TNO Automotive

Homologations
Schoemakerstraat 97
P.O. Box 6033
2600 JA Delft
The Netherlands

www.tno.nl

T +31 15 2696385
F +31 15 2620015
approval@wt.tno.nl

**TNO report**

**04.OR.SA.065.1/RH**

# Impact of Sport Utility Vehicles on Traffic Safety and the Environment in The Netherlands

| | |
|---|---|
| Date | November 30, 2004 |
| Author(s) | R.B.J. Hoogvelt, Y.W.R. de Vries, D. Margarites, E. van den Tillaart, H.C. van de Burgwal, E. Willemsen |
| Sponsor | Ministry of Transport, Public Works and Water Management<br>Directorate-General for Passenger Transport (DGP)<br>Traffic Safety and Infrastructure Directorate<br>P.O. Box 20901<br>2500 EX The Hague<br>The Netherlands |
| Approved by (Project Leader) | R.B.J. Hoogvelt |
| Also seen by | P. Hendriksen |
| Also seen by (Head of Department) | J.S.H.M. Wismans |
| Project code | 009.01638 |
| Research period | October 12, 2004 - December 1, 2004 |
| Number of pages | 79 |
| Number of appendices | 5 |
| Number of figures | 38 |
| Number of tables | 28 |

# Summary

The European car fleet is changing rapidly towards more extreme vehicles as Sport Utility Vehicles (SUVs) on the public roads. Also the SUV sales in The Netherlands show an increase in the last five years.

The impact of SUVs is a subject of discussion at the moment. A fact is that these vehicles are relatively big in shape, heavy in mass and equipped with high capacity engines. Therefore, these vehicles are thought to have an important influence on traffic safety and the environment.

In the field of traffic safety, the discussions are mainly about their aggressiveness. There is a lack of so called ‘compatibility’. Other road-users feel threatened by these vehicles because of the mentioned differences. Accident studies for vehicle compatibility and traffic deaths by vehicle type in the US show that the chance to get killed in a crash with a SUV, being an occupant in a passenger car is higher especially if the SUV is coming from the side. Another safety aspect is their rollover sensitivity.

The environmental effects are caused by the exhaust emissions and fuel consumption of all individual vehicles together. The effect of the currently increasing number of SUVs with respect to the total Dutch vehicle fleet average remains to be defined.

## Objective

The purpose of this study is to investigate the impact of Sport Utility Vehicles on traffic safety and the environment in The Netherlands.

## Strategy

First a SUV type of vehicle is identified. The traffic safety impact is investigated using the Dutch National Accident Database and the TNO Automotive In-depth Accident Database. Accidents are analysed with one or more SUVs involved. The environmental impact of SUVs is related to the number of these vehicles and their cumulative exhaust gas emission values.

## Conclusions

Sport Utility Vehicle (SUV)’ seems to be a term for a collection of vehicles with a trendy appeal to the public. An unambiguous definition for a SUV is necessary in order to be able to carry out statistical analysis on the SUV issue, but such a clear definition for a SUV is hard to give.

For this study the definition of a SUV is set to:
***A SUV is a vehicle with a nose type front-end, a bigger geometry and an increased mass, front and rear bumper height, overall ground clearance and higher centre of gravity, in comparison to normal passenger cars. Terrain (off-road) vehicles and so called ‘pickup-trucks’ are also included in this definition.***

The SUV sales related to the total vehicle sales is 4.5%, but the number has doubled over the last five years, while the total vehicle sales numbers is stable over the last three years with around half a million sales per year. SUV sales in 2010 are estimated (linear trend) to be around 7.0% of the total vehicle sales. The latter is estimated to stay more or less the same.

Conclusions related to traffic safety

In summary, it can be concluded that SUV’s are significantly more aggressive against vulnerable road users. Problems with SUV crashes to other vehicles on the road are related amongst others to compatibility, except for commercial vehicles. However in this study no difference is found between heavy passenger cars and SUVs. SUVs are about as heavy as the average full-size passenger car. So the same mass difference occurs within passenger car classes (e.g. full-size and small cars). Although the bumper height is about 20% higher compared to passenger cars, this difference could not directly be related to an increase in injury severity in this study due to the lack of data. Nevertheless, based on accident pictures in this study and other investigations, it is believed that mass, frontal stiffness and geometry factors play a role in the compatibility between SUVs and other road users.

*Recommendations related to traffic safety*

Concerning the aggressiveness, the ladder chassis construction should be made less aggressive with respect to compatibility. Also the height of the bumper and other load bearing components of SUVs need be more compatible to other road vehicles.

Protruding objects and winches on the vehicle should not be allowed on public roads and attention must be paid to the bull-bar. A bull-bar is of no use in road traffic. A more restricted regulation is needed to allow the use of a bull-bar only if they have no negative effect on the safety of other road-users.

With respect to lethality, a less deformable SUV roof and upper pillars is needed to prevent the roof to collapse during rollover accidents.

*Recommendations to improve the traffic safety analyses*

The effect of mass needs further investigation with a study in which passenger cars and SUVs in identical mass-classes are compared. The two groups need to be of equal mass-distribution. Difference between the two categories could then be explained by geometry (e.g. bumper height) or stiffness characteristics.

The effect of gender needs to be further investigated with a control group. Video shots at random locations should be able to give information about the frequency of male and female drivers in passenger cars and SUVs. Compared with accident data, this information could give valuable information about driving behaviour differences between men and women, and information about average vehicle mass in these categories.

Conclusions related to environmental impact

With respect to the harmful (regulated) emissions CO, HC, $NO_x$ and PM that affect human health and the ecological system the following conclusions are drawn:

1 Both SUVs and ‘regular’ passenger cars (M1 class vehicles) are subject to the same emission regulations. However, the more heavy vehicles with a GVW above 2500 kg (N1 class II and III) have wider limits, and may possibly emit more than ‘regular’ passenger cars.
2 The test results show that the four M1 and N1 petrol SUVs easily satisfy the legislative emission limits for M1 vehicles. Also in real-world driving conditions about the same level of emissions is observed as for regular passenger cars.
3 The statistical value of the SUV test results is restricted due to the limited number of vehicles in comparison to the variation that is normally observed in emission tests.

With respect to fuel consumption and $CO_2$-emissions (climate effect) the conclusions are:

1 No legislation on fuel consumption or $CO_2$-production exists. Instead a covenant between the EU commission and the vehicle manufacturers has been agreed to

achieve a 140 g/km fleet average $CO_2$-emission for newly sold vehicles by the year 2008. N1 class vehicles are not included in this covenant.

2. Due to their comparatively higher mass and air drag resistance, SUVs are expected to have a higher fuel consumption and $CO_2$-emission than their non-SUV alternatives. Another fuel consumption rising influence comes from the usually present four-wheel drive system.
3. The test results of the four <u>petrol</u> SUVs confirm that fuel consumption and $CO_2$-emission are 40-65% higher than those of the non-SUV alternatives. The difference depends on the test cycle and driving style; at high speeds the difference is generally higher than for low speeds

One important note that has to be made here concerns <u>diesel</u> SUVs. Euro 3 diesel cars generally tend to produce emissions that are close to the applicable emission limits for $NO_x$ and $PM_{10}$. As vehicles with a GVW above 2500 kg are subject to less stringent limits (N1 class III), it is expected that manufacturers will take advantage of this extra margin to save costs or to obtain lower fuel consumption (and $CO_2$). Since almost 50% of the SUVs sold in The Netherlands are diesel fuelled, the effect on the total Dutch emissions could be significant.

Depending on the applied technology, hybrid SUVs may reduce the fuel consumption and emissions up to the level of regular non-hybrid passenger cars.

*<u>Recommendations related to environmental impact</u>*

Due to the lack of sufficient, statistically significant and accountable information it is not possible to draw general and reliable conclusions on the impact of all SUVs with respect to the Dutch environment. It is therefore recommended that a more extensive research programme is defined to investigate the SUV fleet as well as their alternatives. Such a programme should comprise more different SUV vehicles (especially diesel SUVs) for a better understanding of their emission behaviour. Furthermore, additional statistical information is required to estimate the environmental impact of SUVs on Dutch roads.

# Contents

**Appendices**

# List of tables and figures

## Tables

## Figures

# 1 Introduction

The European car fleet is changing rapidly towards more extreme vehicles on the public roads. Larger and heavier vehicles, such as Sport Utility Vehicles (SUVs) are taking a larger share than before. Many vehicle manufacturers have one or more of this type of vehicle in their collection or are about to introduce one.

The SUV sales in The Netherlands also show a clear increase in the last five years. The success of these vehicles probably results from a public feeling on good ride and comfort, a safe feeling with respect to crashworthiness (self-protection) driving these cars and the fact that many persons think it is ‘cool’ to own such a car.

At the moment many discussions are going on about the environmental and traffic safety aspects of these vehicles. A fact is that these four-wheel drives are relatively big in shape, heavy in mass and equipped with high capacity engines. Therefore, these vehicles are thought to have an important influence on environment and traffic safety.

The environmental effects are caused by the exhaust emissions and fuel consumption of all individual vehicles together. The desired sportive effect of a SUV is created by the confronting appearance and a powerful engine. In general, high powered or heavier vehicles tend to give higher fuel consumption, which directly relates to $CO_2$-production. With respect to exhaust emissions a less clear correlation exists. The effect of the currently increasing number of SUVs with respect to the total Dutch vehicle fleet average remains to be defined.

In the field of traffic safety, the discussions are mainly about their aggressiveness. Properties as size (geometry) and mass of these vehicles differ considerably from normal passenger cars. There is a lack of so called ‘compatibility’. The worst item concerning compatibility is the height and especial the ‘bumper height’. Other road-users feel threatened by these vehicles because of the mentioned differences. Accident studies for vehicle compatibility and traffic deaths by vehicle type in the US show ([1], [2], [3], [4], and [5]) that the chance to get killed in a crash with a SUV, being an occupant in a passenger car is higher especially if the SUV is coming from the side. Another safety aspect is their rollover sensitivity. Research in this field show that SUVs tend to be more involved in vehicle rollover ([6], [7]). Passenger cars normally never will rollover.

If all this is true, The Netherlands will have an increased compatibility problem and an increase of rollover accidents. Also the Dutch environment may deteriorate when these SUVs get a large market share and therewith start to contribute significantly to the energy use.

Until now the mentioned aspects are mainly speculations, about whether these vehicles are really safer for the driver and passengers and more dangerous for the other road users and whether these engines really have a negative contribution to emission values. Answers to these questions need to be provided in this study.

