristics of a Van. Those parameters are required by the software used for all of the simulations, the Pc-Crash. This program helps to simulate motions and collisions of vehicles and biomechanical objects after setting all the parameters necessary.

Afterwards, it has been compared the unloaded van in front of four different passenger cars; urban, compact, sedan and a SUV (Sports Utility Vehicle). On the issue of vans, has always been a widespread belief that they are much more insecure than a conventional tourism. Doing a little analysis of the results achieved in different simulations, it has been tried to find out if this idea is well founded or not.

Moreover, it has been studied how different load configurations for the van affects to the dynamic behavior. This has been done by changing the load position along the longitudinal axle of the vehicle and also varying the height. At this point, it has also been studied how ESC can avoid or mitigate collision consequences.

Finally, unsecured cargo scenario has been simulated. Two different loads without lashing have been introduced on a multibody system in order to analyse changes produced by the unsecured load on the vehicle. Also, it has been studied the forces acting on the partition wall.

### 1.4 Project limitations

The limitations of this project are basically two reasons. One is the software, PC-Crash, which despite being considered one of the best systems for the reconstruction of accidents and validated in numerous studies, must be consider as what it is, a program for reconstruction of accidents. Results can be considered realistic, but these results therefore need to be interpreted with caution.

On the other hand, studies like *New Sliding Tests and their Evaluation The ESC Simulation Model in PC-Crash* [2], carried out by the creators of the software Dr. Andreas Moser and Dr. Hermann Steffan, shows that the PC-Crash vehicle dynamics model and ESC model are valuable tools in reproducing the vehicle movement and dynamics for the tests with and without ESC. Also it shows that excellent correlation has been achieved between simulation and test data.

Finally, this project has tried to reproduce common situation while analyzing vans security. On the contrary, there are multitudes of cases and scenarios, which obviously can not be studied entirely.
Chapter 2. General description of a VAN (Opel Movano)

For this project, the Opel Movano has been chosen to do all the simulations and tests in PC-Crash regarding active and passive security of Vans.

The Opel Movano is a mid-sized commercial vehicle sold in Europe from year 1999 and underwent its first facelift in late 2003. The vehicle is available in a wide range of variants, including a choice of three wheelbases, three roof heights and three gross vehicle weights. As well as cargo carrying panel vans, there are also six and nine seat Combi variants, a seven seat crew cab and chassis cabs models. A sixteen seat bus model is also available.

The development of Movano was undertaken by French manufacturer Renault and is also sold as the Renault Master and Nissan Interstar.

Finally, the model that has been chosen is the Opel Movano 2.5 CDTI L2H2. Following tables and schemes shows the most relevant parameters needed to define each simulation.

2.1 Dimensions

2.1.1 Exterior

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>5399 mm</td>
</tr>
<tr>
<td>Total height</td>
<td>2721 mm</td>
</tr>
<tr>
<td>Total width</td>
<td>1990 mm</td>
</tr>
</tbody>
</table>

Table 3: Opel Movano exterior dimensions

2.1.2 Interior

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective front head space</td>
<td>1216 mm</td>
</tr>
<tr>
<td>Effective back space</td>
<td>1708 mm</td>
</tr>
<tr>
<td>Effective hips space</td>
<td>1578 mm</td>
</tr>
</tbody>
</table>

Table 4: Opel Movano interior dimensions
2.2 Wheelbase, tracks and free distance to the ground
The distance values between axles, tracks, front overhang and free distance to the ground are the following:

Wheelbase = 3578 mm
Front overhang = 862 mm
Rear overhang = 959 mm
Track-axle 1 = 1740 mm
Track-axle 2 = 1725 mm

2.3 Interior distribution and distance from front axle to H point
There is just one row of seats on the front part of the vehicle. H point distance is referred to the front axle in x direction and distance to the ground.

2.4 Volume and distance from the load space to the front axle
In relation with the dimensions of the vehicle, is it possible to calculate the maximum loading space, which is approximately:

\[ V_{total} = 12.000 \text{ dm}^3 \]
Where:

\[ A = 3134 \text{ mm}; \]
\[ B = 1764 \text{ mm}; \]
\[ C = 2146 \text{ mm}; \]
\[ D = 1282 \text{ mm}. \]

2.5 Kerb weight and plated weights

It is important to know the position of the gravity center (CoG) for each situation. In this case when the van is empty and also when it is fully loaded.

2.5.1 Characteristics Kerb weight Van

<table>
<thead>
<tr>
<th>Plated weights and kerbweights [Kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>2.5 CDTI L2H2</td>
</tr>
</tbody>
</table>

Table 5: Opel Movano Plated weight and Kerbweights

\[
\begin{align*}
\text{Front axle} &= 1213 \text{ kg} \\
\text{Rear axle} &= 659 \text{ kg} \\
\text{Kerb weight} &= 1871 \text{ kg}
\end{align*}
\]

Table 6: Kerbweight axle distribution

Those values represent a load distribution of 64.7% for the front axle and 35.3% for the rear axle.
Note: Kerb weight for standard vehicles includes coolant, oil, 90% full fuel tank and spare wheel. The maximum authorised mass should be shown on the departments manufacturing plate fitted to the vehicle. This means the marking on a goods vehicle, by means of a ministry plate, showing the maximum weights for that particular vehicle eg maximum authorised mass, and in certain cases, train weight.

\[
Kerb = F_{RA} + F_{FA}
\]

\[
1213 \cdot X_{CoG} = 659 \cdot (3578 - X_{CoG})
\]

\[
X_{CoG} = 1260 \text{ mm}
\]

![Diagram](image)

Figure 15: Opel Movano Kerb Weight Center of gravity [mm]

<table>
<thead>
<tr>
<th>CoG position (Kerweight)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight distribution</strong></td>
</tr>
<tr>
<td>FA</td>
</tr>
<tr>
<td>RR</td>
</tr>
<tr>
<td><strong>Distance [mm]</strong></td>
</tr>
<tr>
<td>L1 (CoG to FA)</td>
</tr>
<tr>
<td>L2 (CoG to RA)</td>
</tr>
<tr>
<td>(H_{CoG})</td>
</tr>
<tr>
<td><strong>Axle Load [Kg]</strong></td>
</tr>
<tr>
<td>FA</td>
</tr>
<tr>
<td>RA</td>
</tr>
</tbody>
</table>

Table 7: Opel Movano Kerweight parameters
2.5.2 Characteristics with a loaded Van
In Chapter 4 it will be studied how different load position may affect Van’s dynamic behavior, so this point should be taken as an example on how de CoG has been calculated for the different simulations.

**Maximum authorised mass**

![Figure 16: Opel Movano Load distribution](image)

Figure 16 shows a possible load distribution. This vehicle can represent a Van used for road assistance in case of any mechanic failure on a car. In this case, it will be assumed that there are two occupants on unique row of seats. As mentioned before, Payload figures do not allow for the weight of the driver, or any passengers, which should therefore be deducted from the figures shown.

Table 8 shows that the load admitted on the back part is 1279 kg. Due to the purpose of this vehicle, there should be some space for a workbench, tools or spare parts. This is as example of the possible load:

1. Space for a compressor and tools = 335 Kg.
2. Welding/hydraulic equipment = 335 Kg.
3. Random parts = 149 kg.
4. Spare parts and tires = 460kg.

<table>
<thead>
<tr>
<th>Kerb weight</th>
<th>1871 kg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupants</td>
<td>$2 \cdot 75 = 150$ kg.</td>
</tr>
<tr>
<td>Load</td>
<td>$1429 - 150 = 1279$ kg.</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3300 kg.</strong></td>
</tr>
</tbody>
</table>

Table 8: Total Load
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<table>
<thead>
<tr>
<th>Zone</th>
<th>Mass (kg)</th>
<th>$X_{CoG}$ (mm)*</th>
<th>$h_{CoG}$ (mm)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>335</td>
<td>3352</td>
<td>1041</td>
</tr>
<tr>
<td>2</td>
<td>335</td>
<td>3622</td>
<td>1291</td>
</tr>
<tr>
<td>3</td>
<td>149</td>
<td>1827,5</td>
<td>1441</td>
</tr>
<tr>
<td>4</td>
<td>460</td>
<td>1827,5</td>
<td>1041</td>
</tr>
</tbody>
</table>

**Table 9: Load Distribution**

(*) Referred to FA  
(**) Referred to the ground

Center of gravity of the load:

\[
X_{CoG} = \frac{335 \cdot 3352 + 335 \cdot 3622 + 149 \cdot 1827,5 + 460 \cdot 1827,5}{1279} = 2696,8 \text{mm}
\]

\[
h_{CoG} = \frac{335 \cdot 1041 + 335 \cdot 1291 + 149 \cdot 1441 + 460 \cdot 1041}{1279} = 1153,1 \text{mm}
\]

### Load Distribution

<table>
<thead>
<tr>
<th>DISTANCE TO FA [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st ROW*</td>
</tr>
<tr>
<td>CoG (Kerweight)</td>
</tr>
<tr>
<td>LOAD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOAD [Kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st ROW</td>
</tr>
<tr>
<td>CoG (Kerweight)</td>
</tr>
<tr>
<td>LOAD</td>
</tr>
</tbody>
</table>

**Table 10: Load parameters**

(*) 100 mm has been discounted from the original value due to normative calculations [3]
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Concerning Light Commercial Vehicles

With those values it is possible to find the CoG of Maximum authorized mass Van:

\[ x_{CoG} = \frac{150 \cdot 753 + 1871 \cdot 1260 + 1279 \cdot 2697}{3300} = 1914,7 \text{mm} \]

\[ h_{CoG} = \frac{150 \cdot 1235 + 1871 \cdot 419 + 1279 \cdot 1153}{3300} = 780,1 \text{mm} \]

Now is possible to find the front and rear axle reactions and compare it to the plated values:

\[ MAM = F_{FA} + F_{RA} = 3300\text{kg} \]

\[ F_{RA} = \frac{x_{CoG} \cdot MAM}{L101} = \frac{1914,7 \cdot 3300}{3578} = 1766\text{kg} \]

\[ F_{FA} = MAM - F_{RA} = 3300 - 1766 = 1534\text{kg} \]

<table>
<thead>
<tr>
<th>Axle reactions [Kg]</th>
<th>MAM</th>
<th>Plated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Axle</td>
<td>1534</td>
<td>1750</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>1766</td>
<td>1900</td>
</tr>
</tbody>
</table>

Table 11: MAM situation Axle reaction

Figure 17: Opel Movano. Kerbweight and Load CoG [mm]
## Analysis and Improvement of Security Concerning Light Commercial Vehicles

<table>
<thead>
<tr>
<th>Load</th>
<th>FA</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>KerbWeight</td>
<td>2182</td>
<td>64,7%</td>
</tr>
<tr>
<td>MAM Center</td>
<td>3300</td>
<td>46,5%</td>
</tr>
</tbody>
</table>

*Table 12: Kerbweight and MAM weight distribution*
Chapter 3. Car/Van comparative

About Vans, there has been always a generalized thought that they are much more insecure than a conventional car [4]. Making an analysis and collecting data from the simulations done by Pc-Crash has been tried to prove if this is true. This analysis is based on the handling and braking capabilities, which are the major components of a vehicle’s active safety.

3.1 Tested Vehicles

For that study, lists of the most common sales for 2008 in Europe has been found in order to make it as more generalized as possible.

<table>
<thead>
<tr>
<th>Top sales car in Europe 2008 (number of vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urban cars</strong></td>
</tr>
<tr>
<td>Fiat Panda 173.026</td>
</tr>
<tr>
<td>Fiat 500 138.953</td>
</tr>
<tr>
<td>Renault Twingo 100.019</td>
</tr>
<tr>
<td>Citroën C1 82.965</td>
</tr>
<tr>
<td>Toyota Aygo 81.923</td>
</tr>
</tbody>
</table>

One car from each category has been compared with the Opel Movano van.

Those cars are:

- Citroën C1 1.0 55kw (2005)

| Weight [Kg] | 790 |
| Length [m] | 3.44 |
| Width [m] | 1.63 |
| Height [m] | 1.47 |
| Distance to C.G. from front axle [m] | 0.695 |
| C.G. height [m] | 0.498 |
| ABS | Yes |
| ESC (CSC) | Yes |
| Front Axle | 60.5% |
| Rear Axle | 39.5% |

Table 13: Top sales car in Europe 2008
Table 14: Citroën C1 parameters
-Ford Focus 1.6 ti. (Sedan 85kw (2006))

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight [Kg]</td>
<td>1260</td>
</tr>
<tr>
<td>Length [m]</td>
<td>4.47</td>
</tr>
<tr>
<td>Width [m]</td>
<td>1.84</td>
</tr>
<tr>
<td>Height [m]</td>
<td>1.45</td>
</tr>
<tr>
<td>Distance to C.G. from front axle [m]</td>
<td>0.84</td>
</tr>
<tr>
<td>C.G. height [m]</td>
<td>0.515</td>
</tr>
<tr>
<td>ABS</td>
<td>Yes</td>
</tr>
<tr>
<td>ESC</td>
<td>Yes</td>
</tr>
<tr>
<td>Front Axle</td>
<td>62.5%</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>37.5%</td>
</tr>
</tbody>
</table>

Table 15: Ford Focus parameters

-VW Passat 1.9 Tdi 77Kw (2006)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight [Kg]</td>
<td>1562</td>
</tr>
<tr>
<td>Length [m]</td>
<td>4.77</td>
</tr>
<tr>
<td>Width [m]</td>
<td>1.82</td>
</tr>
<tr>
<td>Height [m]</td>
<td>1.47</td>
</tr>
<tr>
<td>Distance to C.G. from front axle [m]</td>
<td>0.99</td>
</tr>
<tr>
<td>C.G. height [m]</td>
<td>0.496</td>
</tr>
<tr>
<td>ABS</td>
<td>Yes</td>
</tr>
<tr>
<td>ESC</td>
<td>Yes</td>
</tr>
<tr>
<td>Front Axle</td>
<td>57%</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>43%</td>
</tr>
</tbody>
</table>

Table 16: VW passat parameters

-BMW X5 3.0d 150kw (2005)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight [Kg]</td>
<td>2230</td>
</tr>
<tr>
<td>Length [m]</td>
<td>4.67</td>
</tr>
<tr>
<td>Width [m]</td>
<td>1.88</td>
</tr>
<tr>
<td>Height [m]</td>
<td>1.71</td>
</tr>
<tr>
<td>Distance to C.G. from front axle [m]</td>
<td>1.25</td>
</tr>
<tr>
<td>C.G. height [m]</td>
<td>0.43</td>
</tr>
<tr>
<td>ABS</td>
<td>Yes</td>
</tr>
<tr>
<td>ESC</td>
<td>Yes</td>
</tr>
<tr>
<td>Front Axle</td>
<td>48%</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>52%</td>
</tr>
</tbody>
</table>

Table 17: BMW X5 parameters

Center of gravity and weight distribution of each vehicle has been calculated. The center of gravity height [5], relative to the track, determines the load transfer and it’s related with the weight distribution. Height of the center of gravity relative to the wheelbase determines load transfer between front and rear axle. Those values are used to update the rear brake force distribution.
3.2 Simulations

Three different tests have been done in order to represent situations that may occur on daily use:

- Deceleration test
- Lane changing test
- Over steering test

For these tests some values will remain constant:

General conditions for all the tests:

- Friction coefficient: $\mu = 0.8$
- Maximum deceleration therefore: $7.85 \text{ m/s}^2$
- ABS (Assisted Braking System): All vehicles
- ESC: All except the van
- Suspension properties: normal
- Tire model: Linear (Appendices I.5)
- Occupants and cargo: Front Occupant = 75 Kg.

It is important to notice that all vehicles except the van are equipped with ESC system. This is due that ESC is included as standard equipment in all the vehicles except the Opel Movano.

Three generations of vans were manufactured in the past. At the present, the last two generations of these vans are common on the road [4]:

- 1st generation: rear drum brake, no ABS
- 2nd generation: vans built between 1995 and 2005 with rear disc brakes, mainly with ABS but without ESC.
- 3rd generation. Vans built after the 2005, generally equipped with both ABS and ESC

During the last five years, different institutions conducted breaking tests. These show that the vans’ deceleration capacity increased considerably between the first and the second generation. This fact has been studied on the deceleration test.
3.2.1 Deceleration test

Vans are usually implicated on accidents where the impact is against the back of a passenger car. This fact is well known by the factories and is one of the mean reasons why almost all the vans build nowadays have ABS as standard equipment.

The initial speed has been defined to 100 km/h for the first test and 130 km/h for the second one. Immediately afterwards, brake sequence has been defined as a fully brake pedal situation. The same road and load conditions have been defined for all the vehicles.

Regarding Pc-Crash, the stop criterion it is defined to stop the vehicle when it reaches a really low energy value. This value usually is between 0.3 and 0.4 km/h and is used to avoid the inexactitude of results in velocities close to 0 km/h. It is possible to notice on a velocity-time diagram that the curve never gets to cross the x-axis.