## 1.1 Objective

The objective of this study is to investigate the impact of Sport Utility Vehicles on traffic safety and the environment in The Netherlands.

## 1.2 Strategy

In this report, the impact on traffic safety and the environment of SUVs in The Netherlands is discussed. First the SUV is identified in Chapter 2 together with the analyses of the SUV sales/market share over the last five years in The Netherlands from several databases (RAI figures, Autoweek and RDW databases).

The traffic safety impact is investigated from: the number of traffic accidents with one or more SUVs involved, the type of accident, the cause of this accident and the injury related to the accident. Both Dutch National Accident Database and a TNO Automotive In-depth accident database are used to investigate the relation of SUVs and mentioned accidents. In Chapter 3 the impact of SUVs on traffic safety is analysed.

The environmental impact of SUVs is related to the number of these vehicles and their cumulative exhaust gas emission values. For every type of vehicle, its emissions are related to the applied engine technology, the driving behaviour, the total distance travelled and the location (domestic area, highways, etceteras). Chapter 4 describes the research on the impact to the environment and related aspects.

In Chapter 5, the overall conclusions for impact of SUVs on traffic safety and the environment are presented.

# 2 Definition of a SUV and market share

The first step in this ‘Impact of SUVs’ study is to define this type of vehicle. What specific parameters make this car different from other passenger cars?
The traffic safety impact from vehicles can be related to parameters like: compatibility, aggressiveness and crashworthiness. These safety parameters will be defined in Section 2.2. With a description of these parameters the definition of a SUV is given in Section 2.3. The environmental impact of SUVs is related to the number of these vehicles and the emission values per vehicle. The latter is discussed in-depth in Chapter 4. In this chapter, vehicle classes are analysed and potential SUVs are identified. For these vehicles, the sales numbers in The Netherlands in the last five years are investigated in Section 2.4.

## 2.1 General

A wide variety of vehicles exists that may be classified as SUV. Vehicles usually are referred to by their brand and model names, and for many people the first impression of the vehicle is formed by its exterior. When analysing the car sales data, it becomes clear that the number of vehicles with the same brand and model name requires a further subdivision due to the different versions of a model that are sold. Main differences are engine type (petrol or diesel), engine volume (e.g. 2.0 to 4.6 litres) or transmission type (manual or automatic, two- and four-wheel drive). When other versions are available, these usually indicate a luxury level (presence of features like electric windows, air-conditioning system, sunroof, etceteras). The impact of a SUV is not only dependent on its exterior, but also on the applied technology under the hood.

Vehicle specifications for SUVs are put together on the basis of databases by Autoweek [8], Autovisie [9] and the German Kraftfahrt-Bundesambt [10]. These sources describe vehicles and versions that are available through the regular car dealers. The applied criteria for including a vehicle as a SUV are mainly based on a first impression about the exterior of a vehicle. By far the largest number of vehicles sold in The Netherlands has been sold through these car dealers. Additionally vehicles that are being imported to The Netherlands through parallel channels need to be added to the list, although these account for a very small percentage of total vehicle numbers.

The Environmental Protection Agency (EPA) in the US uses the following vehicle classification system with nine (9) categories for vehicles that are sold in the US [11]:
- Small car;
- Medium car;
- Large car;
- Wagon;
- Pickup;
- SUV;
- Minivan;
- Van;
- Other.

Within some of these classes, subclasses may be defined: e.g. small, medium, large, extremely large.

Other vehicle classification systems in use in the EU are:

- EuroNCAP:
  - Super-minis;
  - Small Family Cars;
  - Large Family Cars;
  - Executive Cars;
  - Roadsters;
  - Large Off-Roaders;
  - Small Off-Roaders;
  - Small MPVs;
  - MPVs;
- European regulation classification:
  - Class A up to E;
  - Class M;
  - Small MPV;
  - MPV;
  - Small SUV;
  - SUV;
  - LCV.

The above mentioned vehicle classification systems show that one identical name is hard to give, not to mention one clear definition for a SUV.

## 2.2 Compatibility, aggressiveness and crashworthiness

Compatibility is an important subject in accidents where more than one road user is involved. Compatibility issues result from the differences in various properties like mass, chassis stiffness and geometry. Compatibility refers to a status where a vehicle has been designed to provide protection both for the occupants of the vehicle (self-protection) as well as the occupants of the crash partner (partner-protection).

When the vehicles involved in a crash are incompatible, one of the parties suffers from the relative aggressiveness of the other. Aggressiveness refers to the property of a car to cause damage to the other car or injure the other car's occupants. It is related to crashworthiness, which describes the car's ability to deal effectively with other vehicles in a crash and protect its occupants. The two items have some discrepancies for design reasons.

During the last decades extensive research has been done on the statistics of car-to-car crashes giving a/o rates of aggressiveness of vehicles in car-to-car crashes [12] and [13]. There are two main injury-causing aspects to car collisions in general, but also with respect to compatibility: excessive deceleration and intrusions [14]. A lighter car undergoes larger deceleration than a heavier car in a collision between each other. Therefore, in the lighter car the occupants can get injured more easily, due to these large decelerations and contacts directly resulting from these decelerations.

On the other hand, intrusions relate to the undesired entering of structural car parts into the passenger compartment that should thus be avoided as much as possible. A first important step to avoid intrusions is the avoidance of geometrical mismatch. Shearlaw and Thomas [15] show that it is very difficult to tackle the question whether or not cars are compatible with respect to these intrusion effects.

Furthermore, the passenger compartment integrity should be preserved as much as possible: collapse of the compartment should be avoided. For this purpose, the global strength of the passenger compartment should be higher than the strength of the front-end and, of course, high enough to withstand the forces during the whole crash. This also means that the strength of two cars in a crash should be optimized such, that the collision energy is dissipated without compartment collapse of any of the cars [16].

There are four main issues playing a role in compatibility:

- Mass will always play an important role with respect to passive safety;
- Geometrical or structural interaction between the vehicles;
- Front-end stiffness;
- Compartment strength.

Within this study an important vehicle parameter related to geometrical interaction between the vehicles is the bumper height, illustrated in Figure 1.

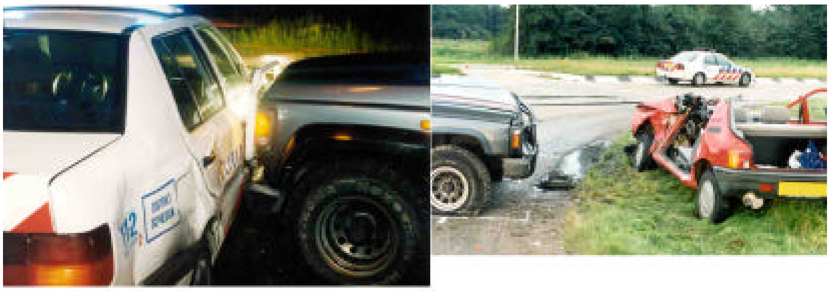


*Figure 1 – Bumper height at a side impact ‘SUV to passenger car’*

## 2.3 Definition of a SUV

A SUV is a luxury version of a terrain or off-road vehicle with ride and comfort performance that is optimised for common road use. Figure 2 shows examples of some SUVs. Instead of being used off-road, SUVs are normally driven on paved roads (highways, rural and urban). Vehicle parts as tires and suspension characteristics are modified to fulfil the demands on handling, ride and comfort.

*Figure 2 – Examples of SUVs: The Chevrolet Avalanche, one of the biggest SUVs on the Dutch market; the popular BMW X5 and the Lexus RX330*

A SUV(-like) vehicle list is drawn up from databases by Autoweek [8], Autovisie [9] and the German Kraftfahrt-Bundesambt [10] as reference book (see Appendix A). This list is used in this study to analyse the technical specifications of (potential) SUVs in The Netherlands. Although one quite easily creates a general (subjective) impression of what a SUV would be, the figures illustrate the wide spread in vehicle parameters and show that a more solid and clear technical definition for a SUV may be very difficult to generate.

Some ranges from the reference book:
- Empty Mass : 1000 up to 3250 kg (and even higher for some special vehicles);
- Average bumper height : 470 up to 655 mm (and even higher for some special vehicles); average 560 mm;
- Engine volume : 1.8 up to 6.6 litre;
- Engine power : 48 up to 430 kW (65 – 585 HP).

Almost all mid-size and large passenger cars will fulfil these ranges except for the ‘geometry’ (height, bumper height). Studies in the US [4] show that the bumper heights are approximately 200 mm higher than those of passenger cars, which create a mismatch in the structural load paths. The average bumper height of SUVs in The Netherlands is about 20% higher than those of passenger cars (460mm).

For this study the definition of a SUV is set to:

***A SUV is a vehicle with a nose type front-end, a bigger geometry and an increased mass, front and rear bumper height, overall ground clearance and higher centre of gravity, in comparison to normal passenger cars. Terrain (off-road) vehicles and so called ‘pickup-trucks’ are also included in this definition.***

## 2.4 Sales figures, market share and SUV related parameters

The actual impact in The Netherlands logically depends on the number of SUVs in use. Moreover it is necessary to know what kind of technology is found under the hood to judge the environmental impact.

Various sources have been analysed. Autoweek [8] and The Dutch ‘Centraal Bureau voor de Statistiek’ [17] provide information on the number of vehicles that have been sold. In general, information is available per brand and per model. This database has been examined for the following number of vehicles sold in the years 1998 through 2004 (until Q3 = 3rd quarter):

- The SUV(-like) models;
- Total of all vehicle sales;
- Total of SUV(-like) sales.

The Autoweek database does not contain sales information for every car model. For some brands no sales information per model is available, instead all models are listed together. It is even possible that no sales information is available at all. This seems to occur for brands and models that are less common in The Netherlands or vehicles that have been introduced to the market recently. It is expected that this has only a minor influence on the analysis.

Table 1 lists and Figure 3 shows the total number of vehicles and SUV-likes that have been sold since 1998. These sales numbers show that the share of SUVs in the total number of vehicles that are sold each year is steadily growing. In 1998, where the SUVs basically were the terrain/off-road vehicles, their share was about 1.3%. In 2004, the forecast for their share is around 4.5% of total vehicle sales. The prediction from the figures with a linear trend is that the SUV sales in 2010 will be around 7.0% of the total vehicle sales. The total vehicle sales will be around half a million per year.