The first test that has been done is the deceleration evaluation from 100 km/h to 0. Figure 18 shows Distance-Velocity diagram.

The breaking distance for the Opel is 55.42 m. The test starting at 130 km/h shows similar relative results.

<table>
<thead>
<tr>
<th>1- Opel Movano</th>
<th>100 [km/h]</th>
<th>130 [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2- Citroen C1</td>
<td>51.82</td>
<td>87.28</td>
</tr>
<tr>
<td>3- Ford Focus</td>
<td>50.58</td>
<td>85.49</td>
</tr>
<tr>
<td>4- VW Passat</td>
<td>49.99</td>
<td>84.56</td>
</tr>
<tr>
<td>5- BMW X5</td>
<td>49.41</td>
<td>83.32</td>
</tr>
</tbody>
</table>

Table 18: Braking distance
This means that the van needs a 12.16% longer distance on the 100-0 test and a 12.33% on the 130-0 test. This is compared with the vehicle of most braking capability, in this case, the BMW X5. Stopping distance needed by the van is really close to the rest of the passenger cars.

It is also important to analyze the maximum deceleration that each vehicle can reach. Figure 20 shows Longitudinal and Vertical acceleration for each vehicle. It is important to notice the ABS regulation, especially during the building phase. Figure 21 shows how the acceleration curve would look if no ABS system had been applied.

**Table 19: Maximum acceleration**

<table>
<thead>
<tr>
<th></th>
<th>Maximum Acceleration [m/s²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Opel Movano</td>
<td>-6.96</td>
</tr>
<tr>
<td>2- Citroen C1</td>
<td>-7.53</td>
</tr>
<tr>
<td>3- Ford Focus</td>
<td>-7.62</td>
</tr>
<tr>
<td>4- VW Passat</td>
<td>-7.72</td>
</tr>
<tr>
<td>5- BMW X5</td>
<td>-7.85</td>
</tr>
</tbody>
</table>
3.2.2 Lane changing test
Afterwards, an evasive action has been done in order to know the dynamic properties that a vehicle can reach on a simple lane changing. It is no rare to drive at more than 100 km/h on a motorway, and also is not the first time that happens that a heavy truck loses some load on the causeway or that there is something on the middle of the lane. Without any time to stop the vehicle before the impact, the driver has to react quickly by doing a simple lane changing. This situation was conducted in this test, defined according to the ISO standard.

Figure shows the structure of the simulation.

For these tests a rapid steer angle change is required. In order to compare this value between all the vehicles, speed of 40 km/h has been defined in order to not compromise the stability of the vehicles.

Figure 22 shows the steering for both, left and right front wheel. On left turns, a bigger angle of the left wheel is required.
It can be observed that the highest steering angle is needed on the van with a maximum value of 7.97 degrees on the first turn, -9.10 on the second and 6.62 on the last one. On the first turn, the slope of the curve indicates a steering angle velocity required on the van of 10.93 degrees/second.

By increasing vehicles speed at the test, it has been found what is the maximum speed that each vehicle can reach without instabilities and without hitting any of the marks. It has been found that lateral acceleration increases as velocity does.

At 55 km/h a maximum lateral acceleration up to 7 m/s² has been reached on the van. On the other hand, it is important to notice that at this speed, instabilities were achieved. Tire marks were visible on the road due to combined longitudinal and lateral tire forces. That happens if those forces are more than 95% of the available frictional force.

It can be predicted that in curves and when negotiating evasive actions, lateral accelerations of approximately 6m/s² without instabilities can be achieved by the Opel Movano.

Afterwards, speed was raised up until the first vehicle crashed with one of the marks. At 60 km/h at the entrance, the van hits the last mark. The crash happens after a sliding movement of approximately 14 meters. The impact with a hypothetic obstacle would occur at 55.24 km/h.

Other vehicles maximum speed:

<table>
<thead>
<tr>
<th>Maximum Speed [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citroen C1</td>
</tr>
<tr>
<td>Ford Focus</td>
</tr>
<tr>
<td>VW Passat</td>
</tr>
<tr>
<td>BMW X5</td>
</tr>
<tr>
<td>Movano</td>
</tr>
</tbody>
</table>

Due to the dynamic properties and the use of ESC, vehicles with more weight (like the BMW X5) can go through the test with a higher speed than the van. BMW speed is a 15% higher than the Opel Movano. On the other hand, and like happened with the deceleration results, the van is still really close to the values achieved by the rest of the passenger cars.
It is important to remark, that by supplying ESC system to the van, the maximum speed would have been 64 km/h, which is even closer to the other cars maximum velocity. On the other hand, and as mentioned before, the main target of these tests is to compare common situations on the road, which means a high percentage of passenger cars with ESC and a low percentage of vans with that system.

Further studies of ESC application have been done in Chapter 4.

3.2.3 Over steering test

The following test is based on the exit that can be found in every motorway. Situation can be described as the event that happens when the driver has not perceived the exit sign with enough time to reduce the speed moderately. The driver either starts to brake due to the high lateral acceleration or does not brake. This may cause a loss of grip and over steering.

No braking has been applied during the movement along the curve.

Following tests have been done assuming dry conditions, which means coefficient of friction $\mu=0.8$ and maximum deceleration of $7.85 \text{ m/s}^2$. Figure shows over steering test structure.

![Over steering test diagram](image)

For the different tests, Opel Movano and Citroen C1 have been used. This is due to the fact that Opel is the only vehicle without ESC and the Citroen C1 is the vehicle with the shortest wheelbase of all the vehicles tested. In cornering, because of the center of gravity, front-heavy cars tend to under steer and rear-heavy cars to over steer.

Comparing the vehicle without ESC but with the longest wheelbase (with a higher under steering tendency) and the vehicle with ESC but with the shortest wheelbase probably will produce the closest values between passenger cars and vans.

*Understeer is a term for a car handling condition in which during cornering the circular path of the vehicle’s motion is of a greater radius than the circle indicated by the direction its wheels are pointed.

<table>
<thead>
<tr>
<th>Test</th>
<th>Vehicles</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>N01</td>
<td>Opel Movano/Citroen C1</td>
<td>30</td>
</tr>
<tr>
<td>N02</td>
<td>Opel Movano/Citroen C1</td>
<td>40</td>
</tr>
<tr>
<td>N03</td>
<td>Opel Movano/Citroen C1</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 21: Test vehicles speed
With increasing vehicle speed the yaw velocity also increases. In figure 24 the maximum yaw velocity at 30 km/h assumes an asymptotic value of -0.4 rad/s.

As figure 25 shows, if the same test is done at 40 km/h it is possible to notice that the van’s yaw velocity increases to -0.55 rad/s while on the passenger car remains on -0.45 rad/s.

The yaw angle is the angle between a vehicle’s heading and a reference heading. During corner entry the front tires, in addition to generating part of the lateral force required to accelerate the car’s center of mass into the turn, also generate a torque about the car’s vertical axis that starts the car rotating into the turn.

The yaw angular inertia tends to keep the geometrical direction changing at a constant rate. This makes it slower to swerve or go into a tight curve, and it also makes it slower to turn straight again. Those tests define the relation between the steering angle, vehicle speed and yaw angular velocity. Using these data it is possible to define how the vehicle follows the ideal trajectory.

Figures 26 and 27 show a comparison of the trajectories between vehicles on tests N01 and N03. These trajectories show clearly that the Van can not follow the desired path at 50 km/h. The van without ESC (Red) get into a slide movement wherein the vehicle with ESC switched on follows the desired path.
3.3 Conclusions
The widespread opinion that vans have much worse active safety systems (brakes, driving stability when negotiating a turn) than passenger cars could not be verified, neither through literature review nor through own tests.

3.3.1 Deceleration Test
The results of this study show that the full deceleration achievable with vans of the 2nd generation can be compared to the one of modern passenger cars. In both simulations (100 km/h and 130 km/h) the empty van needs around a 12% bigger distance. These findings of the current study are consistent with several other studies [4] [6] [7]. On the other hand, it is important to mention that for example, on the test with a starting velocity of 100 km/h, while the BMW has already stopped the Opel Movano still has a residual velocity of 21, 56 km/h. This can be the difference between hitting another vehicle or stopping without any consequences.

This is a very common accident on vans, especially in queues of traffic congestion on motorways. In the event of a collision against a passenger car, the loads for the occupants are very high.

![Figure 28: RACE Crash Test at 60 km/h](image)

Through tests review done by the RACE (Real automóvil Club de España), the results were catastrophic for tourism. The test speed was considerably higher than the residual velocity of the simulation, but it can provide an idea of the possible consequences.

While the van was only slightly deformed in the engine compartment, welds in the roof supports and feet were separated from tourism to the point where the vehicle was considerably deformed. The driver’s seat was completely distorted and twisted. The driver, sliding backwards, deformed bracket and all of the headrest of the seat frame was badly damaged. In this case, it has to be assumed that there is a high risk trauma throughout the area of the spine. In this kind of accident, the risk of serious neck injury is very high. In addition, injuries can occur in the legs and chest.

Although the deceleration distance needed by the van is close to any passenger car, this difference may cause hard injures when colliding against a vehicle with a lower mass.
3.3.2 Lane changing test
As happened with the breaking distance, in this test the van is also close to the values reached by the passenger car, specially on the 3rd generation Van where a maximum speed of 64 km/h was reached. Maximum lateral acceleration of 7 m/s² has been reached by the van but with important instabilities.
On the other hand, on the 2nd generation van (without ESC) the maximum speed stays at 59 km/h. In curves and when negotiating evasive actions lateral accelerations up to 6 m/s² have been achieved without causing instabilities. Due to the low weight and short total length, the best vehicle in this test has been the Citroen C1 with a maximum entrance speed of 75 km/h.

3.3.3 Over steering test
This is one of the most demanding tests for a light commercial vehicle. Due to this fact, in this simulation there is a bigger difference with the other cars. Maximum velocity of 40 km/h can be reached by a 2nd generation van on a 50 m. radius curve. Yaw angle velocity increases faster on a van than in a passenger car, which makes more difficult to follow the desired path. At 50 km/h the Citroën C1 keeps a safe trajectory whereas the Opel Movano invades the opposite direction.

Results show that even the van is in the last position in all the simulations that have been done, the values obtained can be compared to the one of a modern passenger car. This does not mean that light commercial have similar dynamic properties than the rest of the vehicles, specially when it is loaded, but indeed contradicts the widespread opinion that they are really far from a passenger car.
Chapter 4. Load Distribution/ESC influence on Vans

In spite of improvements in passive safety and effort to alter driver behavior, the absolute number of van fatalities has increased. In order to try to improve van’s security, several tests have been done to understand how a bad load distribution may affect in a possible crash situation. Also, the properties and influence of the ESC has been studied in these simulations.

For these test, Van described in chapter 2 has been used. The four possible loads spaces created provides the opportunity to change the center of gravity of the total vehicle. By doing that, it has been studied how different load position affect to the vehicle stability and also how this fact can increase or decrease Van’s security.

Furthermore, the two last generations of Vans’ mentioned have been used in each test. This pretends to show how active systems (like ESC) can avoid or reduce collision consequences.

- 1st generation: rear drum brake, no ABS
- 2nd generation: vans built between 1995 and 2005 with rear disc brakes, mainly with ABS but without ESC.
- 3rd generation. Vans built after the 2005, generally equipped with both ABS and ESC

4.1 Load configurations

CoG position of the MAM Vans used on the simulations:

Center load:
\[ X_{\text{CoG}} \text{ [mm]} = 1914 \]
\[ H_{\text{CoG}} \text{ [mm]} = 780 \]

High Center load:
\[ X_{\text{CoG}} \text{ [mm]} = 1914 \]
\[ H_{\text{CoG}} \text{ [mm]} = 969 \]

Load on rear axle:
\[ X_{\text{CoG}} \text{ [mm]} = 2100 \]
\[ H_{\text{CoG}} \text{ [mm]} = 814 \]

High load on rear axle
\[ X_{\text{CoG}} \text{ [mm]} = 2318 \]
\[ H_{\text{CoG}} \text{ [mm]} = 1017 \]

Front load:
\[ X_{\text{CoG}} \text{ [mm]} = 1576 \]
\[ H_{\text{CoG}} \text{ [mm]} = 805 \]

High front load:
\[ X_{\text{CoG}} \text{ [mm]} = 1576 \]
\[ H_{\text{CoG}} \text{ [mm]} = 1012 \]

Figure 29: CoG of the different load distributions
The total load capacity is 1279 Kg. and has been positioned in different places, as figure 29 shows. The new centers of gravity have been calculated by positioning the load on the empty spaces designed on Chapter 2. Due to the elevated center of gravity found on the vans with a high load position, which augments the susceptibility to rollover, vans are the preferred target for ESC applications. For example, in the rear configuration load has been distributed between 1-2:

![Rear axle load configuration](image)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Mass (kg)</th>
<th>X_{CoG} (mm)*</th>
<th>h_{CoG} (mm)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>639.5</td>
<td>3352</td>
<td>1041</td>
</tr>
<tr>
<td>2</td>
<td>639.5</td>
<td>3622</td>
<td>1291</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1827.5</td>
<td>1441</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1827.5</td>
<td>1041</td>
</tr>
</tbody>
</table>

(*) Referred to FA  (**) Referred to the ground

Center of gravity of the load:

\[
x_{CoG} = \frac{639.5 \times 3352 + 639.5 \times 3622 + 0 \times 1827.5 + 0 \times 1827.5}{1279} = 3487 \text{mm}
\]

\[
h_{CoG} = \frac{639.5 \times 1041 + 639.5 \times 1291 + 0 \times 1441 + 0 \times 1041}{1279} = 1116 \text{mm}
\]

CoG of Maximum authorized Mass (MAM) Van:

\[
x_{CoG} = \frac{150 \times 753 + 1871 \times 1260 + 1279 \times 2697}{3300} = 2100 \text{mm}
\]

\[
h_{cdi} = \frac{150 \times 1235 + 1871 \times 419 + 1279 \times 1153}{3300} = 814 \text{mm}
\]

(*) 150 kg refers to the two front occupants.

The same procedure has been used for the front cargo configuration, but in this case loading spaces 3 and 4. High load position (red) has been reached by summing 600 mm. to the CoG of each place and by repeating the calculations.

<table>
<thead>
<tr>
<th>Zone</th>
<th>h_{CoG} (mm)</th>
<th>h_{cdi} (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1041</td>
<td>1641</td>
</tr>
<tr>
<td>2</td>
<td>1291</td>
<td>1891</td>
</tr>
<tr>
<td>3</td>
<td>1441</td>
<td>2041</td>
</tr>
<tr>
<td>4</td>
<td>1041</td>
<td>1641</td>
</tr>
</tbody>
</table>
By comparing the new CoG it is possible to observe the big difference with the kerbweight situation where the center of gravity high is 0.419 m. and the distance to the front axle is 1.259 m.

4.1.1 Validation of CoG

In order to verify if those new CoG are feasible it has been obtained data from maximum permitted height for centre of gravity. It has not been possible to find for the exact van used on the simulations (Opel Movano) but it has been possible for a van with similar characteristics, the Volkswagen Transporter T5. The total length is 5290 mm in front of the 5399 mm of the Opel. Width is almost the same between both vans whereas the Transporter height is 200 mm lower. Table 22 shows other important data.

<table>
<thead>
<tr>
<th></th>
<th>Opel Movano</th>
<th>Volkswagen T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheelbase [mm]</td>
<td>3578</td>
<td>3400</td>
</tr>
<tr>
<td>Front overhang [mm]</td>
<td>862</td>
<td>894</td>
</tr>
<tr>
<td>Track-Axle [mm]</td>
<td>1740</td>
<td>1724</td>
</tr>
<tr>
<td>Kerbweight [Kg]</td>
<td>1871</td>
<td>1860</td>
</tr>
<tr>
<td>Of which on front axle [Kg]</td>
<td>1213</td>
<td>1162</td>
</tr>
<tr>
<td>Of which on rear axle [Kg]</td>
<td>658</td>
<td>707</td>
</tr>
<tr>
<td>MAM [kg]</td>
<td>3300</td>
<td>3200</td>
</tr>
<tr>
<td>Perm. axle load front [kg]</td>
<td>1750</td>
<td>1650</td>
</tr>
<tr>
<td>Perm. axle load rear [kg]</td>
<td>1900</td>
<td>1720</td>
</tr>
<tr>
<td>Load capacity [kg]</td>
<td>1279</td>
<td>1331</td>
</tr>
</tbody>
</table>

Table 22: Opel Movano – VW T5 comparative

Due to the similarity between both models, and also the fact are using similar technical systems, following data can be extrapolated to the Movano. The following table shows the height of the centre of gravity permissible on vehicles with standard equipment.

<table>
<thead>
<tr>
<th>Version</th>
<th>Centre of gravity on chassis X [mm]</th>
<th>Gross centre of gravity of vehicle Y1 [mm]</th>
<th>Max. perm. height of CoG for body and load Z [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VW T5</td>
<td>730</td>
<td>920</td>
<td>1375</td>
</tr>
</tbody>
</table>

Table 23: VW T5 CoG position

VW Note: Subject to errors and technical amendments.

There is a strong advise by VW that these heights should not be exceeded. On the other hand, in none of the three configurations with a high load, the CoG exceeds the maximum value of 1375 mm. The highest one, which is the load on the rear axle is still 358 under the limit fixed by Volkswagen.
4.2 Introduction to the Electronic Stability Control

One of the main purposes of these tests is to analyse how the presence of an ESC system aids the driver in maintaining control of the vehicle in different load conditions and how this can avoid or reduce collision consequences. Therefore, it is important to analyze the concept of stability and describe what ESC is and how it works.

4.2.1 Stabilizing concept

In critical driving situations, most drivers are overburdened with the stabilizing task. The average driver cannot judge the friction coefficient of the road nor the grip reserves of the tires. The drivers are typically startled by the altered vehicle behaviour in unstable driving situations; as a result, a well-considered reaction of the driver cannot be expected.

For that reason, the ESC has to be designed to stabilize the vehicle even in situations with panic reactions and driving failures like exaggerated steering. On these tests, this has been represented by the fact that the driver does not press the brake pedal after the risk feeling has been surpassed. The first reaction of the driver is to make an abrupt steering.

The characteristic side slip angles, where the steerability of the vehicle is vanishing, are dependent on the road friction coefficient. On the simulations done, the specified slip angle is $10^\circ$. For the linear tire model (which is the one used), different surface friction coefficients have no effect on the stiffness of a tire, and thus, a lower coefficient of friction, which cannot produce as much side force on a tire, will result in a lower maximum slip angle. For example, with a specified maximum tire slip angle of $10^\circ$ on a surface with a coefficient of friction of 0.7, the maximum tire slip angle possible is $7^\circ$. This is the angle at which the maximum lateral tire force will be reached, which will be 70% of normal force in this case.

The reason why stabilizing a vehicle in critical situations is so challenging can be shown by considering the physical effects. Steering of a vehicle yields a yaw moment, which results in a directional change. The effect of a given steering angle depends on the actual side slip angle of the tires. Only slight alterations of the yaw moment are possible at large side slip angles even for extensive interventions, which can be seen in figure 32.

![Figure 32: Influence of side slip angle on yaw moment for different steering angles at high tire-road friction](Convergence Transportation Electronic Association)
4.2.2 Brief explanation of ESC system technical aspects

It is important to describe how an ESC system works in order to understand how it benefits crash avoidance. The system is performed on limit situations and tries not to exceed the limits of control. By serving on the following variables:

- Steering angle, wheel velocity.
- Lateral acceleration.
- Angle with respect to the vertical axis (Yaw)

The ESC aims to enable the driver’s intention is translated into a dynamic performance of the car adapted to the characteristics of the road.

![Diagram of ESC system](image)

Figure 33: Operation of the ESC

The ESC includes the capabilities of ABS (Antilock Brake System) and TCS (Traction Control System), allowing an active braking on four wheels with a high dynamic sensitivity. Control with braking force and the lateral force is the main objective of the ESC in an attempt to converge into an ideal vehicle’s behaviour. The management system can vary the engine output torque for adjust the ratio of the drive wheels slip. ESC allows to adjust the longitudinal and lateral forces acting on it each wheel separately.

As figure 33 shows, ESC systems are based on steering angle, wheel speed, lateral acceleration and yaw velocity to make a calculation between desired and actual vehicles’ behavior. (Values were measured also in the chapter Car/Van Comparative). This tries to make as closely as possible the response of the vehicle to the conditions response in the normal driving.

As you can not directly change the lateral force, it is impossible to vary the lateral acceleration and slip angle. However, the lateral force caused by Yaw moment (which can be generated) leads to the variation of the optimal slip angle. The ESC may also intervene in the relationship of the sliding tires indirectly influence the longitudinal and transverse forces acting on each wheel, which is done by the subordinated controllers ABS and TCS.
To generate the necessary Yaw angle the ESC transmits the necessary adjustments to the wheels slip selected. ABS and TCS starts the actuators that control the hydraulic braking system and engine management system using data generated by the ESC.

The ESC complete control system is usually based on those components:

1- Wheel brakes  
2- Wheel speed sensors  
3- ECU  
4- Steering-wheel sensor  
5- Hydraulic modulator with primary-pressure sensor  
6- Yaw sensor with lateral-acceleration sensor

The hydraulic modulator with primary-pressure sensor uses the recognition of the emergency braking as a step to increase the braking pressure beyond the call of the driver. Actually, it increases braking pressure on all the wheels to reach the threshold of the block. At this point, is when the ABS acts. Regarding the hierarchy of controls, the ESC has total priority, meaning that defines the relationship of the sliding tires ideal for the ABS and TCS.
4.3 Description of the simulation

Those tests pretend to represent a common situation. The event occurs on a two lane road (one for each direction) with a width of 3.3 meters for each lane. There is also left and right margin, in this case with 1.7 meters each. Furthermore, a roadside barrier has been positioned in order to represent possible off-roadway crashes, in where the first harmful event occurs off the roadway after a vehicle departs the travel road due to loss of control or crossing the edge of the roadway. Those barriers have a length of 1.9 meters each with a weight of 1755 Kg. each. Road section parameters have been taken from the Vasc Country government, just as an example of realistic values.

![Figure 35: Road dimensions](image)

The coefficient of friction is 0.7, which means that this test has been done in dry conditions. Also, no wind or weather effects have been applied. Maximum deceleration that can be reached in those conditions is 6.87 m/s². The scenario represents an overtaking by a BMW 320 Ci to a Mazda 6. Meanwhile, from the other lane, the Opel Movano is cruising at constant speed.

Simulations proceeds as follows:

- **At 0.6 seconds after the simulations has started, the BMW begins the overtake maneuver**

![Figure 36: Simulation. Start of the overtake.](image)

The overtake done by the BMW can be considered as standard regarding dynamic aspects. The lateral offset is 3 meters with a maximum lateral acceleration of 4 m/s². This acceleration is far inside a passenger car’s capabilities (Car/Van comparative chapter) and will not be exceeded while the steering wheel angle is being increased at the start of the lane change maneuver. Steering angular velocity of 5 deg./s has been defined with a lateral rise distance of 2.5%. The Lateral Steer Rise Distance, expressed as a percentage of the Lateral Offset, is the lateral distance the vehicle moves while the steering angle of the front wheels is being increased. Usual range for this value is 1%-4%, considering 1% smooth and 4% abrupt.
- At 1.4 seconds, the Van's driver starts evasive action (reaction time 1-1.2 sec).

![Figure 37: Simulation. Start of evasive action of the van.](image)

- At 2.1 seconds, the BMW is totally invading the opposite lane with a speed of 84.8 km/h.

![Figure 38: Simulation. Invasion of the opposite lane.](image)

Constant values for velocity and acceleration have been defined for both, Mazda and BMW cars. Mazda has a constant velocity of 65 km/h while the BMW starts the simulation at 80 km/h and accelerating. The shift has been defined between 1500 and 5000 rpm with a time delay of 1 second. This time delay is due to the time that the driver needs to change the gear

On the other hand, as figure 39 shows there is no gear change while overtaking. The Bmw can proceed with the maneuver in the same gear. Figure 40 corresponds to an acceleration test done to the Bmw starting from 0 km/h. It is possible to find that this car can reach up to 105 km/h in third gear, which proves the fact explained before. The horizontal slopes of the curve correspond to the time delay between gears. The throttle pedal position is at 50% of maximum.

![Figure 39: Bmw Velocity](image)  ![Figure 40: BMW acceleration test](image)

-At 3.6 sec after avoidance actions, Van's driver presses fully the brakes.

![Figure 41: Vehicles trajectories. Results may vary depending on the simulation](image)
Results
It has been found two very clear tendencies on the results achieved in this simulations. On the Vans where the load has been positionated as low as possible, the main cause of accident is a sliding situation followed by a crash against the barrier (except at high velocity on rear axle). On the other hand, on the Vans with a higher center of gravity, rollover has been found as the result of the evasive action described before. Due to this situation, it has been decided to study both cases separately.

Different methodology has been used. Firstly, on the sliding crashes, Pc-Crash provides different parameters that help to understand the crash severity. On the other hand, when a rollover situation appears, less information is provided by the software, which lead us the opportunity to analyse the stability from a more theoretical point of view.

The first crash type that has been studied is the low cargo configuration.

4.4 Low load distribution: Sliding + barrier crash tendency
As mentioned before, it has been found that the first three loading configurations (center load, load on rear axle and front load) have a higher tendency to commit sliding followed by a crash against the roadside barrier. On the other hand, some results shown that on the rear axle configuration also can commit rollover. This is considered after in this study.

Firstly, it is important to define the collision parameters that have been used. This means that once the proper options have been entered and vehicle motion simulation started, the program have calculated the values of collision parameters as soon as it recognizes that there was a contact (with a vehicle or a barrier).

4.4.1 Crash Parameters
As indicated in the program for the analysis of vehicles accidents done by Dr. Andreas Moser from DSD, the general questions in accidents are:

-Impact constellation (vehicles positions, pre and post-impact directions, damage location, impact velocities and initial velocities )
The driving conditions for both vehicles have been specified before the crash. Then, from conservation of linear and angular momentum and the use of the Newtonian Crash Hypothesis, the post-impact conditions are determined. Below this heading the values provided by Pc-Crash for the post-impact phase are shown:
- **Vel.** is the velocity of the vehicle.
- **Dir.** is the velocity vector direction of the vehicle.
- **$\Delta v$** is the velocity change.

The crash model used is characterized by the definition of the point of impact. The point of impact is the point where the crash force is assumed to be exchanged.

**Accident Severity (EES, deformation depth)**

As a control, the deformation depth of each vehicle, based on the defined positions of the vehicles and point of impact, is also indicated. The deformation depth of each vehicle, calculated in the direction of the crash force vector, is the distance from the point of impact to the outside of the undeformed rectangular vehicle outline. The time from the first contact between the rectangular vehicle outlines to when the impact is calculated is from 30 to 60msec.

Furthermore, calculation of the deformation energy (EES, or Equivalent Energy Speed) in the crash has been obtained. The total deformation energy will be distributed between the vehicle and the barrier, based upon the relation of the masses of the vehicles as well as of the respective deformation depths. The distribution of the deformation energy between two vehicles in collision depends on the vehicle masses and the deformation depths. [Appendices I.10]

In addition, pictures of real Van accidents have been found in order to represent the EES value obtained on the simulation. Those pictures have been provided by AutoExpert Hungary © and AGU Zürich database, where is possible to choose crashes between different vehicle class, place of damage, product, type and obviously EES value.

![Figure 43: Capture of the EES 2005 (DSD)](image-url)
Finally, the elasticity of the collision is considered, based on a coefficient of restitution ($k$). For most high energy impacts a $k$ value of 0.1 can be used. If there is an unusual deep penetration of a vehicle e.g. if a truck hits a Citroen 2CV it is possible to specify a negative value. Higher positive values can be specified for low energy impacts (speeds below 20-30 kmh). This model also considers the sliding of one vehicle along another vehicle or a fixed object, based on a contact plane angle and friction coefficient. [Appendices I.9]

**-Injury potential (damage, injuries)**

On the load distribution simulation, it has been calculated the acceleration suffered on the vehicle by dividing the velocity change $\Delta v$ by the known time of a crash, which is between 0.12 and 0.14 seconds.

$$a = \frac{\Delta v}{t}$$

Where,

$\Delta v$: velocity change

t: estimated value for a collision (0.12-0.14 seconds and also related to the EES value)

Afterwards, those values have been compared with daily living accelerations suffered by a person in order to understand the magnitude of the crash. Those data have been provided by a DSD study done in 2005 where it is possible to find five daily actions like:

- Sit on a chair
- Get down from a chair
- Down stair
- Lay on the bed
- Hit by a football ball

Figure 44: Daily living accelerations
There were measured T1 (neck area), chest, and right-left head accelerations for each action. It is important to mention that accelerations were taken on the three axis directions (X, Y and Z) and measured in g forces. Each test was realized to people with different weight and height, starting from a subject of 1,60 height and 60 Kg. to another subject of 1,88m height and 96 Kg. According to the European average (1,75m), it has been chosen the number 7, a 33 year old man of 1,74m height and 76 kg. This subject can adjust to a Van’s driver profile.

4.4.2 Center load

The first distribution that has been studied is the Van loaded on the center. This means a $h_{CoG}$ of 780 mm. and a distance to the front axle of 1914 mm. Those values correspond to the following loading position:

![Figure 45: Center load configuration](image)

The total load capacity (1279 Kg) is distributed in all the spaces described in point 2.3. This provides a CoG as much centered as possible. Furthermore, same loaded Van has been tested with and without ESC in order to understand how this system helps in critical crash situations.

The first thing that has been found is the maximum entrance speed that both Vans (the only difference is the ESC) can reach without crashing. The Van without the stability system can handle 89 km/h while the 3rd generation van (ABS+ESC) can reach up to 108 km/h. This means a difference 19 km/h.

Figure 46 shows the simulations till stopping velocities. By comparing the final position of both Vans after the simulation, it is possible to observe that even though the Van without ESC has not crashed, this fact is more due to the braking capability than the ability to follow the desired path. The 3rd generation Van would still have been able to continue the trip without any additional maneuvers. It is also possible to observe the tire marks left by both vehicles. As mentioned before, tire marks were visible on the road due to combined longitudinal and lateral tire forces. That happens, as defined for these simulations, if those forces are more than 95% of the available frictional force.

![Figure 46: Final position. Blue: 2nd Generation van. Red: 3rd Generation van.](image)
In order to understand why the 3\textsuperscript{rd} generation Van is capable to pass through the critical situation without crashing against the roadside barrier (while the 2\textsuperscript{nd} generation does), it has been simulated both Vans passing at the same entrance speed of 90 km/h.

- 2\textsuperscript{nd} and 3\textsuperscript{rd} Generation vans at starting velocity of 90 km/h

It has been analysed how the ESC prevents the accident by comparing the lateral acceleration, yaw rate and the brake factors. As was explained on the Electronic Stability Program introduction, the main target of the ESC is to calculate the deviation between the actual and desired vehicle behavior. In this case, ESC counteracts oversteering by applying brakes at the front axle. Figure 48 shows the brake factors diagram for both Vans, understood brake factor as the brake/acceleration forces applied to each wheel, in % of normal static force.

It is possible, by observing the red and dark blue curves, that the brakes are only applied on the Van number 1. This is due to the ESC function because the driver does not press the pedal brake until 3.6 seconds after the start of the simulation. Three different phases can be perceived. On phase number two, from 1.67 to 2.29 seconds, instability can be perceived by measuring yaw angular velocity. To counteract this fact, brakes are applied on the left-front wheel. Afterwards, an opposite yaw angular is detected, so this time brakes are applied on the right front wheel from 2.33 seconds to 3.6 second. At this moment of the simulation, and like was defined on point 4.3, brakes are applied by the driver. Finally, the 3\textsuperscript{rd} generation Van keeps a safe position and ready to continue after avoiding the critical situation. On the other hand, the 2\textsuperscript{nd} generation Van has suffered a crash against the barrier.
Below it has been done a further study of 2nd generation van crash following the most important questions regarding accidents.

**- Impact Constellation**

This crash occurs at 6.42 seconds with a pre-impact velocity of 18.65 km/h. After avoiding the BMW, the van enters in a sliding movement that ends up with the front part colliding against the roadside. The velocity vector direction $Dir$ of the vehicle is -21.77º, which shows that the severity of the crash is reduced by the fact of having a velocity almost parallel to the roadside barrier. The velocity change $\Delta v$ is 6.93 km/h. This value has been also used to calculate the acceleration suffered on the crash.

![Figure 51: Center Load. 2nd generation van impact.](image)

**- Accident Severity**

Due to the low speed crash, the elasticity of the collision $k$ has been considered by using a coefficient of restitution of 0.2, which is higher positive value than the 0.1 used for high energy impacts. If the vehicle and the barrier are still engaged and approaching each other, secondary impacts appear. In this simulation 8 secondary impacts have been found. It has been defined a value of 45 msec between each impact if the vehicles are still engaged and approaching each other, which seems to be realistic.