Table 1 SUV- and vehicle-sales in 1998 through 2004 [8] [17]

| Year | Dutch fleet[1] | Total vehicle sales | Total SUV sales | SUVs sales[%] |
|---|---:|---:|---:|---:|
| 1998 | n/a | 543,110 | 6,999 | 1.3 |
| 1999 | 6,436,717 | 611,776 | 11,636 | 1.9 |
| 2000 | 6,631,322 | 597,623 | 13,062 | 2.2 |
| 2001 | 6,791,563 | 530,287 | 14,503 | 2.7 |
| 2002 | 6,933,809 | 510,744 | 15,799 | 3.1 |
| 2003 | 6,982,908 | 488,977 | 20,278 | 4.1 |
| 2004 (incl. Q3[2]) | n/a | 397,123 | 17,812 | 4.5 |
| 2004 (forecast[3]) | n/a | 529,497 | 23,748 | 4.5 |
| Total 2003-2004 | n/a | 1018474 | 44,026 | 4.3 |

1. Dutch fleet of vehicles with a maximum weight of 3500 kg (includes passenger cars and light commercial vehicles), fleet number on December 31 of the mentioned year.
2. 3rd quarter
3. Linear forecast

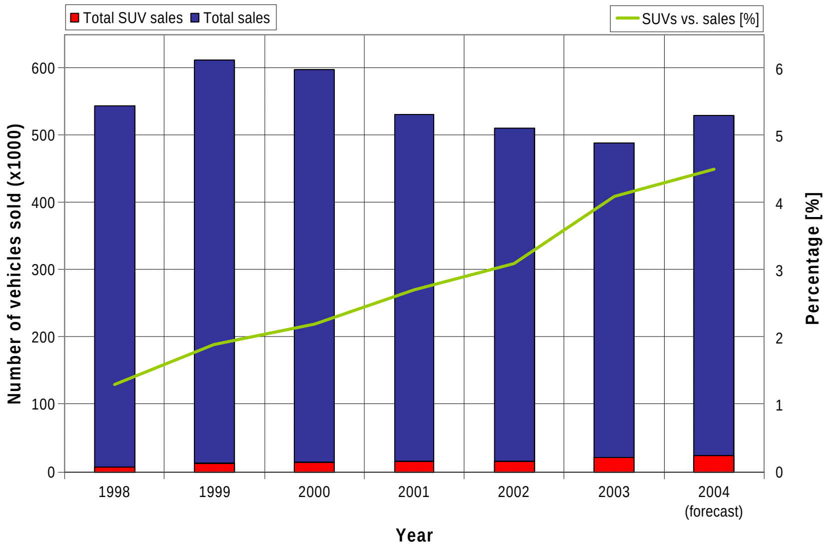


*Figure 3 – SUV and total vehicle sales in 1998 through 2004*

The list of SUV-like cars is large and still contains many miscellaneous vehicles. It therefore is very interesting to investigate the type of vehicles that are sold most and therewith statistically will have the largest influence on the Dutch traffic conditions. Table 2 lists the SUV models that have been sold since 1998 and are still sold in 2004. This list only includes models for which the sales numbers are available in the Autoweek database [8]. New models are introduced frequently and uncommon models may also have been overlooked. The list in Appendix A therefore is subject to change and regular updates need to be made.

As the label SUV is a quite recent development it is decided to sort these vehicles according to the cumulative sales numbers for the years 2003 and (forecast for) 2004. Of course, the current Dutch SUV fleet is represented by all vehicles that have been sold in the past and are still used in the field. The mid-term fleet average will more and more be represented by vehicles that are sold most at the moment, as vehicles age and eventually are removed from the fleet.

Table 2 SUV(-like) models (only if information is available) sold since 1998 [8] [17]

| # | Year → <br> Model ↓ | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 (Q3) | 2004 (forecast) | Total sales 2003 + 2004 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Kia Sorento | | | | | 232 | 2375 | 1526 | 2035 | 4410 |
| 2 | Toyota RAV4 | | | 484 | 1381 | 1354 | 1502 | 1693 | 2257 | 3759 |
| 3 | Hyundai SantaFe | | | 24 | 1550 | 1212 | 1288 | 1327 | 1769 | 3057 |
| 4 | Volvo XC90 | | | | | | 1015 | 1456 | 1941 | 2956 |
| 5 | BMW X5 | | | 286 | 838 | 1120 | 1053 | 961 | 1281 | 2334 |
| 6 | Suzuki (Grand) Vitara | 672 | 1026 | 1143 | 907 | 879 | 1069 | 754 | 1005 | 2074 |
| 7 | Chrysler PT Cruiser | | | 538 | 1689 | 1368 | 1010 | 758 | 1011 | 2021 |
| 8 | Nissan X-Trail | | | | 355 | 808 | 736 | 953 | 1271 | 2007 |
| 9 | Volvo XC70 | | | | | 873 | 852 | 743 | 991 | 1843 |
| 10 | Mitsubishi Outlander | | | | | | 795 | 729 | 972 | 1767 |
| 11 | Honda CR-V | 780 | 674 | 732 | 426 | 936 | 776 | 641 | 855 | 1631 |
| 12 | Subaru Forester | 913 | 1204 | 806 | 519 | 606 | 819 | 498 | 664 | 1483 |
| 13 | Volkswagen Touareg | | | | | | 595 | 642 | 856 | 1451 |
| 14 | Jeep[1] | 719 | 1010 | 1053 | 832 | 922 | 726 | 438 | 584 | 1310 |
| 15 | Suzuki Jimny | 311 | 1804 | 1494 | 890 | 732 | 621 | 387 | 516 | 1137 |
| 16 | Mercedes ML | 118 | 442 | 856 | 1019 | 1023 | 654 | 330 | 440 | 1094 |
| 17 | Landrover Freelander | 339 | 538 | 717 | 722 | 662 | 438 | 459 | 612 | 1050 |
| 18 | GM USA[2] | 723 | 898 | 815 | 751 | 649 | 527 | 384 | 512 | 1039 |
| 19 | Toyota Landcruiser | 148 | 174 | 211 | 185 | 140 | 400 | 250 | 333 | 733 |
| 20 | Landrover RangeRover | 291 | 358 | 269 | 170 | 390 | 269 | 187 | 249 | 518 |
| 21 | Landrover Discovery | 208 | 318 | 433 | 486 | 249 | 235 | 190 | 253 | 488 |
| 22 | Daihatsu Terios | 701 | 709 | 613 | 317 | 251 | 245 | 180 | 240 | 485 |
| 23 | Honda HR-V | | 351 | 651 | | 374 | 257 | 165 | 220 | 477 |
| 24 | SsangYong[3] | 87 | 103 | 109 | 98 | 64 | 73 | 254 | 339 | 412 |
| 25 | Opel Frontera | 121 | 782 | 908 | 582 | 363 | 226 | 129 | 172 | 398 |
| 26 | Ford USA[4] | 362 | 674 | 337 | 281 | 136 | 123 | 90 | 120 | 243 |
| 27 | Mitsubishi Pajero | 78 | 61 | 141 | 116 | 72 | 84 | 56 | 75 | 159 |
| 28 | Nissan Patrol | 155 | 124 | 114 | 103 | 74 | 48 | 31 | 41 | 89 |
| 29 | Other[5] | … | … | … | … | … | … | … | … | … |

1. Includes all Jeep models: Cherokee, Grand Cherokee and Wrangler
2. Includes all GM models with US origin, so not only SUVs
3. Includes all SsangYong models: Korando, Musso, Rexton
4. Includes all Ford models with US origin, so not only SUV
5. Models for which no (detailed) sales information is available

# 3 Impact of SUVs on traffic safety in The Netherlands

This chapter describes the analyses of traffic accidents that have been conducted to generate the impact of SUVs on traffic safety in The Netherlands.

Traffic safety is mostly related to the annual number of road fatalities in policy documents concerning mobility. In the recent Dutch policy document 'Nota Mobiliteit' [18] the government is focusing on the improvement of traffic safety despite growing mobility and that Dutch roads will remain among the safest in the European Union. The objective is a fall in the annual number of road fatalities from around 1100 at the moment, to 900 road fatalities in 2010 and 640 in 2020. That will serve to reduce the personal suffering and economic loss caused by accidents. Besides the fatalities also the injuries in traffic accidents show the status of traffic safety.

In this analysis two traffic accident databases are used. In Section 3.1 the impact to traffic safety is analysed from the ‘Dutch National Accident Database’ in combination with the Dutch licence plate database to filter out the accidents where Sports Utility Vehicles (SUV) are involved. The analysis of the TNO Automotive In-depth Accident Database is described in Section 3.2. Each section ends with conclusions.

## 3.1 National Traffic Accident Statistics Analyses

This section is divided in five subsections. Section 3.1.1 describes the data-selection and degree of representation of the data, followed by a general analysis on Aggressiveness and Lethality of SUVs versus passenger cars in Section 3.1.2. In the next Section 3.1.3 the same type of analysis is done for each collision partner type coded in the Dutch National Traffic Accident database. Differences from the general analysis will be described. The section ends with a discussion on the mentioned database in Section 3.1.4.

### *3.1.1 Methodology*

A database with all SUV and passenger car accidents is built from the combination of the Dutch National Traffic Accident Statistics or in the Dutch ‘Verkeers-Ongevallen-Registratie’ (VOR) database of 2001 until August, 2002 and the Dutch licence plate registration system (RDW-data) to identify the vehicle types in a collision. More updated versions of the two coupled databases are not available. All passenger car accidents and SUV accidents were extracted from the database. Normally all SUVs should be coded as passenger cars, however in the VOR in some cases these vehicles are also coded as ‘Van’ or ‘Truck’; this is taken into account in the selection. The names of SUV type vehicles were selected from several internet sources and year book lists. In total approximately 120[1] SUV types were identified. The collision partners of the selected vehicles were found by coupling the vehicles in the VOR-database that were involved in the primary collision.

The filtered database was exported to the statistical analyses tool ‘SPSS 12’ [19] and further analysed. For each of the variables a cross-tabulation was made between that variable and SUV vs. passenger car.

---

[1] The number of SUVs for the accident analyses is higher than the listed SUVs in Table 1 from the fact that older SUVs (before 1999) and SUVs which are not for sale anymore are also included here.

When in these cross-tabulation a significant correlation between the two variables was detected by the Pearson Chi-squared test, the adjusted residuals (a.r.) were inspected for significant deviation, which are two or more standard deviations from the expected values. The expected values are calculated based on the assumption of independence of two variables.

The VOR database contains accidents with killed (K), seriously injured/hospitalised (SI), slightly injured/non-hospitalised (SLI), unknown injuries and ‘damage only’ (DO). Table 3 shows the estimated distribution of the registered accidents data in the VOR and Figure 4 shows this distribution in a ‘pie’ format.