The deformation depth of each vehicle is the distance from the point of impact to the outside of the undeformed rectangular vehicle outline. The total deformation energy is distributed between the van and the barrier, based upon the relation of the masses of the vehicles as well as of the respective deformation depths. Taking into account that the mass of the Van is 3300 kg. and that each barrier portion is 1755 kg. the EES value results bigger on the roadside barrier. In this simulation, EES value of 5.61 km/h has been obtained for the Van whereas the barrier has registered 8.89 km/h. Those values reveal that this is not a severe accident but both, EES and acceleration, have been compared with real crash tests.
Real Crash figures show the post-crash situation between a Ford Galaxy and a Peugeot 206. In this case, the vehicle’s pre-impact velocity was 14.6 km/h that resulted on EES value of 6 km/h.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Ford Galaxy</th>
<th>Peugeot 206</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1996</td>
<td>2000</td>
</tr>
<tr>
<td>Weight</td>
<td>1770 kg</td>
<td>988 kg</td>
</tr>
<tr>
<td>Pre-Impact Velocity</td>
<td>14.6 km/h</td>
<td>0 km/h</td>
</tr>
<tr>
<td>Velocity change $\Delta v$</td>
<td>6.8 km/h</td>
<td>12 km/h</td>
</tr>
<tr>
<td>Acceleration</td>
<td>1.7g</td>
<td>3.1g</td>
</tr>
<tr>
<td>Place of damage</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Collision direction</td>
<td>-90º</td>
<td>90º</td>
</tr>
<tr>
<td>EES</td>
<td>6 km/h</td>
<td>8 km/h</td>
</tr>
</tbody>
</table>

Table 24: Real crash parameters

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Simulation: Opel Movano</th>
<th>Roadside Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2005</td>
<td>-</td>
</tr>
<tr>
<td>Weight</td>
<td>3300 kg.</td>
<td>1770 kg.</td>
</tr>
<tr>
<td>Pre-Impact Velocity</td>
<td>18.65 km/h</td>
<td>0 km/h</td>
</tr>
<tr>
<td>Velocity change $\Delta v$</td>
<td>6.93 km/h</td>
<td>-</td>
</tr>
<tr>
<td>Acceleration</td>
<td>1.64g</td>
<td>-</td>
</tr>
<tr>
<td>Place of damage</td>
<td>Front</td>
<td>Front</td>
</tr>
<tr>
<td>Collision direction</td>
<td>-21.77º</td>
<td>-90º</td>
</tr>
<tr>
<td>EES</td>
<td>5.61 km/h</td>
<td>8.89 km/h</td>
</tr>
</tbody>
</table>

Table 25: Simulation parameters

Due to the difficult task of finding an identical situation to the simulation, this is the real accident that most resembles. There is an important difference of the total weight of the vehicle, and also, in one case the impact is against a roadside barrier while in the real scenario is against another car. On the other hand, velocity change, acceleration and EES are parameters with similar values.

Figure 52: Center Load. Possible 2nd generation van crash consequences.

[Wintherthur Versicherungen, Accident Research WPCA]

Pictures should have been taken as a possible damage caused by the accident.
-Injury potential

By knowing the velocity change $\Delta v$ and the estimated time value for a collision $t$ it is possible to calculate the average acceleration suffered by the vehicle. The velocity change is $\Delta v = 6.93 \text{ km/h}$ (1.93 m/s) and the time is 0.12 seconds. This involves an acceleration of $16.06 \text{ m/s}^2$ or 1.64g. This values can be compared with the data obtained from real crash tests made by crashtestservice.com ® for DanCrash. [Appendices]

If this value is taken to the daily living situations, it is possible to compare the average acceleration suffered by the vehicle (1.64g) with the quotidian action of sitting. On the data provided, it is possible to observe that the maximum acceleration is reached at 0.8299 sec. with a value of 0.91596 g. It is important to notice that when talking about peak values in a short time, which is an impulse, it is not considered a force as conventionally used. The impulse is not as damaging, e.g. a pilot can handle only about 9g in his jet over a few seconds, while a hummingbird smashed in the head doing 120 mph hardly affects him.

Due to this fact, has been calculated the average of acceleration during the same length of time than the impact (0.12 sec.). It has been found that while sitting, an average acceleration of 0.79g is suffered between 0.7619 and 0.8819 seconds. This means that on the crash the driver suffers an acceleration just almost the double acceleration suffered while sitting, which probably might not cause injuries. On the other hand, and when talking about accelerations, the position of the body is very important at the instant of impact.

![Figure 53: T1 acceleration suffered while sitting](DSD tests 2005)

4.4.3 Front load

The second distribution that has been studied is the Van loaded on the front. This means a $h_{CoG}$ of 805 mm. and a distance to the front axle of 1576 mm. Those values correspond to the following loading position:

![Figure 54: Front load configuration.](DanCrash)
The total load capacity (1279 kg) is distributed just on the front spaces. As was done in the previous simulation, the same loaded van has been tested with and without ESC in order to understand how this system helps in critical crash situations.

By trying to reach the maximum entrance speed that both Vans can handle, it has been found values really close to the center load configuration. The Van without the stability system can handle 87 km/h while the 3rd generation Van (ABS+ESC) can reach up to 105 km/h. It is possible to observe that the speed it is just 2 km/h and 3 km/h under compared with the previous case. Afterwards it will possible to observe that these similarities also occurs on the high load configurations (point 4.5), which may lead to the conclusion that there is not a big difference between center and front configuration in this critical-crash situation.

On the other hand, and also like in the previous cargo configuration, the use of ESC allows the Van an entrance speed considerably higher. In this case, a range of 20 km/h above the 2nd generation Van can be perfectly corrected by the sole fact of equipping ESC.

A further study of this configuration crash has been carried on at the end of this chapter in order to compare the three different load options.

### 4.4.4 Rear axle load

The last distribution that has been studied is the Van loaded on the rear axle. This results on a $h_{CoG}$ of 814 mm. and a distance to the front axle of 2318 mm. Those values correspond to the following loading position:

![Figure 55: Rear axle load configuration.](image)

The total load capacity is distributed evenly between the two back spaces, which means 639.5 in the space number 1 and 639.5 Kg. in the number 2.

A has been done with the two previous cargo configurations, maximum entrance speed of the Van with and without ESC has been found. In this case, the Van without the stability system can handle 72 km/h while the 3rd generation Van (ABS+ESC) can reach up to 84 km/h. It is possible to observe a big difference between this load configuration and the center load scenario. For example, by comparing the 2nd generation vehicles, there has been found a reduction of 19% of the maximum allowed speed (89 km/h center – 72 km/h rear) whereas on the 3rd generation it is even bigger 22% (108 km/h center – 84 km/h rear).

That proves the loading a van on the rear part is the worst option found. This statement is increased by the fact that it has been found the rollover as cause of the accident instead of an impact against the barrier. It is important to note that injury in such vehicles tend to be much more severe in case of overturning, since in many cases the airbag for example, loses its effectiveness as an element of passive safety.
It is true that many passenger vehicles are equipped with the amount airbag or near windows, which provides a degree of security in the event of overturning. Instead, this option is not provided or extra equipment for commercial vehicles.

4.4.5 Center load vs. Front load vs. Rear axle load at 90km/h
Finally, simulation has been carried comparing the three possible load configurations on a 2nd generation Van. At 90 km/h, the three vehicle crash against the roadside barrier. On point 4.4.2 has been studied how ESC can avoid an accident. Following the same procedure, it has been proved that the load distribution may affect even in a harder way.

This test has been realized comparing the crash severity of three Vans with exactly the same technical properties and entrance speed. The only difference between them is the load distribution. It has been used the same methodology than before, which means that the impact constellation, the accident severity and finally the injury potential parameters have been measured.

-Impact Constellation

Center load
Crash values for center loaded Van were obtained on point 4.4.2. This crash occurred at 6.42 seconds with a pre-impact velocity of 18.65 km/h. The velocity vector direction $\text{Dir}$ of the vehicle was $-21.77^\circ$ with a velocity change of $\Delta v$ 6.93 km/h.

Front load
On the other hand, with a front load the crash occurs at 6.045 seconds with a pre-impact velocity of 29.54 km/h. After avoiding the BMW, the van enters in a sliding movement that ends up with the front part colliding against the roadside with 11 km/h higher speed than in the previous simulation. It is important to notice that the front load distribution subtracts braking capability to the rear axle of the vehicle. The brake force distribution between the front and rear wheels for each vehicle (center load: Red, front load: blue) can be observed in figures 56 and 57.

These parameters identify the defined brake force distribution, as follows:

- **$\text{Phi}$** Slope of the first line
- **$z1$** Point where slope changes
- **$m$** Slope of the second line.
Graphs show the proportion of rear brake force \((q_h)\) to the front brake force \((z)\). The theoretically ideal curve as well as the assumed or defined distribution is shown. Immediately after entering a C.G. height a suggested distribution curve is calculated. This is because many modern vans are equipped with automatic re-adjustment of brake distribution as a function of vehicle cargo. Further explanation of correction of braking forces has been explained on point Appendices I.4.

![Figure 58: Yaw angular velocity. Front load (blue). Center load (red)](image)

Due to the different braking distribution mentioned before, it is possible to observe on figures 58 and 59 the relation between the yaw angular velocity and trajectory that has followed each van. At 3.6 seconds the brake sequence starts (start is marked in both figures). After that point, the blue curve (front cargo) separates from the red one (center cargo) showing the lower capacity of the front cargo van to counteract the negative yaw velocity. The smaller braking capacity on the rear axle causes greater tendency of this to advance the front axle, thus the ability to follow the desired path is reduced. Figure 58 shows how both vehicles are following exactly the same path just until the point where the brakes are applied. This is one of the reasons of the increase of the damage suffered by the van with front cargo.

The velocity vector direction \(\text{Dir}\) of the front load vehicle is \(-18.15^\circ\). As happened on the simulation with center cargo, the vehicle and the barrier are still engaged and approaching each other after the first impact, which means that 7 secondary impacts have been found. On the second one, the highest velocity change \(\Delta v\) is produced with a value of 8.31 km/h.

**Rear axle Load**

On the rear cargo configuration, it has been found a critical rollover situation. As mentioned before, Pc-Crash provides less information regarding this type of accident, so is not possible to provide the same parameters than in the center and front configuration. In this scenario, the lateral forces create a large enough moment around the longitudinal roll axis, causing a rollover instead of a sliding crash if necessary friction is available. With an entrance velocity of 90 km/h the van commits rollover at 2.9 seconds with a speed of 84.7 km/h. Considering a friction between the van body and the ground of 0.5, it has been found that once the van hits the asphalt slides for 34.44 m. until it gets stopped on the opposite lane. This crash has some particularities in common with the high cargo configurations, which have been studied in point 4.5.
- **Accident Severity**

**Center load**

Longer description has been done in point 4.4.2, but in order to compare with the other cargo configurations, the most important parameters are remembered. The collision parameter considered has been 0.2. There have been 8 secondary impacts. The EES obtained has been 5.61 km/h.

**Front load**

Even the speed in this crash is 60% higher than on the center load van, the elasticity of the collision $k$ has been considered the same by using a coefficient of restitution of 0.2. This is due to the fact that accelerations are only comparable using EES if the coefficient of restitution is the same in both (every) crash. Also, with an impact speed still lower than 30 km/h is still feasible to use $k=0.2$.

As in the center load simulation, the vehicle and the barrier are still engaged and approaching each other after the first impact. In this case, 7 secondary impacts have been found.

EES value of 8.36 km/h on the 2$^{nd}$ impact has been obtained. It refers to the most severe impact which in most cases is the sum of the deformation energy e.g. if a car hits a tree with 45 km/h the deformation will not get any deeper by hitting the tree another 10 times with 10 km/h. It has not been possible to find a real crash test with similar characteristics as happened on the front load configuration. On the other hand, on the Spring Seminar in Linz organized by DSD [Appendices II], it was possible to obtain data from a front collision at 31 km/h which is close to the 29.54 km/h pre-impact velocity registered in this configuration.

It is important to mention that the sled test done in DSD facilities was performed with a reinforced car body which means a total mass 570 kg. Also, it is possible to observe by comparing figures 59 and 60 the difference between the angle of incidence of the real test and the simulation.

![Figure 59: Pc-Crash simulation](image1)

![Figure 60: Sled test at DSD](image2)

There is a difference of approximately 20º between both contact planes. Therefore, both simulations should be compared cautiously.
Rear axle Load
Finally, the rollover situation for the rear load configuration is shown on figure 63. This proves again, that the rear load configuration produce much more severe consequences than the center and front cargo positioning.

By comparing the accident severity based on the results obtained in Pc-Crash, it is possible to observe the differences between the crash consequences on the three different configurations. On figure 62, inside the red box, slight damage is produced mainly on the right-front side whereas on figure 61 the damage is more severe. Also, it is possible to see a bigger deformation on the roadside barrier in the front load configuration.

Injury potential
Center load
Previously, it has been found that with a center load distribution, the crash of the vehicle against the roadside barrier produces an average acceleration of 1.64g. As mentioned before, this means almost the double of the acceleration suffered while sitting, which is hardly probable that may cause severe injuries neither on the driver nor on a hypothetic passenger.
**Front load**
The injury potential for the front load configuration has been compared with the data obtained from the sled test carried out by DSD at the Spring Seminar. Two tests have been performed, with a belted/unbelted Dummy on the driver seat. In both cases it has been analysed the x-axle acceleration suffered on the head and chest.

In the belted Dummy has been found a peak value of 3.5g on the head and 10.1g on the chest. As has been done on the center load distribution, the average acceleration suffered on the estimated crash duration (0.12 seconds) has been calculated. The acceleration suffered during the collision time is 2.5g on the head whereas in the chest is 2.7g.

In the unbelted Dummy, accelerations increase considerably. Peak value of 13.1g on the head and 15.6g on the chest has been found. The average acceleration suffered on the estimated between 0.0459 sec. and 0.1659 sec. of the crash the head suffers 8.18g whereas the neck gets 6.7g.

![Belted Dummy rest position after 30 km/h crash.](image)

Doing the analysis with the data obtained on the simulation, it is possible to find the average deceleration by dividing the velocity change $\Delta v$ 8.31 km/h by the collision time. Using the formula $\Delta v/ \Delta t$ it has been found an acceleration of 7.05g. This value is close to the ones provided by the real sled test.

Finally, and again comparing this value with the daily living accelerations, it has been found that the acceleration suffered in the front load distribution is almost 10 times the acceleration suffered while sitting. In this case this may produce more severe consequences.

**Rear Load**
Again, due to the lack of information on rollover situations provided by PC-Crash, is not possible to give data of the injury potential. Injuries in this type of accident depend a lot on the use of the belt. If the driver is belted, the main injuries are caused on the head whereas if it is unbelted, the accelerations may move the body along the inside the vehicle causing major injuries.
4.5 High load distribution: Rollover tendency

4.5.1 Rollover and Static Stability Factor

The rollover occurs when the lateral forces create a large enough moment around the longitudinal roll axis of the van for a sufficient length of time. Critical lateral forces can be generated under a variety of conditions. The vast majority of rollover crashes take place after a driver lost control over the van [8]. By skidding off the road, the van may get in lateral contact with a mechanical obstacle like a curb, a hole or a plowed furrow which yields a sudden large roll moment. This results in a so called tripped rollover.

On the other hand, an un-tripped or friction rollover is the one that has been studied on the simulation. This one takes place during severe steering maneuvers solely as a result of the lateral cornering forces. Although the ratio of un-tripped to tripped rollovers is small, the un-tripped rollovers account for the most severe crashes.

Has been found that the ratio of the track width $T$ and the height of the center of gravity $h_{CoG}$ gives a first indication for the rollover propensity of vehicles.

$$SSF = \frac{T}{2 \cdot h_{CoG}}$$

The Static Stability Factor [8] is an important parameter affecting vehicle rollover risk and is both relevant for tripped as well as un-tripped rollover. The track width is a fixed parameter ($T=1.74m$) while the center of gravity height varies with subject to different load conditions.

<table>
<thead>
<tr>
<th>Load Position</th>
<th>SSF</th>
<th>Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center load</td>
<td>1.13</td>
<td>***</td>
</tr>
<tr>
<td>Load on rear axle</td>
<td>1.07</td>
<td>**</td>
</tr>
<tr>
<td>Front load</td>
<td>1.08</td>
<td>**</td>
</tr>
<tr>
<td>High Center load</td>
<td>0.90</td>
<td>*</td>
</tr>
<tr>
<td>High load on rear axle</td>
<td>0.86</td>
<td>*</td>
</tr>
<tr>
<td>High front load</td>
<td>0.86</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 26: Vans’ load distribution SSF

Therefore, the SSF is used to get the star rating for a single vehicle according to the following table:

<table>
<thead>
<tr>
<th>SSF</th>
<th>Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1.45</td>
<td>*****</td>
</tr>
<tr>
<td>[1.25; 1.44]</td>
<td>****</td>
</tr>
<tr>
<td>[1.13; 1.24]</td>
<td>***</td>
</tr>
<tr>
<td>[1.04; 1.12]</td>
<td>**</td>
</tr>
<tr>
<td>&lt; 1.03</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 27: Star Rating [NHTS]

Just the van with center load, with a limit value of 1.13, can reach three stars. From that point, the rest of vans (load on rear axle and front load) with a low load position reach two stars.
On the other hand, all the vehicles loaded with an increase of 60 cm. on the load height have a SSF value under 1.03. It can be predicted a really high rollover tendency for those vans.

How the load condition influence on the rollover propensity is shown in figure 65 in a simplified manner for different types of vehicles and loading conditions. The static stability factor for typical passenger cars is far above the lateral acceleration which can be transferred by the maximum tire grip. This is the reason why passenger cars are usually not subject to untripped rollovers even in extreme loading conditions. If the adhesion limit between the tires and the road surface is reached before the lateral acceleration gets rollover critical, the vehicle starts to skid over the front wheels. The situation is different especially for light commercial vehicles, where elevated loading may play a major role.