Table 3 Accidents distribution in the VOR database

| Accidents related to | % |
|---|---|
| Killed | 1 |
| Seriously Injured Persons | 5 |
| Slightly Injured Persons | 10 |
| Unknown injuries & ‘Damage only’ | 84 |

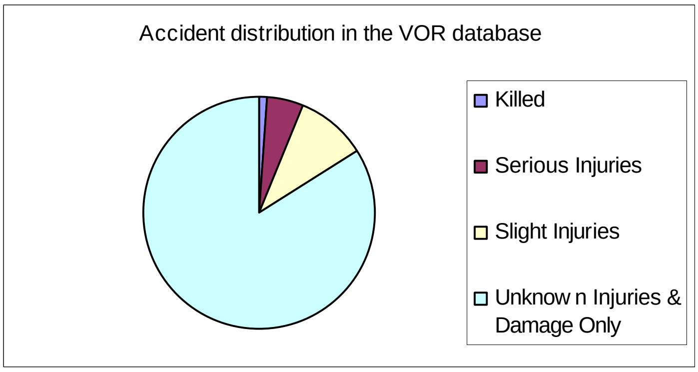


*Figure 4 – Accidents distribution in the VOR database*

It is known that around 95% of all accidents related to fatalities are registered in the VOR database. It is estimated that 85% of all traffic accidents are included in the database, where a persons was injured. For accidents with slight injured persons involved a value of 40% is estimated and 15% of the ‘unknown injuries & ‘damage only’ (DO) accidents are included in the database. Especially for DO accidents it is expected that the degree of representation varies greatly with vehicle type and collision partner, possibly due to damage costs (owners of more expensive vehicles may be more eager to have police assistance). For this reason only accidents in which fatalities and/ or injuries (K+SI+SLI) occurred are discussed in the following sections.

### *3.1.2 General analyses on aggressiveness and lethality*

A total of 650 SUV accidents are analysed, where fatality and or injury has occurred within the SUV and or the passenger car. With the same criteria 44559 passenger car accidents are analysed. This second group is used as a so-called ‘comparison group’ or ‘control group’.

First co-linearity is treated in Section 3.1.2.1, followed by a general analysis of passenger car and SUV accidents in Section 3.1.2.2. This general analysis is done, to identify to what extent vehicle accidents might ‘differ from’ or ‘be equal to’ SUV accidents. All variables that were coded in the VOR-database that might influence accident causation or severity were analysed, see Section 3.1.2.3.

#### 3.1.2.1 *Co-linearity*

In the research on aggressiveness of SUVs compared to passenger cars a major problem exists. The main factors which distinguish SUVs from passenger cars (mass, bumper height, stiffness) are highly correlated with these vehicles, except for mass. The large bumper heights and high body stiffness are found in SUVs and not in passenger cars. This high correlation between SUVs and these other parameters makes it impossible to state statistically what causes have a relationship with the aggressiveness. The only statement that can be given is whether SUVs are more aggressive than passenger cars, either compensated for the mass effect or not. It cannot be said that this may be due to bumper height or vehicle stiffness.

#### 3.1.2.2 *Cross-tabulation analysis*

For all variables that are coded in the VOR-database that might have a relationship with accident causation or might influence accident severity, cross-tabulations are executed between those variables and the vehicle type, being SUV or passenger car. So a comparison is made between passenger cars and SUVs. All the frequency counts that are presented in the cross-tabulations (N) are the number of SUVs that are involved.
The objective is to find to what extent the SUV crashes differ from passenger car crashes. If no differences are found, this can be considered positive for the analysis, because then both classes are involved in the same type of accidents. When differences are found, they might have influence on accident severity. So in order to say something about possible differences in lethality or aggressiveness, one needs to statistically compensate for these differences. This can be done with a method called (logistic) regression analysis (see Section 3.1.2.3).

Table 4 and 5 show a strong relationship between vehicle mass and gender (gender effect). Female drivers were driving significantly lighter vehicles than male drivers in the accidents that are stored in the database.

Table 4 Gender effect for ‘Not SUVs’

| Gender | Mean mass | N | Std. Deviation | Median |
|---|---|---|---|---|
| Male | 1083 | 26305 | 248 | 1050 |
| Female | 965 | 12374 | 219 | 932 |
| Unknown | 1063 | 287 | 226 | 1050 |
| Total | 1045 | 38966 | 246 | 1015 |

A suv_1 = not SUVs

Table 5 Gender effect for ‘SUVs or Pickups’

| Gender | Mean mass | N | Std. Deviation | Median |
|---|---|---|---|---|
| Male | 1690 | 484 | 372 | 1744 |
| Female | 1460 | 152 | 371 | 1400 |
| Unknown | 1673 | 5 | 413 | 1840 |
| Total | 1635 | 641 | 384 | 1660 |

A suv_1 = SUV or PICKUP

For the following variables that are coded in the VOR-database, no differences between passenger car accidents and SUV accidents were found:

- The type of accident;
- The accident cause;
- Impact location, both bullet and target vehicle;
- Movement of the vehicle(s) after the accident, both bullet and target vehicle;
- Type of manoeuvre;
- Locations on the road before the accident (bullet + target);
- Road type;
- Weather;
- Intended manoeuvre (bullet + target);
- Gender of the driver of the target vehicle;
- Collision opponent.

Also no difference in aggressiveness between SUVs is found based on SUV vehicle mass and SUV bumper heights. So, heavier SUVs are not more aggressive than lighter SUVs. Nor are SUVs with a higher average bumper height more aggressive than SUVs with a lower bumper height.

Factors that did differ significantly between passenger car accidents and SUV accidents are:

- Accident types:
  - Gender of the driver of the bullet vehicle; Significant more male drivers of SUVs (76%) are involved in accidents, for passenger cars this figure is (68%);
  - Speed limit roads; SUVs are more involved in accidents on 80 km/h roads (a.r.=3.1, N=180, 28%) and less on 50 km/h roads (a.r.= -2.4, N=362, 56%);
  - Areas; There are more SUV related collisions found in non-urban areas in comparison to passenger cars, 42% versus 37%, (a.r.=2.6, N=272). Less SUV related collisions are found in urban areas in comparison to passenger cars, 58% versus 63%, (a.r.=-2.6, N=378).
- Accident severity:
  - SUV occupants are less likely to get killed in an accident than passenger car occupants, 0.3% versus 1.3%, (a.r.=-2.3, N=2);
  - SUV occupants have significantly less chance to get killed or seriously injured in case of an accident than passenger car occupants, 8.5% versus 13%, (a.r.=-3.1, N=55);
  - Opponent vehicle occupants have a significantly higher chance to get killed being involved in an accident with a SUV then being involved in a passenger cars accident, 2.6% versus 1.1%, (a.r.=-3.8, N=17);
  - Persons in the target vehicle have a significant higher chance to get killed or being seriously injured when involved in an accident with a SUV then when involved in a passenger cars accident, 25% versus 19%, (a.r.=-4.2, N=164).

It has to be noted that these differences in accident severity do not yet indicate that there is a higher aggressiveness of SUVs compared with passenger cars. The aggressiveness can only be estimated when taking into account the differences in accident types and differences in vehicle characteristics (mass, geometry and stiffness).

### *3.1.2.3 Regression analysis*

Logistic regression analysis is a statistical predicting method based on one ore more factors or variables. The method estimates the independent effects of input parameters on the outcome as for example aggressiveness.

Aggressiveness

A logistic regression analysis was performed to identify to what extent vehicle mass and gender relate to vehicle aggressiveness, more explicit: the probability that a collision opponent will get killed or seriously injured, taking into account vehicle type, mass and gender of the driver. Table 6 shows that increasing mass, increases the probability to get killed or seriously injured (sig< 0.05 and Exp(B)> 1). A significance level less than 0.05, indicates a significant difference with a 95% confidence level. An Exp(B) larger than 1 indicates an increasing probability.

Table 6 Variables in the equation for the prediction of aggressiveness

| | | | | | | | | 95.0% C.I.for EXP(B) | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | S.E. | Wald | Df | Sig. | Exp(B) | Lower | Upper |
| Step | Mass | .001 | .000 | 98.68 | 1 | .00 | 1.001 | 1.000 | 1.001 |
| 1 | Gender | .092 | .097 | .91 | 1 | .34 | 1.097 | .907 | 1.326 |
| | SUV | -.139 | .028 | 24.85 | 1 | .00 | .870 | .824 | .919 |
| | constant | -1.690 | .093 | 330.29 | 1 | .00 | .184 | | |

A Variable(s) entered on step 1: mass, SUV (0= no, 1= yes), gender (male = 0, female = 1).

Females have an injury reducing effect, possibly due to the fact that they drive lighter cars (sig<0.05, Exp(B)<1). Whether the actual vehicle is a SUV, is not relevant (sig>0.05, Exp (B) ~1). The global effect of aggressiveness can be mainly related to vehicle mass , according to the VOR analysed accidents.

Self-protection (Lethality)

A logistic regression analysis was also performed to identify to what respect vehicle mass and gender relate to vehicle lethality, more explicitly the probability that the driver or passengers in the SUV will get killed or seriously injured. In Table 7 it is shown that an increasing mass (sig<0.05, exp(B)< 1) has an injury reducing effect. Gender plays a role but is not significant at the 95% confidence level. Whether the vehicle is a SUV or not is not relevant. Therefore the mass is the most relevant factor for self-protection. A larger vehicle mass reduces the injury level for the occupant, according to the VOR analysed accidents.

Table 7 Variables in the equation for prediction of self-protection

| | | | | | | | | 95.0% C.I.for EXP(B) | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | S.E. | Wald | Df | Sig. | Exp(B) | Lower | Upper |
| Step | Mass | -.001 | .000 | 225.6 | 1 | .000 | .999 | .999 | .999 |
| 1 | Gender | -.056 | .032 | 3.03 | 1 | .082 | .945 | .887 | 1.007 |
| | SUV | .153 | .148 | 1.06 | 1 | .302 | 1.165 | .871 | 1.558 |
| | constant | -.743 | .115 | 41.5 | 1 | .000 | .476 | | |

A Variable(s) entered on step 1: mass, gender (0= male, 1= female), SUV (0= no, 1= yes)

### *3.1.3 Analyses in relation to the collision partner*

A total of 650 SUV accidents are analysed, where fatality and or injury has occurred within the SUV and / or the passenger car. With the same criteria 44559 passenger car accidents are analysed.

Accidents with the following collision partners are analysed in this section:

- Passenger cars;
- Trucks;
- Vans (Light Trucks);
- Busses;
- Two-wheeler;
- Pedestrians;
- Others and Single sided accidents.

#### *3.1.3.1 Passenger cars*

The number of SUVs involved in a collision with a passenger car is 192 and the number of passenger car to passenger car collisions equals 19739.

For both SUVs and passenger cars the head-tail collisions are most frequent (45%), followed by side impacts (40%) and thereafter frontal impacts (12%). The parking accidents occur in 3% of the cases.

The impact location on the mid-front is more pronounced (45%). With SUVs the impact point is somewhat more to the right-front, 10% versus 6% (a.r = 2.6, N=28)

More male drivers are involved in relation to passenger-drivers, 73% versus 67% (a.r.=2.0, N=212).

Related to the type of road and road side, SUVs are significantly more often involved in accidents with passenger cars on the right side of normal two lane roads, 71% versus 65%, (a.r.=2.1, N=207).

There is a slight indication that SUVs are more involved on 80 km/h roads, 30% versus 26% (a.r.=1.5, N=88).

Most accidents occur in urban areas on 50 km/h roads (51%).

The probability to get killed, for both vehicles, in an accident with SUV involvement is not higher than in accidents with only passenger car involvement. There is however a trend that is confirmed when taking into account severe injuries in the analysis.

The probability to get killed and/or seriously injured for:

- SUV passengers is significantly lower than for the persons in passenger cars, 8.2% versus 15% (a.r.= -3.0, N =24). This effect disappears in a logistic regression analysis with the vehicle mass taken into account;
- The passengers in the collision opponent is significantly higher with a SUV collision related to a passenger car to passenger car collision, 21% versus 15%, (a.r.=3.0, N=61).

Logistic regression analysis shows that mass is the main predictor for accident severity. The vehicle type is not anymore relevant and the difference found above is caused by the higher vehicle mass compared to the mean mass of passenger cars (see also 3.1.2.3).

#### *3.1.3.2 Heavy Vehicles*

In accidents between SUVs and passenger cars with heavy vehicles focussing on killed and injured persons, less significant deviations are found mainly due to the very small number (N=13) of SUVs.
The location of impact is in case of an accident with a SUV more often left-front then with an accident with a passenger car (a.r.=4.4, N=5).
The distribution over the gender is more or less even for SUVs and passenger cars.
Accidents with SUVs take place more often on 80 km/h roads in relation with passenger car to truck accidents, 61% versus 35%, (a.r.=2.1, N=8)
There is no difference in self-protection between SUVs and passenger cars with these accidents, 34% fatality and/or seriously injured.
Due to the small numbers no regression analysis could be performed.

#### *3.1.3.3 Vans (Light Trucks)*

The number of SUVs involved in an accident related to Vans is 34 and the number of passenger car within this type of accident equals 2574. The numbers are small and the results are therefore presented as trends and not as real significant differences.

There is a trend towards more head/tail accidents with SUVs, in comparison to passenger car accidents, 65% versus 47%, (a.r.=2.0, N=22) and towards slightly less side impacts, 21% versus 40%, (a.r.=-2.3, N=7).

There is more often a collision point on multiple locations on the Van in collisions with SUVs (24%), in comparison with passenger car – Van accidents (5%) (a.r.= 4.7, N=8).

More male SUV drivers are involved in accidents with Vans then male passenger car drivers, 85% versus 66%, (a.r.=2.4, N=29).

A strange observation is that in Van - SUV accidents, the driver of the Van is percentage wise more often a female driver (32%) in comparison with car – Van accidents (9%) (a.r.= 4.5, N = 11). This difference cannot easily be explained.

No difference is found in road type, which is in contradiction to other categories.

There is no difference in aggressiveness between SUVs and passenger cars against Vans. There seems to be a light trend towards better self-protections for SUV occupants (a.r.= -2.1, 6% vs. 20% fatal and/or seriously injured, N= 2 vs. N=521). But when vehicle mass is taken into account in a regression analysis, this effect disappears.

#### *3.1.3.4 Buses*

With only two SUV accidents this is not a relevant group.

#### *3.1.3.5 Two-wheelers*

The two-wheeler selection covers: motorcycles, mopeds, mofas and bicycles.
The number of SUVs involved in an accident with a two-wheeler is 224 and the number of passenger cars within this type of accident equals 15292.

More male SUV drivers are involved with respect to passenger car drivers (78% vs. 67%, a.r.=3.4, N=174).

Relatively more accidents occur on normal roads, in bends (a.r.=2.5, N=12) and on straight sections (a.r.=2.1, N= 84, 38% SUVs and 31% cars) and less on crossings (a.r.= -2.3, N=60, 27% for SUVs and 34% for cars).
For the roads with speed limits significant differences have been found. SUVs are relatively more frequent involved in accidents with two-wheelers on rural roads, 80 km/h roads (a.r.=2.7, 19%, N=43) and on 70 km/h roads (a.r.=2.0, 2.7%, N=6) and less frequently involved on urban 50 km/h roads (a.r.= -2.0, 73%, N=164). The speed limit is related to injury severity.

Fatality or injury rate of the two-wheeler rider related to the SUV accident is significantly higher than related to a passenger car accident.

- Fatality rate SUV versus passenger car, respectively 4.5% and 1.6% (a.r.=3.3, N=10);
- Fatality or seriously injured rate SUV versus passenger car, respectively 36% and 29% (a.r.=2.2, N=80).

The injury levels of the SUV occupant do not differ significantly from car occupants in two-wheeler accidents.
Binary logistic regression analysis shows again that vehicle mass is the main indicator for injury severity. Gender of the SUV driver is not a significant factor in two-wheeler accidents.

### *3.1.3.6 Pedestrians*

The number of SUVs involved in an accident with a pedestrian is 32 and the number of passenger cars within this type of accident equals 1756.
There is no difference in male SUV or passenger car drivers involved in accidents with pedestrians.

'SUV – pedestrian' accidents on 50 km/h roads occur relatively less than accidents between passenger cars and pedestrians on 50 km/h roads. (69% vs. 82%, a.r.= -2.0, N=22). Relatively more accidents occur on 80 km/h roads (19% vs. 6%, a.r.= 2.8, N=6).

The probability to get killed or seriously injured for pedestrians is independent of the vehicle type (SUV or passenger car). The numbers are too small to draw a conclusion. There seems to be a trend towards higher probability for pedestrians to get killed or seriously injured in an accident with a SUV (56% versus 42%, a.r.= 1.6, N=18).

However, when a logistic regression analysis is done, a trend is spotted for higher aggressiveness of SUVs (sig<0.1, 90% confidence interval), due to the compensation of gender (sig<0.05, females reduce accident severity possibly due to lower vehicle weight). Therefore, for pedestrians the geometry or stiffness of a SUV may be of influence (see Table 8).

Table 8 Variables in the equation for the prediction of aggressiveness towards pedestrians.

| | | | | | | | | 95% C.I.for Exp(B) | |
|---|---|---|---|---|---|---|---|---|---|
| | | B | S.E. | Wald | Df | Sig. | Exp(B) | Lower | Upper |
| Step 1 | Mass | 0.000 | 0.000 | .434 | 1 | 0.510 | 1.000 | 0.999 | 1.000 |
| | SUV | 0.692 | 0.375 | 3.399 | 1 | 0.065 | 1.997 | 0.957 | 4.168 |
| | Gender | -0.245 | 0.111 | 4.915 | 1 | 0.027 | 0.782 | 0.630 | 0.972 |
| | Constant | 0.333 | 0.359 | .859 | 1 | 0.354 | 1.395 | | |

a. Variable(s) entered on step 1: mass, SUV (0=no, 1=yes), gender (0= male, 1= female).
b. Type_2 = Pedestrian

#### *3.1.3.7 Other and Single sided accidents*

The number of single sided SUV accidents is 53 and the number of single sided passenger car accidents equals 3917. In 62% of the accidents the impact point on the vehicle is mid-front.

There is a slight indication that relatively more males are involved in SUV single impacts than in car single impacts, but not significant (a.r.= 1.7, 83%, N=44).

There is no significant difference in road types between SUV and passenger car single sided accidents, but there is a slight trend towards roads with a higher speed limit.

The lethality (or self-protection) for SUVs and passenger cars is the same.

### *3.1.4 Discussion based on VOR database*

The most frequent accident location (in both categories) is on 50 km/h roads, followed by 80 km/h roads. On 80 km/h roads SUV accidents occur generally more frequently compared to passenger car accidents. On 50 km/h roads SUV accidents occur generally less frequent. SUV accidents on 80 km/h roads increase the probability to get killed or severely injured for the collision opponent, cause of the higher speed.

With all accident types the most frequent SUV driver is the male and in all cases over represented in accidents compared to passenger car drivers. This strongly indicates that males are more frequently driving SUVs than females do, or that they more frequently have accidents in a SUV than in a passenger car. Regression analysis shows that gender is a predictor on whether the accident will be with severe or lethal injuries. Males increase and females decrease the probability to get killed or severely injured for the collision opponent. This could indicate that men drive more aggressively than women. Another possibility is that women drive lighter or less aggressive cars and therefore reduce the injury level in the other vehicle (supported by the fact that the women involved in accidents do drive lighter vehicles). Further in-depth investigation in this area is needed to come to firm conclusions.

It is also found in the different accident types that the gross vehicle mass of the SUV or passenger car compensates the seemingly aggressive effect of the SUV. It is not certain whether geometry parameters and stiffness are highly correlated with mass or vehicle type and thus ‘hidden’ in the variable that represents vehicle mass. From the total analysis it seems that vehicle mass and gender of the SUV driver are the main predictors for accident severity.

In accidents with Vans another strange result appears. Female drivers in the Van are over represented in ‘SUV and Van’ accidents compared to ‘Car and Van’ accidents. This is not the case in any other impact type, and cannot easily be explained. The numbers are large enough for statistical analysis.

## 3.2 TNO Automotive In-depth Accident Database analyses

This section describes the analyses from the TNO Automotive In-depth accident database concerning SUVs. The database contains reliable in-depth data of accidents in two police regions ‘Rotterdam-Rijnmond’ and ‘Haaglanden’ in the period from April 2002 until November 2002. The data is collected by The Dutch Accident Research Team (DART). The analysis concerns both a (descriptive) statistical analysis of the data in Section 3.2.1, as well as a discussion of remarkable details of the accidents from a case-by-case analysis of the accident photographs in Section 3.2.2. The conclusions on both the analysis and from the case-by-case study are written in Section 3.3.

### *3.2.1 Statistical analyses of the in-depth accident database*

This section is divided in three subsections. Section 3.2.1.1 describes the data-selection of the In-depth database, followed by the analyses on damages in Section 3.2.1.2 and injury levels in Section 3.2.1.3.