**Figure 65**: Typical critical lateral accelerations to commit rollover on different types of vehicles. [NHTSA]

Figure shows that the lateral acceleration between a passenger car and a light truck in empty conditions is not as big as in loaded situation. This is also reflected on point 3.2, where the empty van was close to the registers obtained by passenger cars on the over steering and lane changing tests.

On the other hand, and by analyzing the results that have been obtained from the simulations done by Pc-Crash, it has been possible to see if high load configurations can be handled and corrected by ESC systems.

### 4.5.2 High Center load

The first configuration has a $h_{cog}$ of 969 mm and a distance to the front axle of 1914 mm. This means an increase of 189 mm. compared with the same load position but positioned as low as possible. As observed in point 4.4.2, the van with a low configuration was able to bypass the critical situation described without crashing or committing rollover at a maximum initial speed of 108 km/h. This speed was reached using ESC system, while the maximum speed without it was 89 km/h.

**Figure 66**: High center configuration.
On the contrary, results have changed significantly in high load configuration. As mentioned before, the lateral forces create a large enough moment around the longitudinal roll axis, causing a rollover instead of a sliding crash if necessary friction is available. Simulation has been done comparing high and low cargo configuration.

High center configuration vs. Low center configuration

- *With ESC*

By using the same maximum speed reached for the low cargo simulation (with and without ESC) it has been found that with an entrance velocity of 108 km/h and equipped with ESC, the van with a high centered load at 2,38 seconds commits rollover with a speed of 101,4 km/h. That proves that the speed that was possible to reach with the load in the same longitudinal position but lower, is not possible to reach with a higher center of gravity even if the vehicle is equipped with ESC.

Figure 68 shows the instant where both, left-front and left-rear tires lose contact with the ground. At 2.38 seconds, the left-front wheel is the first one that reaches a normal force equal to 0. Is it possible to observe also the force transfer to the right side wheel. Just before the 3 seconds all curves cross the x-axis which means that the van is on the ground. Since is the major parameter to recognize rollover-critical in driving situations the lateral acceleration has been also measured relative to the center of gravity. The vehicle reaction is usually expressed in terms of lateral acceleration and yaw rate.
At 2.6 second, a lateral acceleration of 10 m/s$^2$ is reached which is far above from the maximum lateral acceleration to avoid rollover of the van. As seen in Chapter 3, and as a reference, the van in empty conditions was capable of doing the lane changing test with a maximum lateral acceleration of 7 m/s$^2$.

- **No ESC**

Similar situation has happened in the simulation without ESC. It has been proved that the van loaded in a higher way can not handle the situation with an entrance speed of 89 km/h. In this case, the van commits rollover at 2.81 seconds with a speed of 84.3 km/h.

One difference that has been found between those two tests is the relative position of the Bmw and Mazda due to the variation of the entrance speed. It is possible to see in figure 70 that the Bmw’s overtake is in a more advanced situation when the van rolls over the ground. In addition, the distance traveled once the rollover has occurred is also different.

With a friction coefficient of 0.5 defined between the Van’s body and the ground, the vehicle with ESC and an entrance velocity of 108 km/h travels 66 meters along the ground invading the opposite lane. On the other hand, the vehicle without ESC but with a lower entrance speed of 89 km/h leaves marks on the ground on 51.5 m. Those values are directly related with the entrance speed.

**High center configuration with ESC vs. low cargo configuration without ESC**

Afterwards, it has been simulated if the high center loaded van can avoid the rollover if it is equipped with ESC and starts at the same entrance velocity that was reached by the van without ESC but with a lower CoG. (89 km/h). Results show that even at 89 km/h, the ESC system is not able to reconduct the rollover critical situation. It has been found a lateral accelerations still close to 10 m/s$^2$, which as mentioned before, is still far above from van’s limit.

**Maximum entrance speed. 2$^{nd}$ generation vs. 3$^{rd}$ generation**

Finally, it has been found in which speed range the ESC results effective with a high center load configuration. After adapting the simulation to the considerably reduction of entrance speed, it has been found that 55 km/h is the maximum speed in which the van equipped with ESC is able to avoid the collision. On the other hand, the van without ESC can only reach 53 km/h.
If two vans, one equipped with ESC (vehicle 1 red) and one without it (vehicle 2 blue), are launched at the same initial speed of 55 km/h it is possible to observe in figure 71 how the first one keeps following the path whereas the second one enters in rollover situation. Important to mention that at this speed, both vehicles are reaching limit situations, and that the van with ESC even lose contact with the ground on the two left side tires.

Figures 71 and 72 show how the curves are similar until the phase close to the 3.5 seconds of the simulation. In that moment, which is represented by figure 74, the highest values of yaw angular velocity and lateral acceleration are reached. At 3.5 seconds, the van number two gets into a yaw angular velocity of 0.55 rad/s whereas the van number one remains at 0.50 rad/s. Those can be compared with the results obtained on the over-steering test (point 3.2.3) where van’s limit stability was reached also at 0.55 rad/s.

Lateral acceleration of 7.91 m/s² is suffered by van number two. On the other hand, the van equipped with ESC gets a lateral acceleration of 7.03 m/s². This can also be compared with the tests done between cars and the van. In this case, on the lane changing simulation, the van was capable to pass through the marks with an acceleration up to 7 m/s².

Figure 71: High center configuration. 2nd generation vs. 3rd generation

Figure 72: High center configuration. Yaw angular velocity

Figure 73: High center configuration. Lateral acceleration

Figure 74: High center configuration. Position.
4.5.3 High load on rear axle

In point 4.5.2 it has been demonstrated that is not possible to reach the same speed on the simulation by positioning the load on a higher centered position. In this case, same results are found. The van with high load on rear axle configuration is not able to achieve the same results than the rear load configuration van.

Afterwards, it has been found the maximum speed that the van with a high rear position load can achieve without committing rollover. With ESC, the van can pass through the critical situation at 46 km/h whereas without ESC the speed is 45 km/h.

As it can be predicted, with a really high CoG value, there are slight differences between a van equipped whit ESC and one without it.

On the other hand, a much important difference has been observed within the load positioning. On the previous simulation, a maximum speed of 55 km/h has been reached whereas in this case is 46 km/h. This makes a difference of almost 10 km/h just considering a different load position.

High center load van configuration at maximum speed reached by the high load on rear axle configuration.

It has been proved that the simple idea of loading the van in the center instead than in the rear part allows reaching up to 10 km/h more on the same rollover critical situation. Because of it, it has been decided to study the difference between both loading options at the speed where the rear load configuration commits rollover. (47 km/h)

Both vans are equipped with the same ESC and ABS configuration. Also have the same tires, suspension and geometry. All the parameters are exactly the same except the load positioning. On the rear configuration, the CoG it is just 48 mm higher but with 404 mm more of distance to the front axle (2318 mm against 1914 mm of the high center configuration). See figures 77 and 78.
The program automatically calculates the moment of inertia using the formula described in [Appendices I.7]. All the moments of inertia in this dialog box represent the unloaded vehicle.

Figure 79 shows how the red van (with center load) maintains control whereas the blue van (rear load) commits rollover. It is important to mention that the red van does not even invade the opposite lane, so there are no injuries or damages caused by the evasive action. This simulation proves how a proper load distribution can help to avoid a really rollover critical situation.

4.5.4 High front load

Finally it has been studied the van reaction with the load on a high front positioning.

As previous simulations, the vans are not able to reach the same speed than with a lower load positioning.
Due to this fact, it has been studied further the different reactions with and without ESC and also how this new loading configuration affects to the van's dynamic behavior.

In this case, it has been found again a slightly difference on the maximum speed reached by the van equipped with ESC. The van equipped with the stability program can reach 53 km/h without committing rollover while the van without it can reach 51 km/h.

On the other hand, those values are similar to the results that have been found on the first simulation with a high center load configuration. This can be compared with the similarities that were found while comparing low center and low front cargo configurations. Again both achieve similar results, leaving the rear as the worst option to load a light commercial vehicle.

On the other hand, while talking about high load configurations, rear positioning does not mean a different type of crash as happened on the low configurations.
4.6 Conclusions

4.6.1 Regarding ESC
The results of several studies show a consistent picture of the ESC with remarkable safety benefits and proof the positive impact, especially on the low cargo configurations. On the other hand, one of the more significant findings to emerge from this study is the slight effect on the high CoG configurations, where ESC has not been able to counteract the high rollover tendency.

![Figure 81: Maximum entrance speed comparing load distribution and the use of ESC](image)

These conclusions can be drawn from figure 81, where it is possible to observe that in all the low cargo configurations the use of ESC allows to reach between 12 km/h and 19 km/h more than on the 2nd generation van. This means that in that range of velocities, by just introducing ESC as standard equipment of the vehicle, there would be no sort of consequences, neither for the vehicle nor the passengers.

In contrast, on the high load configurations it is possible to observe that the difference of adopting the stability system it just between 1 km/h and 2 km/h, therefore it seems that there is not a positive effect of the ESC.

An implication of this is the possibility that, even the use of ESC results effective for some cases, something else is needed to counteract the influence of the high load on the rollover propensity. In highly dynamic manoeuvres like the simulation that has been done, a hybrid dynamical system is required for a suitable anti-rollover control.
4.6.2 Regarding ESC: Possible solution

The Bosch Rollover Mitigation Functions (RMF) is based on the standard ESC sensor set and provides a scalable structure concerning the determination of rollover critical situations as has been found on the high load configurations. [8]

![Diagram of Rollover Mitigation System](image)

Figure 82: Structure of the Rollover Mitigation System

Figure 82 shows the structure of the entire vehicle stabilizing system with the basic Electronic Stability Program (ESC) and the Hybrid Rollover Mitigation Controller (HRMC). This system is based on the statement that each turn or even a subset of the corresponding time interval is characterized by a set of typical driver’s inputs as well as a typical vehicle response. Consequently, each dynamic steering maneuver can be divided into several time slots which follow each other in a specific manner. To get an appropriate stabilization, the controller must provide suitable intervention strategy.

This is why for the detection of severe steering maneuvers and a suitable anti-rollover control, a hybrid dynamical system is used (Figure 82). The input, output and state of such a system is composed of a discrete and a continuous part; the discrete dynamics $D$ and the continuous dynamics $C$.

Transitions between the discrete states are essentially influenced by the driver’s input and the vehicle reaction. Continuous states vary over time dependent on the discrete state. They are influenced by continuous inputs like the steering wheel angle, the lateral acceleration, the yaw rate, the longitudinal velocity, the body slip angle, and other reference variables essential for the rollover prediction.

In summary, the ESC with Rollover mitigation functions helps the driver to stay on the road and to avoid obstacles, e.g. a car overtaking, by a specific yaw control. It also supports the driver with an optimized lateral acceleration control to manage rollover critical situations.

This research has thrown up many questions in need of further investigation. For example, a deeper look into the Hybrid Rollover Mitigation Controller. Also, a reasonable approach to tackle this issue could be to assess the effects of the use of the HRMC in the high load configurations. As PC-Crash does not offer the possibility to simulate this system yet, probably this should have to be studied by producing real tests.
4.6.3 Regarding Load Distribution

- Crash avoidance

On the results achieved it is possible to observe two very clear tendencies. Depending on the height and distance to the front axle of the load, the consequences of the crash vary. The main cause of accident on low cargo configurations is a crash against the roadside barrier, whereas for higher configurations rollover has been found as the main problem.

The results of this study indicate that, regarding crash avoidance, there is a bigger influence of a correct load distribution than the use of ESC.

As above figures shows, if the cargo is distributed in such a way that the centre of gravity of the total cargo lies as close as possible to the longitudinal axis and is kept as low as possible, the difference of the entrance speed could be more than twice between the best and the worst scenario. This also accords with our earlier observations, which showed that high load configurations reached the worst calcification possible on the SSF (rollover risk parameter).

<table>
<thead>
<tr>
<th>Load Position</th>
<th>SSF</th>
<th>Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center load</td>
<td>1.13</td>
<td>***</td>
</tr>
<tr>
<td>Front load</td>
<td>1.08</td>
<td>**</td>
</tr>
<tr>
<td>Load on rear axle</td>
<td>1.07</td>
<td>**</td>
</tr>
<tr>
<td>High Center load</td>
<td>0.90</td>
<td>*</td>
</tr>
<tr>
<td>High front load</td>
<td>0.86</td>
<td>*</td>
</tr>
<tr>
<td>High load on rear axle</td>
<td>0.86</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 28: Vans’ load distribution SSF

On the high cargo configurations it has been found lateral accelerations up to 10 m/s² which are far above from vans’ limit. Vehicle rollover has been found as the most frequent accident due to incorrect load distribution.

In both situations, high and low cargo configurations, rear position excels as the worst option while loading a van. Minor differences have been found between center and front capabilities to avoid a collision.
- **Crash severity**

In case that the impact is unavoidable, has also been studied how the different options of loading may increase or decrease the impact of the consequences. Simulating three 2nd generations vans, with the same speed of entry (90 km/h), has been possible to obtain the impact constellation, accident severity and injury potential of the three different low load distributions.

<table>
<thead>
<tr>
<th>Impact Constellation</th>
<th>Load position</th>
<th>Pre-impact velocity [km/h]</th>
<th>$\text{Dir Vel. Vector direction}[\text{º}]$</th>
<th>$\Delta v$ Velocity change [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center</td>
<td>18, 65</td>
<td>-21,77</td>
<td>6,93</td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>29, 54</td>
<td>-18,15</td>
<td>8,31</td>
<td></td>
</tr>
<tr>
<td>Rear</td>
<td>84,7(*)</td>
<td>---(*)</td>
<td>---(*)</td>
<td></td>
</tr>
</tbody>
</table>

*Table 29: Center, Front and Rear Load configurations. Impact constellation*

<table>
<thead>
<tr>
<th>Accident Severity</th>
<th>Load position</th>
<th>EES [km/h]</th>
<th>Number secondary impacts</th>
<th>$K$ Coefficient of restitution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center</td>
<td>5,61</td>
<td>8</td>
<td>0,2</td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>8,36</td>
<td>7</td>
<td>0,2</td>
<td></td>
</tr>
<tr>
<td>Rear</td>
<td>---(*)</td>
<td>---(*)</td>
<td>---(*)</td>
<td></td>
</tr>
</tbody>
</table>

*Table 30: Center, Front and Rear Load configurations. Accident Severity*

<table>
<thead>
<tr>
<th>Injury potential</th>
<th>Load position</th>
<th>Average acceleration suffered [g]</th>
<th>Daily living acceleration (sitting on a chair)[g]</th>
<th>Number of time daily living acceleration suffered[g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center</td>
<td>1,64</td>
<td>0,79</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>7,05</td>
<td>0,79</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Rear</td>
<td>---(*)</td>
<td>---(*)</td>
<td>---(*)</td>
<td></td>
</tr>
</tbody>
</table>

*Table 31: Center, Front and Rear Load configurations. Injury Potential*

(*) Data missing from the rear configurations is due that in this case, the van commits rollover instead of sliding and colliding against the roadside barrier [Point 4.4]. Because of this, the pre-impact velocity refers to the speed at which the van commits rollover.
4.6.4 Regarding Load Distribution: Possible solution

It is important to remark that still, up to 25% of accidents involving vans and trucks can be attributable to inadequate cargo securing [9]. If the cargo is not positioned and secured adequately it can be a danger to others and to the passengers. Not secured cargo could fall off the vehicle, cause traffic congestion or as it has been analyzed on chapter 5, could hurt or kill you during strong braking or a crash. Also it has been possible to observe that the steering of a vehicle is also affected by how the cargo is distributed and/or secured on the vehicle, making it more difficult to control the vehicle.

Legal requirements and common sense demand that all load carried on vehicles are secured, whatever porpoise of the trip. Van drivers should be aware of the additional risk of the loaded vehicle, or parts of the load, moving when the vehicle is being driven.

On the other hand, it still common to find that when any load is placed upon the vehicle, the maximum authorized dimensions or the axle and maximum authorized weights are exceeded. In this project this has been reflected on the front and rear load configurations, where the respective axles were overloaded.

<table>
<thead>
<tr>
<th>Axle reactions Front Configuration [Kg]</th>
<th>MAM</th>
<th>Plated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Axle</td>
<td>1847</td>
<td>1750</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>1453</td>
<td>1900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Axle reactions Rear Configuration [Kg]</th>
<th>MAM</th>
<th>Plated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Axle</td>
<td>1363</td>
<td>1750</td>
</tr>
<tr>
<td>Rear Axle</td>
<td>1937</td>
<td>1900</td>
</tr>
</tbody>
</table>

Table 32: Front and Rear configurations. Axle reactions

An implication of these findings is that both load distribution and cargo securing should be taken into account when loading a van.

The driving license required for freight transportations in a vehicle with a MAM lower than 3500 kg. in Spain is the same than the license required for a passenger car. In addition, is necessary to pass an exam called B priority Transport (BTP) (required for example for ambulances or taxi drivers) or another one called Professional capacity (for transportation of goods).