#### *3.2.1.1 Methodology*

For an internal TNO Automotive study every accident was investigated where a SUV was involved and where the Technical department of the police (TOD) made a report.

The police officers from the mentioned regions contacted DART when an accident with a SUV happened. The team started an investigation when the criteria are met.

Apart from these cases, DART collected data from old SUV accident cases from 1998 to 2002 in the region Rotterdam-Rijnmond. The team did not collect any information at the specific accident location nor inspected the vehicles involved, because of the time gap between the accident occurrence and the investigation. It is obvious that the level of detail of the data will be lower than the normal in-depth research procedure. In total 32 accidents were investigated.

Due to the fact that only SUV accidents were collected and investigated for this part of the study, a comparison between SUVs and cars cannot be made. This analysis will give a descriptive overview of the findings.

Three main groups of collision partners were found in this analysis: passenger cars, motorised two-wheelers and objects. These three groups will be treated separately. Only one truck accident was coded.

#### *3.2.1.2 Damages*

For the SUVs 47 damage locations were identified. In Table 9 the number of deformations per collision partner type is shown.

Table 9 Number of collisions per collision partner type

| Collision partner | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| Truck | 2 | 4.3 | 4.3 | 4.3 |
| Powered two-wheeler | 10 | 21.3 | 21.3 | 25.5 |
| Object or ground | 11 | 23.4 | 23.4 | 48.9 |
| Van | 2 | 4.3 | 4.3 | 53.2 |
| Car or car-derivative | 22 | 46.8 | 46.8 | 100.0 |
| Total | 47 | 100.0 | 100.0 | |

Most frequent are damages on cars followed by objects or the ground and powered two-wheelers.

<u>‘SUV - Car’ deformation locations</u>

Combined deformation locations from CDC-coding (Table 10) show for ‘SUV - Car’ impacts, that cars seem to be more frequently damaged on the side (8+4) than SUVs (4+2) and that SUVs seem to be more frequently damaged from the back (6 versus 0). There seems to be no real difference in frequencies of frontal interactions. Five damages are caused by side to side interactions. In three cases no damages are found on the SUV, while the car is damaged.

Table 10 Deformation location on the SUV versus deformation location on the car

| | | | Car: Area of Deformation | | | |
|---|---|---|---|---|---|---|
| | | | F | L | R | Total |
| SUV: Area of | | | | 1 | 2 | 3 |
| Deformation | B | 2 | 3 | 1 | | 6 |
| | F | 2 | 2 | 2 | 1 | 7 |
| | L | | 1 | 2 | 1 | 4 |
| | R | | | 2 | | 2 |
| Total | | 4 | 6 | 8 | 4 | 22 |

a. Categorised body style 2 = car or car-derivative

When vertical and lateral locations are taken into account, it can be checked if over-ride situations occur. Over-ride would appear in CDC-coding as G, M or A of the passenger car (see Appendix B) and L, M or E for the SUV. Of course, M against M is not considered as an over-ride. It can be seen in Table 11 that there are no clear over-ride cases where the glass of the car is damaged (G code), but there are four cases in which the car is hit at a higher point than the SUV (three cases with the whole height of the car A versus SUV E or L and one case above bumper M for car versus bumper for SUV). One contrary case was found on which the SUV seemed to be damaged somewhat higher than the car. Furthermore, it is striking that in eight cases the bumper of the SUV is involved (L), but only three of these cases concern potential over-ride cases and these cases were included in the four cases that were mentioned earlier. There is a weak indication for some over-ride problems in collisions between cars and SUVs. More proof for under-ride will be given in Section 3.2.2.

Most frequently the lower half of both vehicles is damaged (E). In five cases the total height of the car is damaged (A); for the SUV only two damages are coded over the total height (A).

Table 11 Specific vertical or lateral areas on SUV versus cars

| | | | Car: Specific vertical or lateral area | | | | |
|---|---|---|---|---|---|---|---|
| | | | A | E | L | M | Total |
| SUV: Specific | | | | 1 | 1 | 1 | 3 |
| vertical or | A | | 2 | | | | 2 |
| lateral area | E | | 1 | 6 | | | 7 |
| | L | 3 | 2 | | 2 | 1 | 8 |
| | M | | | 1 | | | 1 |
| | W | 1 | | | | | 1 |
| Total | | 4 | 5 | 8 | 3 | 2 | 22 |

a. Categorised body style 2 – car or car derivative

<u>‘SUV - Object’ deformation locations</u>

In four cases an impact occurred but no deformation on the SUV was found (see Table 12). The front and left side seem to be most frequently damaged in a collision with an object.

Table 12 Deformation locations on the SUV in impacts with objects or ground

|  |  | Object or ground | Total |
|---|---|---|---|
| SUV: Area of |  | 4 | 4 |
| Deformation | F | 3 | 3 |
|  | L | 3 | 3 |
|  | T | 1 | 1 |
| Total |  | 11 | 11 |

a. Categorised body style 2 = Object or ground

‘SUV - Powered two-wheeler’ deformation locations

The deformation locations on the ‘powered two-wheelers’ seem to concentrate on the front of the vehicle (see Table 13).

Table 13 Deformation locations on SUV versus powered two-wheelers

|  |  | PTW: Area of Deformation |  |  |  |
|---|---|---|---|---|---|
|  |  |  | B | F | Total |
| SUV: Area of |  |  |  | 2 | 2 |
| Deformation | F | 1 | 1 | 3 | 5 |
|  | R |  |  | 3 | 3 |
| Total |  | 1 | 1 | 8 | 10 |

a. Categorised body style 2 = Powered two-wheeler

In impacts with powered two-wheelers, there seems to be a tendency that the full height of the two-wheeler is damaged (A), while on the SUV only the lower half or bumper area is damaged (E and L). See Table 14 and also appendix B for CDC codes.

Table 14 Specific vertical or lateral areas on SUV versus cars

|  |  |  | Powered two-wheeler: Area of Deformation |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  |  | B | F |  |
|  |  |  | PTW: Specific vertical or lateral area | A | A | G |
|  | SUV: Specific vertical or lateral area |  |  |  | 2 |  |
| F | SUV: Specific vertical or lateral area | E |  | 1 |  | 1 |
|  |  | L | 1 |  | 2 |  |
| R | SUV: Specific vertical or lateral area | E |  |  | 1 |  |
|  |  | G |  |  | 1 |  |

### 3.2.1.3 *Injury levels*

For the SUV in-depth research, it was tried to obtain the injuries from the victims. In 21 accidents of the 32 investigated accidents, persons were injured. 40 known injuries were coded and from eight persons it was known that they were injured but the injury level was unknown.

<u>‘SUV - Powered two-wheeler’ injury levels</u>

For the riders of powered two-wheelers it is shown (see Table 15) what the injury contact codes are. It can be seen that most injuries caused by the vehicle side are abdominal injuries and injuries on the extremities (mostly fractures). Injuries resulting from the contact with the pavement are various.

Table 15 Injuries versus injury contact codes for two-wheeler riders in SUV impacts

| | | -1 | AF | AS | MC | PV | Total |
|---|---|---|---|---|---|---|---|
| Face | Whole area | | | 1 | | | 1 |
| Neck | Whole area | | | | | 1 | 1 |
| Thorax | Whole area | | | | | 1 | 1 |
| | Organs (incl. muscles / ligaments) | | | 1 | | | 1 |
| | Skeletal (incl. joints) | | | 2 | | | 2 |
| Abdomen | Organs (incl. muscles / ligaments) | | | 4 | | | 4 |
| Spine | Skeletal (incl. joints) | | | | 2 | 1 | 3 |
| Upper Extremity | Whole area | | | | | 1 | 1 |
| | Organs (incl. muscles / ligaments) | | | 1 | | | 1 |
| | Skeletal (incl. joints) | | | 2 | | 1 | 3 |
| Lower Extremity | Organs (incl. muscles / ligaments) | | | | | 1 | 1 |
| | Skeletal (incl./ joints) | | 2 | 2 | | 1 | 5 |
| Unspecified | 9.00 | 1 | | | | | 1 |
| Total | | 1 | 2 | 13 | 2 | 7 | 25 |

-1 = unknown; AF = SUV front; AS = SUV side; MC = motorcycle; PV = pavement

The injury levels for the powered two-wheeler rider vary from AIS 1 to AIS 4 (see Table 16). Most frequently AIS 2 injuries were noticed, which are mainly fractures and some dislocations. AIS 4 injuries are a lung hemothorax with hemomediastinum and a gallbladder laceration.

Table 16 Injury type versus injury level for two-wheeler riders in SUV impacts

| | | AIS Level | | | | |
|---|---|---|---|---|---|---|
| | | 1.00 | 2.00 | 3.00 | 4.00 | 9.00 |
| Face | Whole area | | 1 | | | |
| Neck | Whole area | 1 | | | | |
| Thorax | Whole area | 1 | | | | |
| | Organs (incl. muscles / ligaments) | | | | 1 | |

| | | AIS Level | | | | |
|---|---|---|---|---|---|---|
| | | 1.00 | 2.00 | 3.00 | 4.00 | 9.00 |
| | Skeletal (incl. joints) | | 2 | | | |
| Abdomen | Organs (incl. muscles / ligaments) | | 1 | 2 | 1 | |
| Spine | Skeletal (incl. joints) | | 3 | | | |
| Upper Extremity | Whole area | 1 | | | | |
| | Organs (incl. muscles / ligaments) | | 1 | | | |
| | Skeletal (incl. joints) | 1 | 2 | | | |
| Lower Extremity | Organs (incl. muscles / ligaments) | | 1 | | | |
| | Skeletal (incl. joints) | | 4 | 1 | | |
| Unspecified | 9.00 | | | | | 1 |

### ‘SUV - Car’ injury levels

Unfortunately, for car occupants many injury causes are unknown. Injuries caused by the car interior, are mainly injuries on head and face (see Table 17).

Table 17 Injury type versus impact location for the car occupant in ‘SUV – Car’ impacts

| | | Object code impact location | | | | |
|---|---|---|---|---|---|---|
| | | -1 | -2 | 0 | AN | Total |
| Head | Whole area | 1 | | | 1 | 2 |
| | Organs (incl. muscles / ligaments) | | | | 1 | 1 |
| | Head –LOC | | | | 1 | 1 |
| Face | Whole area | | | | 1 | 1 |
| Neck | Skeletal (incl. joints) | 1 | | | | 1 |
| Spine | Organs (incl. muscles / ligaments) | 1 | | 1 | | 2 |
| | Skeletal (incl. joints) | 1 | | | | 1 |
| Upper Extremity | Whole area | | 1 | | | 1 |
| Unspecified | 9.00 | 3 | | | | 3 |
| Total | | 7 | 1 | 1 | 4 | 13 |

-1 = unknown, -2 = not coded, 0 = not applicable, AN = interior

AIS levels for the car occupant are at maximum AIS 3 (see Table 18). Here, the AIS3 injury is an unspecified brain injury. Also some low injury spine and neck injuries were found.

Table 18 Injury location versus injury level for the car occupant in ‘SUV – Car’ impacts

| | | AIS Level | | | |
|---|---|---|---|---|---|
| | | 1.00 | 2.00 | 3.00 | 9.00 |
| Head | Whole area | 2 | | | |

| | | AIS Level | | | |
|---|---|---|---|---|---|
| | | 1.00 | 2.00 | 3.00 | 9.00 |
| | Organs (incl. muscles / ligaments) | | | 1 | |
| | Head –LOC | | 1 | | |
| Face | Whole area | 1 | | | |
| Neck | Skeletal (incl. joints) | | 1 | | |
| Spine | Organs (incl. muscles / ligaments) | 2 | | | |
| | Skeletal (incl. joints) | | 1 | | |
| Upper Extremity | Whole area | 1 | | | |
| Unspecified | 9.00 | | | | 3 |

‘SUV – Pedestrian’ injury levels

Two accidents with pedestrians were recorded. Injuries are caused by the SUV front (bumper and ornament) and the pavement (see Table 19).

Table 19 Injury type versus impact location for pedestrians in SUV accidents

| | | Object code impact location | | | |
|---|---|---|---|---|---|
| | | -1 | AF | PV | Total |
| Head | Whole area | | | 1 | 1 |
| Upper Extremity | Skeletal (incl. joints) | | 1 | | 1 |
| Lower Extremity | Whole area | | 1 | | 1 |
| Unspecified | 9.00 | 1 | | | 1 |
| Total | | 1 | 2 | 1 | 4 |

-1 = unknown, AF = vehicle front, PV = pavement

SUV occupant injuries

SUV occupants were hardly injured in the investigated accidents; only some bruises were found and some unknown injuries (see Table 20). The injuries were obviously caused by the SUV interior: one by the steering wheel and one by the front door. It seems that injury levels for the SUV occupant might be lower than that of their collision partners; SUV occupants are more frequently uninjured, which might point to a safer environment for the SUV occupant.

Table 20 Injury location versus injury severity for the SUV occupant

| | | AIS Level | |
|---|---|---|---|
| | | 1.00 | 9.00 |
| Upper Extremity | Whole area | 2 | |
| Unspecified | 9.00 | 1 | 2 |

### 3.2.2 *Case-by-case analysis from accident photographs*

The photographs of accidents from the TNO Automotive In-depth database concerning SUVs and from the European Accident Causation Study (EACS) project were used for further analysis of the vehicles’ damage. In total, 37 cases were analysed from which 10 from the EACS project. The pictures were taken by the various research groups (TNO Automotive and/or other European institutes) or by the Dutch accident police departments during the on-scene inspections, the reconstruction of the impact position of the vehicles, and/or the technical inspection of the vehicles.

The 37 cases can be divided into five categories:
1 Frontal/rear impact;
2 Side impact;
3 Rollover;
4 Impact with two-wheelers, and
5 Impact with pedestrians.
Figure 5 shows the number of cases per category.

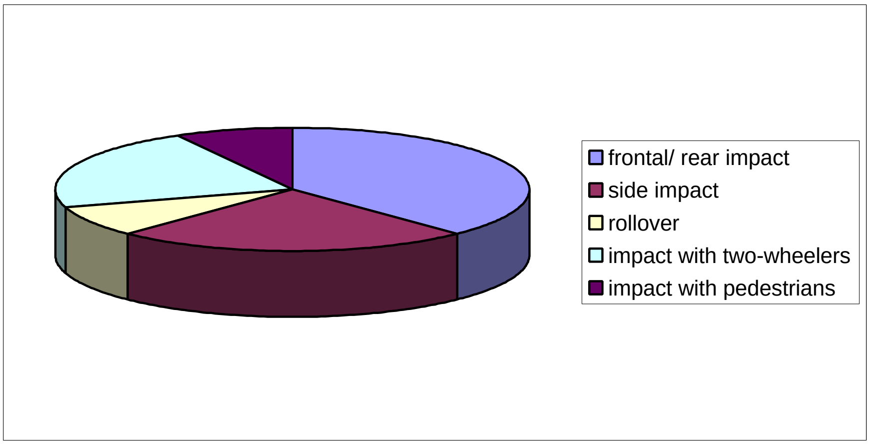


*Figure 5 – Number of cases per accident category*

The photographs of different cases are analysed and problems that may occur more often are described in the following sections:
- 3.2.2.1 - Bumper height;
- 3.2.2.2 - Protruding objects;
- 3.2.2.3 - Stiffness of the SUV;
- 3.2.2.4 - Rollover of SUVs.

#### *3.2.2.1 Bumper height*

The height of the bumper of the SUV was a parameter, which influenced the development of the crash in many accidents. The accident configurations that have been studied are head-on collision (SUV versus passenger car), rear-end collision (SUV versus passenger car and vice versa) and side impact (SUV versus passenger car and vice versa).

Figure 6 illustrates the height of the lowest point of the bumper of a SUV from the ground compared to the height of the bumper of a passenger car. This difference exists because the vehicles are built as terrain vehicles. A terrain vehicle and now the SUV too is equipped with large diameter tires and with big stroke shock absorbers so the ground clearance of the frame and the components underneath the vehicle needs to be high enough to avoid contact with the rough surface during off-road driving.

*Figure 6 – Difference in the height of the bumpers*

The difference in bumper height is smaller (or even zero) between a small SUV and a passenger car (see Figure 7), from the fact that the tire size and the suspension stroke are smaller.

*Figure 7 – Comparison of the bumper height between a small SUV and a passenger car*

It is noticed from the analysis of the photographs that when a passenger car crashes into the rear of the SUV, the front of the passenger car dives under the rear of the SUV (see Figure 8-Left). This is even more serious when the passenger car decelerates before the impact. The front suspension system is compressed, the front of the vehicle lowers towards the ground and the passenger car dives under and lifts the rear end of the SUV during the impact (see Figure 8-right). The disadvantage in both scenarios is that energy is absorbed by the top of the hood, whereas the hood is not designed for this purpose and this gives huge deformations. The easily deformed metal sheet could cause injuries to the occupants.

*Figure 8 – Under run effect*

The ‘SUV - passenger car’ collisions will be compared with the ‘car-to-car’ collisions. In the ‘car-to-car’ collisions, the first contact area is the bumper for both vehicles (Figure 9). More energy is absorbed (in comparison to the previous accident scenario and with similar deformation length) by the deformed parts of this zone, therefore the deformation extent is less and the severity of the accident is reduced.

*Figure 9 – Passenger car rear end collision*

Figure 10 shows another accident scenario where the SUV runs into the rear of a Van. The SUV hits the rear door because of the high positioned SUV bumper and the low positioned bumper of the Van. The Van normally has a low height of the loading floor from the ground, which makes the loading of the vehicle easier.

*Figure 10 – Deformation of the rear door of a small van*

A possible danger in this case is that the rear door can easily collapse during an impact and the SUV may penetrate the loading compartment. Some Vans are modified by the manufacturer into ‘nine-person’ buses. The rear row of seats (usually three seats) is placed very close to the rear door and in case of an impact this may cause injuries.

Figure 11 and Figure 12 show that SUVs run into the side of a passenger car at a much higher location compared to a medium class passenger car. An accident configuration in which injuries might be very severe. The penetration depth is high. Modern passenger cars might comply with the side impact regulation, but these vehicles are tested in a ‘passenger cars to passenger cars’ configuration (without a big difference in mass and stiffness). The cars are not tested in a ‘SUV to car’ configuration. A SUV is sometimes twice as heavy as a passenger car and the SUV is much stiffer and higher than a passenger car.

*Figure 11 – Impact much higher than the sill beam height, without any bull-bar deformation*

In Figure 12 it can be seen that the sill beam (one of the stiffer parts of a vehicle) deforms during the impact and therefore absorbs a part of the energy. This will reduce the penetration depth at the height of the occupant's knees, because the energy is absorbed by three vehicle sections (B-pillar, sill beam and doors) and not only two (B-pillar and doors), as it occurs in the 'SUV to car' scenario.

*Figure 12 – Impact at the sill beam height*

The SUV is probably safer for SUV driver and passengers if a passenger car impacts the side of the SUV. Figure 13 shows the difference in ground clearance that allows an impact at the low zone of the door. The impact height will be lower than the height of the seat of the SUV occupant. A pelvis injury of the occupant of the SUV may be avoided in this configuration.

*Figure 13 – Height of the impact of a passenger car against a SUV*

#### 3.2.2.2 *Bull-bars and other protruding objects*

Many objects installed on a SUV are observed in the pictures, which can increase the severity of an accident. A frequently seen object is the ‘Bull-bar’(see Figure 14). The shape and the material of the bull-bar are the two important parameters. The danger of this construction is that the bar will apply the impact force and not a broad surface. This will increase the local penetration depth. In two-wheeler and pedestrian accident the bull-bar will increase the chance for a bone fracture of the rider and the pedestrian.

*Figure 14 – Example of a pointed construction*

Bull-bars, which are extending at the side of the SUV, may increase the deformation during glance-off impacts. Figure 15 show that the crash would have been limited to only an interaction between the two bumpers, if the SUV had been equipped with no or a less wide bull-bar, where as now the sheet metal may deform as well.

*Figure 15 – Deformation increase due to the extending bull-bar*

Another danger for a severe injury may occur, when a two-wheeler scrapes along the bull-bar. An extremity of the body of the rider may be entangled between the bull-bar pipes, causing a serious bone fracture or even an amputation.

In many cases the pipes of the bull-bar were not deformed during the impact (see Figure 15. The difference in stiffness between the bull-bar and the impact partner was huge. As a result of this, the deformation of the partner increased. Bull-bars must be banned from vehicles in normal traffic or more attention must be paid to the design of the bull-bars and to the choice of the material.

Another object that could be dangerous is the outside mounted spare wheel at the rear door of the SUV. When a passenger car crashes into the rear of a SUV, the spare wheel will push the hood towards the rear (see Figure 16). The deformed or displaced hood may break the windshield and may come through the occupant's compartment. The spare wheel largely increases the under run effect.