On the other hand, and by making a review of the contents required to pass the exams, it has been found a lack of information regarding load distribution and cargo securing. Those are the points related to the load security found in chapter 11 of the manual for the BTP exam. [10]

- People transportation
  - General rules
  - Location and arrangement of people
- Load transportation
  - General commandments
  - Load position
  - Load dimension
Analysis and Improvement of Security Concerning Light Commercial Vehicles

- Load securing
- Load/Unload
- Maximum dimension, MAM
- Traffic signs

This information is summarized in just 4 out of 144 pages that the manual has. This contrasts with the 208 pages of the European Comission Guideline on Cargo Securing for trucks. Obviously, there are big differences between vans with a MAM of 3500 kg. and trucks that can reach up to 40,000 kg.

However, it would of interest to introduce some of the results of this project and contents of the guideline into the minimum knowledge requirements for a van driver. According to European Commission Directive 2000/56 EC “Safety factors relating to the vehicle, the load and persons carried” have to be contents of the driver license test for all categories of vehicles.

According to Directive 2003/59 EC of 15 July 2003 the training for "professional drivers" has to contain (among many other issues):

- ability to load the vehicle with due regard for safety rules and proper vehicle use
- forces affecting vehicles in motion, use of gearbox ratios according to vehicle load and road profile, calculation of payload of vehicle or assembly, calculation of total volume, load distribution, consequences of overloading the axle, vehicle stability and centre of gravity, types of packaging and pallets
- main categories of goods needing securing, clamping and securing techniques, use of securing straps, checking of securing devices, use of handling equipment, placing and removal of tarpaulins.

This general description of contents could be complemented with the results obtained on this project, especially regarding forces affecting vehicles in motion, load distribution and vehicle stability and centre of gravity. Furthermore, a training program on Cargo Securing for vans would be effective.

Detailed information on the contents of cargo securing training is described in the German VDI standard "VDI 2700, Blatt 1" or the “ ECE Guidelines for Packing of Cargo Transport Units”. The following recommendations are based on these standards and on the European Comission.

It is suggested that the personnel that should be trained is [9]:

- Van drivers
- personnel concerned with loading/unloading of vehicles (if not the driver)
- fleet managers
- personnel concerned with planning of itinerary, loading and unloading locations

At least in bigger enterprises it is recommended to have at least one person with a very high qualification in cargo securing to support all other staff member in question of cargo securing, or even giving internal training on cargo securing and to handle difficult problems which cannot be solved by less trained staff members.
Structure and contents of possible training for light commercial vehicles:

All training courses or lessons should be started by providing information on the basic issues of cargo securing:

- Legislation on cargo securing, responsibilities and technical rules.
- National and international technical standards for cargo securing.
- Physical principles, weights and forces.
- Basic principles and methods of cargo securing.
- Restraining material.

As one approach, the following types of cargo and other fields of knowledge may be grouped in a useful way and distributed on different types of course elements to be combined to a training measure fitting the customers’ needs:

- Mixed cargo on pallets or similar transportation devices*
- Mixes cargo directly loaded into the van (not palletised load)*
- Stacked cargo
- All cargo with securing problems deriving from its shape (e.g. drums, rolls, tubes, sacks, etc.)
- Sheet material (steel sheets, glass, concrete) in vertical, almost vertical and horizontal position

And finally, and with special attention in this study:

- Exact calculation methods for cargo securing
- Load distribution plan

(*)On the following chapter, it has been studied how unsecured cargo on pallets and directly load into the load compartment affects the vans’ dynamic behaviour.
Chapter 5. Unsecured load

The study of the changes in braking deceleration and driving behaviour of heavily loaded delivery vans [4] that was carried by EVU provides in-depth analysis of the braking capabilities of a van. The tests were conducted in dry summer weather conditions on dry asphalt with speeds between 70 – 90 km/h.

While conducting the third test, it was found that the load, despite being lashed, crashed through the partition wall into the passenger compartment. Because of this, the driver was hurt slightly by glass fragments stemming from the glass pane built into the partition wall. Further tests with overload were abandoned and the van was cleared of load. A deeper study has been done to examine the effects of unsecured cargo on an emergency braking situation.

Figure 83: Partition wall

Vehicles are generally regarded as rigid bodies for the simulation of traffic accident collisions with kinetic 3D simulation programs. This simplification is reasonable for the simulation of vehicle - vehicle collisions, vehicle - trailer collisions and vehicle collisions with rigid obstacles such as trees or roadside barriers. However, for vehicle cargo collisions inside the vehicle, this simplification does not allow the motion to be accurately modeled. Multibody simulations is required.

5.1 Simulation description

Simulation pretends to recreate the test done by EVU. As mention before, tests were conducted in dry summer weather conditions on dry asphalt which can represent a coefficient of friction $\mu = 0.8$. Therefore the maximum deceleration is $7.85 \, \text{m/s}^2$.

The hypothetic load consists of 1 tone mass which leads to a total weight of 2871 kg. The geometry is defined by a block with 1 meter length in x, y and z direction. The moments of inertia are calculated automatically whereas the stiffness $S$ of the body, defined as a measure of the resistance offered by an elastic body to deformation has been calculated by:

$$S = \frac{P}{\delta}$$

Where
- $P$ is a steady force applied on the body
- $\delta$ is the displacement produced by the force
It has been assumed a deformation of 1 cm=1/100 m. which leads to a coefficient of stiffness of 1.000.000 N/m. Figure 84 shows the parameters in Pc-Crash.

![Figure 84: Pc-Crash Multibody parameters](image)

The coefficient of friction between the multibody load and the van has been specified following the friction tables found on the European Commission of transport [9]. Obviously, the higher the friction coefficient, the better friction forces contribute to the securing. The best option to determinate the real friction between vehicle and load is to measure it. The values used may be considered as a rule of a thumb if such measurement is not possible. These values will also be only applicable, if the load platform is in good condition, clean and dry.

In this simulation has been compared two different vans, with the only difference that one has secured cargo whereas the other it is only held by the friction between the load and the platform. On one side, the first van has been configured in the same way that was done on previous tests. This means that the load is added in the front part of the load compartment and afterwards the new center of gravity has been calculated.

On the other hand, the unsecured situation has been modeled by adding the multibody block inside the van. The load’s centre of gravity has been located at 0.5 m above the load platform and 2.26 m from the front axle. By doing that it has been possible to obtain the same initial CoG for both vehicles.

### 5.2 Secured:

<table>
<thead>
<tr>
<th>Kerbweight Van (1871 kg.)</th>
<th>Load (1000 kg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoG to Front Axle= 1,26 m.</td>
<td>CoG to Front Axle= 2,26 m.</td>
</tr>
<tr>
<td>( h_{\text{CoG}} = 0,42 \text{ m.} )</td>
<td>( h_{\text{CoG}} = 0,5 + 0,3 = 0.8 \text{ m.}(*) )</td>
</tr>
</tbody>
</table>

*The load platform is at 0.3 m. height referred to the ground.*
Kerbweight + Load:

\[ x_{\text{CoG}} = \frac{1871 \times 1260 + 1000 \times 2260}{2871} = 1608\,mm \]

\[ h_{\text{CoG}} = \frac{1871 \times 419 + 1000 \times 800}{2871} = 551.7\,mm \]

\[ \text{CoG to Front Axle} = 1.61\,m. \]

\[ h_{\text{CoG}} = 0.55\,m. \]

5.3 Unsecured cargo:

By adjusting x and z position with Pc-Crash, it has been possible to achieve the same starting CoG for the unsecured cargo configuration.

![Figure 86: Unsecured Cargo. Multibody system.](image)

Figure 86 shows how the load is positioned at 2.26 m. on the longitudinal direction from the front axle of the van (1.26 m. + 1m.) and also zmin indicates that the load is on the vans’ platform.

5.3.1 Load type. Friction coefficient.

In order to represent different situations, two different loads have been simulated. First of all, it has been considered that the load is supported by a Euro-pallet (ISO 445-1984), which is the most common pallet used for good transportation. It is made primarily of wood, and the standard dimensions are 800x1200x150 mm.

The pallet constitutes a load carrier similar to a load platform without sideboards. Measures to prevent the cargo from sliding or tipping in relation to the pallet should be taken by lashing. The friction between the surfaces of the cargo and pallet are therefore important for calculating the cargo securing. Once the cargo is secured in relation to the pallet, it has been found the presumable friction coefficient between the wooden pallet and the load platform (steel). \( \mu_{\text{static}} \) is friction between two solid objects that are not moving relative to each other. \( \mu_{\text{dynamic}} \) occurs when two objects are moving relative to each other and rub together and it has been considered as \( 0.7 \times \mu_{\text{static}} \).

<table>
<thead>
<tr>
<th>Material combination in the contact area</th>
<th>Friction coefficient ( \mu_{\text{static}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wooden pallet against steel</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 33: Pallet friction
Afterwards, it has been considered that the load is basically painted flat metal sheets of mixed sizes. Usually, the load platform of the van is also painted, so the friction coefficient considered is the painted rough metal sheet against painted rough steel.

<table>
<thead>
<tr>
<th>Material combination in the contact area</th>
<th>Friction coefficient $\mu_{\text{static}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>painted rough metal sheet against painted rough steel</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 34: Meta sheet friction

Like the tests that were run by EVU, the simulation represents a full break sequence after 2 seconds at 90 km/h. As happened on the deceleration test done on the Van vs. Car comparative, the stop criterion is defined when the vehicle reaches a low energy value, which usually is between 0.3 and 0.4 km/h.

5.4 Results

5.4.1 Euro-pallet

The first thing that has been possible to notice is that due to the move of the load, the total distance required by the van with unsecured cargo increases. In this case, the difference between each van is approximately 5 meters. Figure 88 shows how the blue van (unsecured load) needs 95.06 meters to stop whereas the red one (secured load) needs 89.98 meters. Figure 87 also shows how the load transfer increases the speed from 69.02 km/h to 71.92 km/h on the moment that the load impacts against the vehicles’ interior.

Figure 87: Unsecured load. Velocity diagram.  
Figure 88: Unsecured load. Final position.

Figure 88 shows that the 5 meters correspond to almost the length of the van (5.4 meters). The pink colour of the load system indicates, as mentioned before, that there has been an impact between the load and the van. At 0.75 seconds after pressing the breaks, this impact has produced a peak longitudinal acceleration on the vehicle of 40.57 m/s$^2$, from a deceleration of -7.85 m/s$^2$ to an opposite acceleration of 32.72 m/s$^2$. 

DanCrash
5.4.2 Metal sheet
As happened on the load positioned above the euro pallet, while carrying metal sheets it has also been found an increase of the total breaking distance. This distance is also approximately 5 meters but in this case a higher velocity change has been found, from 70, 84 km/h to 74,41 km/h. As figure 90 shows, due to the less friction between the cargo and the load platform, a higher acceleration has been found on the vehicle. The longitudinal acceleration suffered on the vehicle is 60.6 m/s$^2$, which is 50% bigger than the previous simulation.

The change of the loads’ speed generates forces. In other words, the only situation where a cargo does not exert any force on its environment (understood as the load compartment) is while driving in a straight line at a constant speed. The higher deviation from this situation the stronger are the forces that the cargo exerts upon the load compartment. In a breaking situation like the simulation done, those forces increase the velocity and the breaking distance of the van. In these situations friction alone is seldom sufficient to stop unsecured cargo from sliding. It would be incorrect to assume that the weight of the load will be sufficient to keep it in position.

5.4.3 Partition wall
During this heavy braking simulation for instance, the force exerted by the cargo towards the front of the vehicle is very high and nearly equal the weight of the cargo [9]. So, it can be assumed that during heavy braking, a 1 tonne load will “push” forward the partition wall with a force of:

$$1000 \, kg \cdot 9,81 \frac{m}{s^2} = 9810 \, N$$

Following the ISO norm ISO/DIS 27956 the partition shall at least cover the driver’s seat including head restrain in the upper position, and be able to resist whatever cargo reaching forwards due to the vehicle’s deceleration on at least 10m/s$^2$. On the other hand, greater forces may be encountered if the van is involved in an accident. Even at low speed it has been possible to observe higher accelerations.

Friction alone cannot be relied upon to prevent unsecured cargo from sliding. When the vehicle is moving, vertical movements caused by bumps and vibrations from the road will reduce the restraining force due to friction. Friction can even be reduced to zero if the load momentarily leaves the bed of the truck. Correct lashings or other restraining methods, in addition to friction, must be installed for an adequate cargo securing.
Chapter 6. Cost-Benefit Analysis

6.1 Effectiveness of the ESC. Estimation for vans.

It has been proved the effectiveness of the Electronic Stability Control in different load distributions; therefore it is important to know if the implementation of this system carries a social benefit. This Cost-Benefit study has been based on previous studies, but for the first time it has been done just for commercial vehicles.

The study of Effectiveness of Electronic Stability Control Systems in Great Britain that was carried out by R.Frampton and P. Thomas [11] starts from the analysis of 890,648 cars of which 8,685 were equipped with ESC. This represents one of the largest datasets available for this type of analysis. However, there have been no controlled studies which compare differences in the use of ESC for vans. For this reason, and given the relative similarity found between cars and vans in chapter 3, it has been decided to use the same model and parameters.

R.Frampton and P. Thomas Model

The case control approach also requires a set of crash types where there is an expectation that ESC will have no effect to be used as a control group. The data provided by R.Frampton and T.Thomas [11] includes several categories of vehicle manoeuvres where one car was essentially stationary before the crash. These were selected to be the control group of manoeuvres. Table 35 shows also the other collision types.

<table>
<thead>
<tr>
<th>Control Manoeuvre types (no ESC effect)</th>
<th>Other Manoeuvres (ESC effect possible)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversing</td>
<td>U turn</td>
</tr>
<tr>
<td>Parked</td>
<td>Turning left</td>
</tr>
<tr>
<td>Waiting to go ahead but held up</td>
<td>Turning right</td>
</tr>
<tr>
<td>Stopping</td>
<td>Changing lane to left</td>
</tr>
<tr>
<td>Starting</td>
<td>Changing lane to right</td>
</tr>
<tr>
<td>Waiting to turn left</td>
<td>Overtaking moving vehicle on it's offside</td>
</tr>
<tr>
<td>Waiting to turn right</td>
<td>Overtaking stationary vehicle on it's offside</td>
</tr>
<tr>
<td></td>
<td>Overtaking on nearside</td>
</tr>
<tr>
<td></td>
<td>Going ahead left hand bend</td>
</tr>
<tr>
<td></td>
<td>Going ahead right hand bend</td>
</tr>
<tr>
<td></td>
<td>Going ahead other</td>
</tr>
</tbody>
</table>

Using the case-control methodology the cars in the sample are distributed between the four case-control categories as shown in Table 35.

<table>
<thead>
<tr>
<th></th>
<th>Control Maneuvers’ types</th>
<th>Other Maneuvers type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Vehicles (ESC)</td>
<td>$N_{xx}$</td>
<td>$N_{xy}$</td>
</tr>
<tr>
<td>Control Vehicle (no ESC)</td>
<td>$N_{yx}$</td>
<td>$N_{yy}$</td>
</tr>
</tbody>
</table>

Table 35: Case-Control Maneuvers

It should be noted the case-control method does not assume that vehicles are in the same collision.
Firstly, the method calculates the probability of a case car being involved in the two crash types (Eq. 1).

\[
\text{Probability}_{\text{ESC}} = \frac{N_{xx}}{N_{xy}}
\]

Then the Probability ratio is used to compare the two groups of cars (Eq. 2).

\[
\text{Probability Ratio} = \frac{\text{Probability}_{\text{ESC}}}{\text{Probability}_{\text{no ESC}}} = \frac{N_{xx} N_{yy}}{N_{xy} N_{yx}}
\]

Finally effectiveness of ESC is defined in (Eq. 3)

\[
\text{Effectiveness}_{\text{ESC}} = (1 - \text{Probability ratio}) \cdot 100\%
\]

The results using this model and also provided by the Real Automóvil Club de Catalunya (RACC) are:

<table>
<thead>
<tr>
<th>Cases</th>
<th>All</th>
<th>Slight injures</th>
<th>Severe injures</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>All type of accidents</td>
<td>7%</td>
<td>6%</td>
<td>11%</td>
<td>25%</td>
</tr>
<tr>
<td>Road surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Wet</td>
<td>7%</td>
<td>7%</td>
<td>22%</td>
<td>38%</td>
</tr>
<tr>
<td>- Dry</td>
<td>5%</td>
<td>5%</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>- Snow or ice</td>
<td>19%</td>
<td>19%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Sliding</td>
<td>21%</td>
<td>21%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>Rollover</td>
<td>33%</td>
<td>33%</td>
<td>59%</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Men</td>
<td>7%</td>
<td>6%</td>
<td>10%</td>
<td>48%</td>
</tr>
<tr>
<td>- Women</td>
<td>5%</td>
<td>4%</td>
<td>15%</td>
<td>19%</td>
</tr>
<tr>
<td>Impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Frontal</td>
<td>10%</td>
<td>10%</td>
<td>2%</td>
<td>23%</td>
</tr>
<tr>
<td>- Lateral</td>
<td>9%</td>
<td>7%</td>
<td>22%</td>
<td>27%</td>
</tr>
</tbody>
</table>

Table 36: ESC Effectiveness

### 6.2 Effectiveness of ESC on the reduction of victims for vans

For the estimation of the economical impact that the installation of the ESC produces it has to be excluded the accidents were pedestrians, bicycles, mopeds and motorbikes were implicated. The data provided in the introduction of this project for both countries, Spain and Denmark, only concerns to the driver and passengers of the van so it can be considered that the requirement has been full fit.

Table 37 shows the total number of injured and dead people inside vans in Spain for 2006.

<table>
<thead>
<tr>
<th>Source: DGT</th>
<th>Total 2006</th>
<th>Total</th>
<th>Severe</th>
<th>Slight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diver</td>
<td>6,984</td>
<td>6,754</td>
<td>1,069</td>
<td>5,685</td>
</tr>
<tr>
<td>Passenger</td>
<td>2,954</td>
<td>230</td>
<td>2,877</td>
<td>451</td>
</tr>
<tr>
<td>Total</td>
<td>9,938</td>
<td>7,000</td>
<td>5,936</td>
<td>2,711</td>
</tr>
</tbody>
</table>

Table 37: Van victims in Spain 2006
On the other hand, for Denmark it has been only possible to find the number of total severe and slight injured persons also for year 2006.

Assuming that the estimated effectiveness for the United Kingdom would not be different that the one that could be found in Spain and Denmark, it has been applied the effectiveness ratios found on the study made by R.Frampton and P.Thomas. If in 2006 all the vans (100%) in Spain and Denmark have had ESC system the number of victims would have been reduced as follows:

<table>
<thead>
<tr>
<th>Source: statisk banken</th>
<th>Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victim role</td>
<td>Total</td>
</tr>
<tr>
<td>Diver</td>
<td>21</td>
</tr>
<tr>
<td>Passenger</td>
<td>3</td>
</tr>
<tr>
<td>Total 2006</td>
<td>330</td>
</tr>
</tbody>
</table>

Table 38: Van victims in Denmark 2006

Taking as a reference the study done by RACC it is also important to analyse the result with different stock penetration of the ESC. Calculations have been done again assuming 70, 50%, 25% and 10% of implementation on the vans.

Spain

<table>
<thead>
<tr>
<th>Year 2006</th>
<th>ESC efectiveness</th>
<th>Reduction</th>
<th>Victims with ESC in all the vans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6.984</td>
<td>7%</td>
<td>489</td>
</tr>
<tr>
<td>Dead</td>
<td>230</td>
<td>25%</td>
<td>58</td>
</tr>
<tr>
<td>Severe injured</td>
<td>1.069</td>
<td>11%</td>
<td>118</td>
</tr>
<tr>
<td>Slight injured</td>
<td>5.685</td>
<td>6%</td>
<td>341</td>
</tr>
</tbody>
</table>

Table 39: Victim reduction Spain

Denmark

<table>
<thead>
<tr>
<th>Year 2006</th>
<th>ESC efectiveness</th>
<th>Reduction</th>
<th>Victims with ESC in all the vans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>330</td>
<td>7%</td>
<td>23</td>
</tr>
<tr>
<td>Dead</td>
<td>24</td>
<td>25%</td>
<td>6</td>
</tr>
<tr>
<td>Severe injured</td>
<td>110</td>
<td>11%</td>
<td>12</td>
</tr>
<tr>
<td>Slight injured</td>
<td>196</td>
<td>6%</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 40: Victim reduction Denmark

Taking as a reference the study done by RACC it is also important to analyse the result with different stock penetration of the ESC. Calculations have been done again assuming 70, 50%, 25% and 10% of implementation on the vans.

Spain

<table>
<thead>
<tr>
<th>100%</th>
<th>75%</th>
<th>50%</th>
<th>25%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6.495</td>
<td>6.617</td>
<td>6.739</td>
<td>6.862</td>
</tr>
<tr>
<td>Dead</td>
<td>172</td>
<td>187</td>
<td>201</td>
<td>216</td>
</tr>
<tr>
<td>Severe injured</td>
<td>951</td>
<td>981</td>
<td>1010</td>
<td>1040</td>
</tr>
<tr>
<td>Slight injured</td>
<td>5.344</td>
<td>5429</td>
<td>5515</td>
<td>5600</td>
</tr>
</tbody>
</table>

Table 41: Implementation ESC Spain

Denmark

<table>
<thead>
<tr>
<th>100%</th>
<th>75%</th>
<th>50%</th>
<th>25%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>307</td>
<td>313</td>
<td>318</td>
<td>324</td>
</tr>
<tr>
<td>Dead</td>
<td>18</td>
<td>20</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Severe injured</td>
<td>98</td>
<td>101</td>
<td>104</td>
<td>107</td>
</tr>
<tr>
<td>Slight injured</td>
<td>184</td>
<td>187</td>
<td>190</td>
<td>193</td>
</tr>
</tbody>
</table>

Table 42: Implementation ESC Denmark
6.3 Social benefit from the implementation of ESC for vans

Accidents obviously represent a cost for society. Therefore a monetary value should be given to them.

- Costs in Spain

The cost in Spain for accidents involving dead, slight and serious injuries is considered and taken from Lladó and Roig in the RACC study [1].

These costs estimated for 2004 were:

<table>
<thead>
<tr>
<th></th>
<th>Dead</th>
<th>Severe injuries</th>
<th>Slight injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>565.059</td>
<td>118.681</td>
<td>32.355</td>
</tr>
</tbody>
</table>

Table 43: Victims social cost Spain 2004

with a percentage annual increase for each year of:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.7%</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

These costs estimated for 2006 are:

<table>
<thead>
<tr>
<th></th>
<th>Dead</th>
<th>Severe injuries</th>
<th>Slight injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>602.959</td>
<td>126.641</td>
<td>34.525</td>
</tr>
</tbody>
</table>

Table 44: Victims social cost Spain 2006

- Costs in Denmark

The same procedure for Denmark from the data taken from procvejdirektoratet.dk.

These costs estimated for 2001 were:

<table>
<thead>
<tr>
<th></th>
<th>Dead</th>
<th>Severe injuries</th>
<th>Slight injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>8.223.000</td>
<td>850.000</td>
<td>232.000</td>
</tr>
</tbody>
</table>

Table 45: Victims social cost Denmark 2001

with a percentage annual increase for each year of:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,4%</td>
<td>2,1%</td>
<td>1,2%</td>
<td>1,8%</td>
<td>1,9%</td>
</tr>
</tbody>
</table>

Accident costs for year 2006:

<table>
<thead>
<tr>
<th></th>
<th>Dead</th>
<th>Severe injuries</th>
<th>Slight injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>8.953.308</td>
<td>932.925</td>
<td>254.633</td>
</tr>
<tr>
<td></td>
<td>1.193.744</td>
<td>124.390</td>
<td>33.951</td>
</tr>
</tbody>
</table>

Table 46: Victims social cost Denmark 2006

If the results obtained from the estimation of victims are multiplied by the cost of each, it is possible to obtain the total costs in relation to the stock implementation. Therefore, the social savings have been obtained by the difference between (1) and each stock penetration.
Spain

<table>
<thead>
<tr>
<th>Millions of €</th>
<th>No ESC (1)</th>
<th>100% (2)</th>
<th>75% (3)</th>
<th>50% (4)</th>
<th>25% (5)</th>
<th>10% (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>470</td>
<td>409</td>
<td>424</td>
<td>440</td>
<td>455</td>
<td>464</td>
</tr>
<tr>
<td>Dead</td>
<td>139</td>
<td>104</td>
<td>113</td>
<td>121</td>
<td>130</td>
<td>135</td>
</tr>
<tr>
<td>Severe injuries</td>
<td>135</td>
<td>120</td>
<td>124</td>
<td>128</td>
<td>132</td>
<td>134</td>
</tr>
<tr>
<td>Slight injuries</td>
<td>196</td>
<td>185</td>
<td>187</td>
<td>190</td>
<td>193</td>
<td>195</td>
</tr>
</tbody>
</table>

Table 47: Costs related to % implementation Spain

<table>
<thead>
<tr>
<th>Millions of €</th>
<th>100% (1)-(2)</th>
<th>75% (1)-(3)</th>
<th>50% (1)-(4)</th>
<th>25% (1)-(5)</th>
<th>10% (1)-(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>61</td>
<td>46</td>
<td>30</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Dead</td>
<td>35</td>
<td>26</td>
<td>18</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Severe injuries</td>
<td>15</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Slight injuries</td>
<td>11</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 48: Savings related to % implementation Spain

Denmark

<table>
<thead>
<tr>
<th>Millions of €</th>
<th>No ESC (1)</th>
<th>100% (2)</th>
<th>75% (3)</th>
<th>50% (4)</th>
<th>25% (5)</th>
<th>10% (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>49</td>
<td>40</td>
<td>43</td>
<td>44</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>Dead</td>
<td>29</td>
<td>21</td>
<td>23</td>
<td>25</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Severe injuries</td>
<td>14</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Slight injuries</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 49: Costs related to % implementation Denmark

<table>
<thead>
<tr>
<th>Millions of €</th>
<th>100% (1)-(2)</th>
<th>75% (1)-(3)</th>
<th>50% (1)-(4)</th>
<th>25% (1)-(5)</th>
<th>10% (1)-(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Dead</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Severe injuries</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Slight injuries</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 50: Savings related to % implementation Denmark

Once the savings for each country have been calculated it is necessary to know the costs of the installation of the ESC. According to Bauman, Gravenhoff and Geisler [12] the cost of equipping a car with ESC is stated with 130 €. This reflects the additional equipment costs for ESC as an addition to an existing Antilock Braking System (ABS). This figure is not the costumer price. The value refers to the production and installation costs since is the appropriate figure in CBA from a society’s point of view because it reflects the resource consumption. As all the vans are equipped also with ABS system, it has been considered that the cost of installation would be the same that in a car.
By following the formula proposed by Bauman, Grawenhoff and Geisler:

\[ g = K_0 \cdot \frac{i \cdot (1 + i)^n}{(1 + i)^n - 1} \]

where:
- \( g \) = annual cost
- \( K_0 \) = investment cost
- \( i \) = discount rate (5%)
- \( n \) = lifetime of a vehicle (12 years)

Considering that there are approximately 2,435,706 vans in Spain and 459,082 in Denmark (see chapter 1) there is an investment cost \( K_0 \) of 317 million€ and 60 million€ respectively. By applying again the implantation percentage it is possible to find the benefit for each option:

### Spain

<table>
<thead>
<tr>
<th>Implementation</th>
<th>Social Savings (million €)</th>
<th>Annual Cost (million €)</th>
<th>Benefit (million €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>25%</td>
<td>15</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>50%</td>
<td>30</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>75%</td>
<td>46</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>100%</td>
<td>61</td>
<td>36</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 51: Benefit Spain

### Denmark

<table>
<thead>
<tr>
<th>Implementation</th>
<th>Social Savings (million €)</th>
<th>Annual Cost (million €)</th>
<th>Benefit (million €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>1</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>25%</td>
<td>2</td>
<td>1.7</td>
<td>0.3</td>
</tr>
<tr>
<td>50%</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>75%</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>100%</td>
<td>9</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 52: Benefit Denmark

### 6.4 Evaluation of the Cost-Benefit of ESC in Spain and Denmark

From the analysis of the introduction of ESC for vans in Spain and Denmark and taking into account the objectives and methodology raised to develop, it is possible to highlight a number of data related with the potential safety and cost-benefit.

**ESC safe lives. Can be considered the most important safety development since the seatbelt [NHTSA]**

- Considering 100% of implementation, approximately 58 passengers and van drivers could have saved his live. 6 in the case of Denmark.

**Even with the lowest implementation, there is a social benefit.**

- 2 million € in Spain in contrast to the 0.3 million€ in Denmark. This is due basically to the difference on inhabitants and total number of registered vans. Nevertheless, it is considered beneficial to society in both countries.
Conclusions

The result of several simulations shows that even the 2nd generation van gets the worst results in each test, the values obtained can be compared to the ones reached by modern passenger cars. This does not mean that light commercial have similar dynamic properties than the rest of the vehicles, specially when it is loaded, but indeed contradicts the widespread opinion that they are really far from a passenger car.

There is a consistent picture of the ESC with remarkable safety benefits and proof the positive impact, especially on the low cargo configurations. On the other hand, one of the more significant findings to emerge from this study is the slight effect on the high CoG cargo configurations, where ESC has not been able to counteract the high rollover tendency. The evidence from this study suggests that, regarding crash avoidance, there is a bigger influence of a correct load distribution than the use of ESC in vans loaded with a high CoG. The ESC with Rollover Mitigation function should be studied as a support for the van driver in rollover critical situations.

Furthermore it’s a common misunderstanding that heavy cargo needs to be less or none secured, due to the weight. Friction alone cannot be relied upon to prevent unsecured cargo from sliding. On a fully breaking situation the total distance required by the van with unsecured cargo increases considerably. Correct lashings or other restraining methods, in addition to friction, must be installed for an adequate cargo securing.

Even with the lowest percentage of implementation of ESP, there is Social benefit for both countries studied. This is 2 million € in Spain in contrast to the 0.3 million € in Denmark. Difference is basically due to the total number of registered vans. Nevertheless, it is considered beneficial to society in both countries.
Environmental impact

Nowadays, the environmental impacts of human activity is quantified mainly by emissions of CO$_2$ emitted, causing the greenhouse effect due to the waste generated.

In this project the waste generated is almost null and CO$_2$ emissions are derived primarily by the consumption of electricity. For the estimated grams of CO$_2$ emitted into the atmosphere per kWh has been taken into account the current Spanish energy system.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>% of the production</th>
<th>g CO$_2$ per kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Natural</td>
<td>18,80%</td>
<td>365</td>
</tr>
<tr>
<td>Nuclear</td>
<td>22,40%</td>
<td>-</td>
</tr>
<tr>
<td>Carbon</td>
<td>30,30%</td>
<td>950</td>
</tr>
<tr>
<td>Fuel-Oil/Gas</td>
<td>3,80%</td>
<td>802</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>24,70%</td>
<td>-</td>
</tr>
</tbody>
</table>

From table it follows that the amount of 387 grams of CO2 are emitted into the atmosphere per kWh produced. To simplify the calculations it has been ignored the losses from the electricity and assume that the 100% of what is consumed comes from the plant. The start of this project was in December 2008 and ended in April 2009 which has a total of 151 days. According to the calendar this amount is reduced to 86 days where is considered an average of 6 hours per day:

<table>
<thead>
<tr>
<th>Consumption [kWh]</th>
<th>Hours</th>
<th>g CO$_2$/h</th>
<th>g CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laptop</td>
<td>0,1</td>
<td>516</td>
<td>38,7</td>
</tr>
<tr>
<td>TFT Screen</td>
<td>0,017</td>
<td>516</td>
<td>6,579</td>
</tr>
</tbody>
</table>
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Concerning Light Commercial Vehicles

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Acknowledgments

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I would like to thank my family for all their support, especially to my parents Jesús and Teresa and my sister Marta, who encouraged me to go abroad to do my Master Thesis and were always giving me the best of them.

Also, I would like to thank all my friends in DTU. Nikolas, Pablo, Adrián, Guillermo, Reynald, Joan, Joao, Ramon, Dimitris, Tomas, Sara... Without them these lasts months in Denmark would not have been the same.

I can’t forget my friend back home, Alex, Victor, Cristian, Roger, Javi, Guille and Pepe and all the good times we shared together before coming to Denmark and the time that we will share in the future.

And last but not least, I have to thank my girlfriend Elisabeth, for supporting me all this time, for being patient and helping a lot despite the distance. After those months abroad, it was easy to understand why she is the most important part of my life.
Appendices

A. Pc-Crash software description

PC-Crash program has been designed to perform calculations connected with reconstruction of road accidents. It helps to simulate motions and collisions of vehicles and biomechanical objects. It is also a very convenient tool for time-distance analysis of an event.

It is possible to simulate any complex motion of vehicles, collisions as well as accidents involving pedestrians, collisions of single track vehicles and motion of vehicle occupants. In general, it is possible to simulate how the event happened.

Pc-Crash has another great advantage. The friendly work environment not only makes it easily communicate with the program, but also helps to interpret the calculation results almost immediately since the results are currently translated from the numerical language into graphic form.

On the other hand, the user’s knowledge and caution are indispensable before presenting the results. It is not possible to use Pc-Crash program without profound knowledge of its operation, abilities and limitations and without substantial practice in using it.

It was created at the Institute of Mechanics of the Univesity of Technology of Graz, Austria. The author of the original idea and basic physical models was Prof. Hermann Steffan, further assisted by Dr. Andreas Moser and Wolfgang Neubauer. The program is constantly upgraded and developed at Dr. Steffan Datentechnik Company.

1. Physical assumptions of the program

A number of physical models were applied and certain assumptions and simplifications were adopted. In Pc-Crash the vehicle is modelled as a rigid body of six degrees of freedom. The wheels are zero-mass, suspended independently, neglecting the mechanical systems through which the kinematics of real suspensions are carried out. A “flat model” of the vehicle will refer to a vehicle of three degrees of freedom, in which the height of CG position has been declared 0, while a “3D model” will refer to a vehicle of six degrees of freedom which the height of CG position is greater than 0.

2. Co-ordinate systems

Two right-handed co-ordinate systems have been introduced: a global one rigidly connected with the environment and a local on strictly connected with the body, the origin of which is fixed at the vehicle mass centre. The angles of rotation are measured according to the right handed global coordinate system.
3. Forces and moments acting on the vehicle

A vehicle is acted by the following external forces:

- Resistance of motion:
  - Air
  - Grade
- Forces of roadway reaction on the wheel (vertical, transverse and longitudinal)
- Forces of mass
- Forces of collision

Rolling resistance can be introduced by braking of wheels but only when the vehicle is not powered by the engine.

a. Air resistance

The air resistance force is described by the Equation:

\[ F_a = \frac{\rho \cdot C_x \cdot A \cdot V^2}{2} \]

Where:
- \( \rho = 1.3 \) [Kg/m³] - air density
- \( C_x \) - Drag coefficient
- \( A \) - Cross-sectional area of the vehicle, in [m²]
- \( V \) - air relative velocity (simply vehicle velocity), in [m/s]

b. Grade resistance

A vehicle can move on a plane sloping at any angle. The grade can be established by shaping a 3D road object or calculating separate areas.

c. Roadway-wheel reactive forces

The reactive forces are determined during simulation according to the given conditions of motion, considering the local adhesion and road slope. Most often the car is activated by assigning acceleration forces on particular wheels, or optionally, acceleration can be simulated by using the engine characteristics and power transmission ratios.
4. Correction of braking forces

In Figure the following notation has been used:

- $X_p$ - tangent longitudinal force on front axis wheels
- $X_t$ - tangent longitudinal force on rear axis wheels
- $Z_p$ - dynamic vertical reaction on front axis wheels
- $Z_t$ - dynamic vertical reaction on rear axis wheels

Dynamic vertical reactions during braking can be determined by:

$$Z_p = G \left( \frac{h}{l} + 1 - \frac{b}{l} \right)$$
$$Z_t = G \left( \frac{b}{l} - z \frac{h}{l} \right)$$

Where:

- $G = m \cdot a$ - Vehicle actual weight
- $Z = \frac{a}{g}$ - braking intensity (relative deceleration)
- $b$ - distance of CG from front axle
- $h$ - CG height
- $l$ - axle base

If mass is distributed symmetrically in reference to the longitudinal axle (such assumption was adopted in the program), the vertical reaction on particular wheels during straight-line motion will be twice weaker than those corresponding axles:
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\[ Z_0 = Z_1 = \frac{Z_p}{2} = \frac{G}{2} \left( z \frac{h}{l} + 1 - \frac{b}{l} \right) \]

\[ Z_2 = Z_3 = \frac{Z_t}{2} = \frac{G}{2} \left( \frac{b}{l} - z \frac{h}{l} \right) \]

The model of braking forces used in the program refers to planar simulation (h>0).

The coefficient of braking forces distribution has been defined by Equation:

\[ \varphi = \frac{X_t}{X_t + X_p} \]

It gives information on the proportion of the breaking force of rear axle wheels in the total braking force.

To design a perfect breaking system, the breaking force distribution would have to be designed in such a way that the longitudinal force on the given axle was always, regardless of breaking intensity, proportional to the real vertical force on this axle. An ideal distribution of the rear brake force is described by a parabola:

\[ q_{t id} = \frac{X_{t, id}}{G} = \frac{z \cdot Z_t}{G} = z \left( \frac{b}{l} - z \frac{h}{l} \right) \]

As follows from Equation the shape of the parabola depends on the CG position.

Regulations No. 13 of ECE (Economic Commission for Europe) require that in all cars admitted in traffic in Europe, in the whole range of breaking intensity (i.e. z = 0 – 0.8) the first to slip are the front wheels, and rear only after brake pedal is pressed harder.
In Pc-Crash a linear corrector with a “knee-point” for rear wheels has been modeled because this type of braking forces correction is used in the majority of vehicles, including almost all Van’s produced at the present.

Figure shows characteristics of rear brake force $q_t$ corrected ideally an characteristics of real braking force using corrector on rear wheels $q_t'$ and $q_t''$.

5. Tire model

Pc-Crash includes two tire models: a simple linear model and a non-linear model called “TM-Easy”.

In the linear model the transverse component of the force $Y_i$ is linearly dependent on the actual slip angle $\alpha_i$, and can be expressed by Equation:

$$Y_i = \mu_i Z_i \frac{\alpha_i}{\alpha_{i \text{ max}}}$$

Parameter $\alpha_{i \text{ max}}$ describes a slip angle at which the unbraked wheel reaches maximum possible lateral force $Y_{i \text{ max}} = \mu Z_i$ (where $Z_i$ is the vertical force on the wheel).

TM-Easy tire model allows to model non linear effects. Those are the tire parameters that need to be specified independently.

- **Fmax**: The peak frictional force value. The maximum friction is this value multiplied by the specified scene friction coefficient.
- **Smax**: The slip value at which Fmax occurs. For lateral tire properties, the x-axis of the tire model graph is tan ($\alpha$), where $\alpha$ is the lateral slip angle.
- **Fslip**: The sliding frictional force value. The maximum friction is this value multiplied by the specified friction coefficient.
- **Sslip**: The slip value at which F slip occurs.
- **Fop**: The slope of the tire model curve at the origin.
In general it can be said that the lateral slip angle of the tyre causes the lateral tyre force. The lateral tyre force increases with an increasing lateral slip angle, with a maximum depending on the tyre-road surface friction coefficient.

When switching from the linear tire model to the TM-Easy tire model, the change in vehicle motion will be due almost entirely to the difference between the specified F_{slip} value and 1. This is because the default coefficient of friction is the sliding value when using the Linear tire model, but is the static value when using the TM-Easy tire model and F_{max} = 1.

6. Wet friction between tire and road
Pc-Crash makes it possible to use models of both dry and wet friction. Maximum attainable deceleration on a wet road is a function of velocity and is usually described by hyperbolic function. The input values to be applied are deceleration are velocities of 20 km/h (a_{20}) and 80 km/h (a_{80}). On this basis the program calculates parameter n and A to determinate deceleration as a function of velocity:

\[
n = 2 - \frac{\ln \frac{a_1}{a_2}}{\ln \frac{v_1}{v_2}}
\]

\[
A = \frac{a_1 \cdot n}{2} \cdot v_1^{2-n}
\]

\[
a = a(v) = \frac{2A}{n} \cdot v^{2-n}, \; n>2
\]

where:

\[a_1 = a_{20}\]

\[a_2 = a_{80}\]

\[v_1 = 20 \text{ [km/h]} = 5.6 \text{ [m/s]}\]

\[v_2 = 80 \text{ [km/h]} = 22.2 \text{ [m/s]}\]

a = vehicle deceleration

To avoid errors when calculating deceleration curves at low velocities, restriction of friction coefficients to dry friction has to be done.

7. Moment of inertia
These are the moments of inertia of the vehicle about its three main axes:

- **Yaw**, about the vertical axis
- **Roll**, about the longitudinal axis
- **Pitch**, about the transverse axis.
The program calculates the moment of inertia using the following formulas.

For most vehicles, the formula used is:

\[
I_z = 0.1269 \cdot m \cdot WB \cdot L, \\
I_y = I_z, \\
I_x = 0.3 \cdot I_z,
\]

-where:
  \( I_z \) = Yaw moment of inertia
  \( m \) = Mass
  \( WB \) = Wheelbase
  \( L \) = Overall length
  \( I_y \) = Pitch moment of inertia
  \( I_x \) = Roll moment of inertia

For a truck or a trailer (as van is considered) the moment of inertia is calculated by the following formula:

\[
I_z = m \cdot (L^2 + B^2)/12, \\
I_y = I_z, \\
I_x = 2 \cdot m \cdot B^2/12,
\]

- where:
  \( L \) = Overall length
  \( B \) = Overall width

8. Impact Model

The impact model used in PC-Crash enables calculations of vehicles motion parameters immediately after the collision. The model disregards the vehicles motion during the collision and assumes that the impact time is infinitely short. The impact force is applied at a single point. This point of impact is the one where the total crash force is assumed to be exchanged.

The elasticity of the collision is considered, based on a coefficient of restitution \((k)\). The value of this coefficient depends on the collision speed. The lower the velocity and deformation, the closer this value is to 1. For example, at parking velocities, the usual value is 0.5-0.9. It can be assumed \(K=0\) for perfect plastic collisions and \(K=1\) for perfect elastic collisions.
9. **Coefficient of restitution. Impact force impulse.**

According to Newton’s hypothesis the impact is composed of two phases:

1- compression phase in which contact points of both colliding bodies approach each other.
2- Restitution phase in which, due to elasticity, they rebound from each other at the contact point.

Newton combined the two phases during collision and defined two notions: impulse of restitution $S_r$ and impulse of compression $S_k$. He called their ratio a coefficient of restitution $k$:

$$k = \frac{S_r}{S_k}$$

This coefficient depends on the elasto-plastic characteristics of the colliding bodies. After transformation of Equation above:

$$k = -\frac{A_v'}{A_v} = -\frac{v'_{1n} - v'_{2n}}{v_{1n} - v_{2n}}$$

Where:

$V'_{1n}, V'_{2n}$ – normal component of vehicle velocity vector 1 and 2 respectively, at impulse point immediately after impact forces stop.

$V_{1n}, V_{2n}$ – normal component of vehicle velocity vector 1 and 2 respectively, at impulse point immediately before impact.

Note: all the notations used in the formulas marked with (’) denote the state after the collision, those without the sign immediately before.
The total impulse is expressed by the equation:

\[ S = S_k + S_r = S_k (1 + k) \]

Curve of coefficient of restitution \( k \) as a function of relative closing velocity \( v \), for collision of two automobiles. Curve \( k \) depends on many factors such as impact direction, vehicles rigidity and individual characteristics of impact energy absorption, so the diagram should be treated as approximate.

10. **Equivalent Energy Speed**

As a control, the Equivalent Energy Speed (EES) of the impact is indicated for each vehicle. The distribution of the deformation energy between two vehicles in collision depends on the vehicle masses and the deformation depths:

\[
\frac{EES_1}{EES_2} = \sqrt{\frac{m_2 S_{Def1}}{m_1 S_{Def2}}}.
\]

\[
EES_2 = \sqrt{\frac{2ED}{m_2 \left( \frac{S_{Def1}}{S_{Def2}} + 1 \right)}}
\]

where:

- \( m_1, m_2 \) = mass of each vehicle
- \( S_{Def1}, S_{Def2} \) = Crush depth of each vehicle, outer surface to impact point, in line with impact force.
- \( ED \) = Energy lost by both vehicles in collision due to damage. \((\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 \) is all the energy that is provided to the crash)
B. Osterseminar 2009

Thanks to the gently offer of Per Bo Hansen and Thomas Wind from Dan-Crash it has been possible to assist to the spring workshop 2009 organised by Dr. Steffan Datentechnick in Linz, Austria 6-9/04/2009.

1. Crash Test Day

On the first day, there have been done ten different crashes. It was scheduled to run twelve, but finally due to different technical reasons, two of them were not possible to perform. On the other hand, this has been a great opportunity to learn how real tests are produced. During the workshop two kinds of crash tests have been simulated:

- 1 Door collision: collision of vehicles with open/just opening doors of the parking vehicle.

During the collision between a driving vehicle and the front door of a parking vehicle different distances (1m, 0.75m) between the vehicles as well as open and opening doors have been simulated. Target of these tests is to show differences in the damages depending on the certain constellation.

- 2 Sled Tests: Frontal Sled Test with and without Safety Belt.

The sled tests have been performed with a reinforced car body. Two different velocities have been used (30 km/h and 60 km/h). At each velocity two tests have been performed, with a belted/unbelted Dummy on the driver seat. These test have showed the different loads on the driver depending on the different velocity and on the usage of the safety belt. With each test the airbag has been used. Furthermore, with the belted driver the pretensioner has been used too.

Regarding the main topic of the Thesis, it has been found of a high interest the sled test at 30 km/h in both situations, belted and unbelted Dummy. As was described in point 4.4.3, on the front load cargo configuration, it was found a pre-impact velocity of 29.54 km/h which is really close to the test speed. The possibility of attending a live impact of these features facilitates the understanding of the magnitude of this type of crashes, even if it is not a really high velocity.

Sled Test Setup

In order to get a proper recording, two high speed video cameras have been used, both on the passenger left side. On the test, the driver is a Frontal Impact Dummy (H3 50%) with 3 axial accelerometers: head (x/y/z), chest (x/y/z) and pelvis (x/y/z). It also measures the intrusions on the chest (x) and finally forces and moments on the upper neck, upper leg and lower leg (x/y/z).

The reinforced car body that has been used is equipped as mentioned before, with driver airbag and belt with pretensions. This leads to a final mass of 570 kg.

The mechanism that has been used to impulse the car body is the DSD Hyper G. The energy of this system is generated by compressed air stored in a special high pressure cylinder. A piston.
ram transmits the energy to the sled. To get a specific acceleration pulse the ram is braked dynamically by a hydraulic brake device. PICTURES + further Data from DSD????

![Car body, Compressors, piston ram](image)

**2. Workshop**

On the following days of the seminar, several crash reconstructions have been done. Five cases have been studied with different vehicles and conditions.

*Case 1: Oncoming traffic truck*

Driver of an Audi collided with his front side into the axle of an oncoming truck trailer. Audi stopped crosswise on the lane. The main question was which vehicle had wrong driving line.

*Data*

- **Vehicle 1**: Audi A4 1.8t Station Wagon
- **Vehicle 2**: Truck Renault AE 470T with a 3 axles semitrailer.
- **Road Condition**: wet asphalt
- **Light Conditions**: darkness, rain, cloudy.
- **Max. Allowed velocity**: 50 km/h

Also, in each case several measurements, sketches and pictures of the location are shown.

*Case 2: Cyclist*

Driver of a bicycle drove into a crossing and did not see a Fiat Bravo coming from the right side. The bicyclist collided into the left side of the car. The main target is to find the speed of the crash and if there was any possibility to avoid the accident.

*Data*

- **Vehicle 1**: Fiat Bravo
- **Vehicle 2**: Mountain-bike Everest.
- **Road Condition**: dry asphalt
- **Light Conditions**: daylight, bright.
- **Max. Allowed velocity**: 30 km/h
- **Injury**: Cyclist severe
Case 3: Priority Violation

Driver of Opel Vectra wanted to turn left into a crossing and did not see a VW Multivan coming from the left side on the priority road. The speed collision and avoidance are the objectives.

Data

- **Vehicle 1**: Opel Vectra 1.6
- **Vehicle 2**: VW t5 2.5 TDI
- **Road Condition**: wet asphalt
- **Light Conditions**: daylight, drizzle.
- **Max. Allowed velocity**: 70 km/h, stop-sign for vehicle 1
- **Injury**: fatal injuries for driver 1

Case 4: Tractor

Driver of Peugeot 607 wanted to overtake a tractor, which turned left. As a result, the Peugeot collided with the front side into the left side of the slanted tractor.

Data

- **Vehicle 1**: Peugeot 607 3.0
- **Vehicle 2**: Tactor John Deere 5500
- **Road Condition**: plane, asphalt dry
- **Light Conditions**: daylight, sunny, bright.
- **Max. Allowed velocity**: 100 km/h
- **Injury**: both parties slight

Case 5: Tractor

As a result of tire damage, a Peugeot 306 collided with the roadside barrier and was stopped at the middle lane crosswise. Afterwards a truck collided into the left side of the Peugeot.

Data

- **Vehicle 1**: Peugeot 306 Break 1.6
- **Vehicle 2**: Truck Daimler-Chrysler 1841LS, Semi-trailer Schmitz Cargobull 3 axles
- **Road Condition**: Asphat dry
- **Light Conditions**: darkness
- **Max. Allowed velocity**: 100 km/h
- **Injury**: both parties slight

It this last case, different load configurations for the truck were simulated. This was used on the project but with a van instead of a truck.
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Acronyms

ESC: Electronic Stability Control
DGT: Dirección General de Tráfico
CARE: Community Road Accident Database
Euro NCAP: European New Car Assessment Programme
SUV: Sports Utility Vehicle
ABS: Assisted Braking System
LF: Left-Front wheel
RF: Right-Front wheel
LR: Left-Rear wheel
RR: Right-Rear wheel
RACE: Real automóvil Club de España
TCS: Traction Control System
DSD: Dr.Steffan Database
EES: Equivalent Energy Speed
SSF: Static Stability Factor
RMF: Rollover Mitigation Functions
HRMC: Hybrid Rollover Mitigation Controller