*Figure 16 – Spare wheel effect during a rear end impact*

When a high-fronted vehicle (such as a truck, a bus, or van) crashes into the back of a SUV, the spare wheel will move into the SUV (the wheel is stiffer than the door), deforming the rear door at the same time (see Figure 17). The wheel is protruding the rear end approximately 300 to 400 mm and therefore it increases the deformation extent 300 to 400 mm locally. The passengers on the rear seat are more endangered to sustain injuries.

*Figure 17 – Rear door deformation due to the spare wheel position*

Ornaments on the top of the hood (fastened with screws) or fog lights attached to the bull-bar may cause or increase the injuries during an impact with a two-wheeler rider or a pedestrian. Foldable ornaments and fog lights are an easy solution, but this solution is effective only during a frontal impact or only during a side impact with the ornament or the lights, depending on the direction in which they fold.

Two other objects that may be found at the SUV front are a towing hook and/or a winch. Because of their shape and stiffness and the fact that these objects are rigidly attached to the longitudinal ladder frame, these objects may become very dangerous during a side impact or during an impact with a pedestrian.

#### 3.2.2.3 *Stiffness of the SUV*

An important factor in compatibility is the crash stiffness of the SUV. SUVs are much stiffer compared to passenger cars. This is caused by the principle of chassis construction. Most SUVs are built on a ladder chassis with stiff beams as shown in Figure 18, where passenger cars in general have a uni-body construction (see Figure 19).

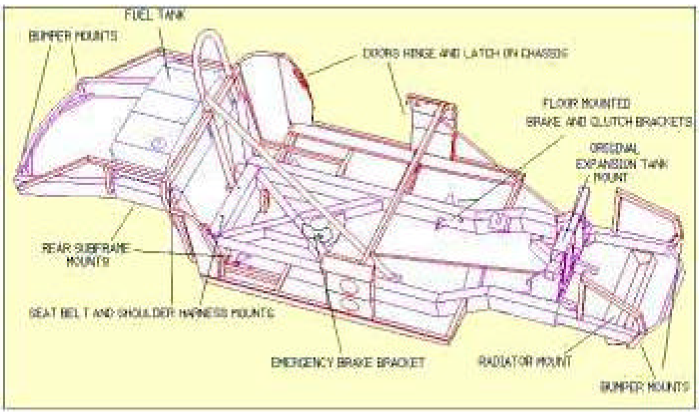


*Figure 18 – Ladder chassis*

*Figure 19 – Uni-body chassis*

The SUV with the ladder chassis construction is more aggressive, due to the fact that the beams of the ladder chassis are very stiff. Also from the pictures of the real accidents it can be seen that the damage to the SUVs is rather small, where the target vehicle has extensive damage, in frontal accidents.

*Figure 20 – A Nissan Patrol drove into the side of a Mazda 323*

*Figure 21 – The front of a small passenger car that drove into the back of a SUV.*

The reason to make use of a ladder chassis is because it gives the car better performance in rough terrain. The frame is without special design very stiff from itself, which unibody constructions do not have. With the ladder chassis it is not easy to make a car with a stiffness that is similar to a passenger car. Therefore a ladder chassis will normally result in a more aggressive car, being less compatible.

#### 3.2.2.4 *Rollover of SUVs*

SUVs tend to rollover more easily due to a higher centre of gravity and this type of accident is of special interest from the fact that a relatively high percentage of the SUV occupants die. The problem with rollover is two-fold:

1 The deformation of the roof of the vehicle gives to the occupants too little space at the top to survive. This is due to the construction of the car, like lowering the centre of gravity by reducing the weight at the upper part, like A-, B- and C-pillar. In case of rollover the construction is not strong enough to resist the impact. An example is the left picture in Figure 22;

2 Most common is the ejection of the SUV passengers in a rollover, especially in the case of not wearing the safety belt.

In the left picture in Figure 22 the windows are broken and ejection may occur.
From the in-depth TNO rollover cases no fatalities are reported.

*Figure 22 – Rolled over SUV, left a frontal rollover, right a side rollover*

## 3.3 Conclusions and recommendations

Conclusions from the VOR analysed accidents:

*General*

- In total 650 SUV accidents were analysed and 44559 passenger car accidents. The second group is used as the so called ‘control group’;
- SUVs are relatively more involved in accidents on 80 km/h roads than passenger cars (except for trucks as collision opponent). This also has a significant influence on the prediction for the collision opponent to get killed or seriously injured;
- Side impacts and head - tail impacts are generally most frequent, followed by frontal impacts;
- In the analysed accidents, SUVs are more frequently driven by males than in the control group. Males in the analysed accidents are found to drive in general heavier vehicles and for that reason they are found to be a significant factor in the prediction for the collision partner to get killed or seriously injured;
- Female SUV drivers significantly decrease the collision opponent’s probability to get killed or seriously injured. This effect might be partly due to the fact that women involved in accidents drive significantly lighter cars than males that are involved in accidents. Lighter vehicles decrease the amount of energy involved in a crash.

*Self-protection (lethality)*

- The increased safety of the SUV occupant is found in the factor 'mass'. Compensated for the 'mass' effect, the SUV is not found to be safer for the occupant than a passenger car. This means that the apparent safety of SUVs is in fact only due to the higher mass of the vehicle and not due to structural differences (geometry and stiffness) and for restraint systems compared to passenger cars.

*Partner-protection (aggressiveness)*

- For aggressiveness it was found that vehicle mass is the main predictor for the accident severity. A higher vehicle mass as such increases the accident severity, whatever the type of vehicle (SUV or passenger car);
- Pedestrians have the highest probability to get killed or seriously injured in an accident with a SUV or a passenger car, followed by two-wheeler occupants;
- SUVs are significantly more aggressive towards pedestrians than passenger cars, even when compensated for the ‘mass-effect’.

Conclusions from the TNO Automotive In-depth Accident Database analysed accidents:

General
- In total 32 accidents were investigated;
- Many variables were recorded, only few provide useful information for statistical analysis since the number of accidents is so small;
- The most frequent collision partner is the passenger car;
- SUVs seem to be damaged more in the rear than passenger cars.

Self-protection (lethality)
- SUV occupants seem to be more frequently not injured, which might point to a safer environment for the SUV occupant.

Partner-protection (aggressiveness)
- Injury levels of powered two-wheeler riders vary from AIS 1 to AIS 4, but most frequently AIS 2. They are mainly fractures;
- Injuries of car occupants are mainly to head and face and at maximum AIS 3.

Recommendations from both analyses
- The effect of mass needs further investigation with a study in which passenger cars and SUVs with the same mass-class are compared. The two groups need to be of equal mass-distribution. Difference between the two categories could than be explained by geometry (bumper height) or stiffness characteristics;
- The effect of gender could be further investigated with a control group. Video shots at random locations should be able to give information about the frequency of male and female drivers in passenger cars and SUVs. Compared with accident data, this information could give information about driving behaviour differences between men and women, and information about average vehicle mass in these categories.

Design recommendations
- The front and rear ladder chassis construction should be changed, to be less aggressive during an impact with a passenger car;
- A less deformable SUV roof and upper pillars have to be researched to decrease the collapse of the roof in rollover accidents;
- The bumper height of SUVs should be lowered to increase geometrical compatibility with passenger cars;
- Ornaments and fog lights should be integrated in the front;
- The use of a winch needs to be considered for strictly limited or no admittance on public roads (e.g. vehicle use, area driven). An easily demountable version of the winch needs to be developed;
- A bull-bar is of no use. A more restricted regulation should be considered, which would allow the use of a bull-bar only if they have no negative effect on the safety of other road-users;
- Attention must be paid to the construction material of the bull-bar;
  - A more close bull-bar construction, allowing less space in between the bars is advised;
  - The bull-bars must not exceed the width of the vehicle;
- The spare wheel should be placed within the vehicle, in a similar way as the spare wheel of the passenger cars.

# 4 Impact of SUVs on the Dutch environment

The environmental conditions and air quality in The Netherlands to a large extent are determined by road transportation, other mobile sources and industrial activities. The growing number of SUVs on the Dutch roads is said to contribute significantly to the climatologically conditions. A solid basis for these statements is not available though.

This chapter describes the research that has been conducted to generate a good impression about the actual environmental performance of SUVs in real-world conditions on the current and near-future situation. As much as possible, statements are based upon or supported with fact figures.

In Section 4.1 the contribution of road transport, and passenger cars in particular, to the total Dutch emissions and the impact of road transport on local air quality will be described first. All vehicles tested need to pass the emission legislation. Section 4.2 describes the current legislation procedure, its emission limits and the relation with the SUV types that have been identified in Chapter 2. Section 4.3 presents TNO’s Engine and Emission Laboratory, the test programme for this research and the vehicles that are selected for the tests. In Section 4.4 the results of the measurements on several SUVs are presented and the impact is analysed.

In Section 4.5 the developments in the field of hybrid technology are discussed and evaluated for their position in relation to their environmental performance and possible impact.

Section 4.6 recalls the various conclusions to give a total overview of the environmental impact of SUVs as assessed through the research of this project.

## 4.1 Overview of emissions from road transport in The Netherlands

Environmental problems caused by exhaust emissions from road transport can be divided into three categories [20]:

1. Human health effects caused by
    - emission of carbon monoxide (CO)
    - increased nitrogen dioxide ($NO_2$) concentration in ambient air
    - ground level ozone formation, or ‘smog’, caused by the reactivity of CO, hydro carbons (HC) and nitrogen oxides ($NO_x$)
    - emission of primary particulate matter (PM)
    - sulphur dioxide ($SO_2$)
    - other components, such as polycyclic aromatic hydrocarbons (PAH), aldehydes, 1.3-butadiene and benzene, toluene and xylene (BTX)

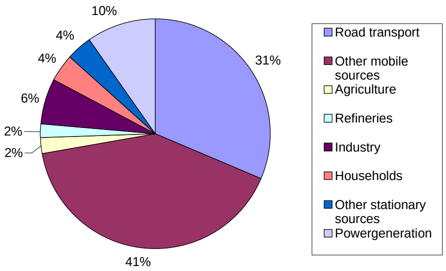
2. Ecological effects caused by
    - acidification through emission components $NO_x$, ammonia ($NH_3$) and sulphur dioxide ($SO_2$)
    - eutrophication through the emission components $NO_x$ and $NH_3$
    - ground level ozone formation, or ‘smog’,

3. Climate effects
    - direct global warming caused by the emission of greenhouse gases, mainly carbon dioxide ($CO_2$), methane ($CH_4$) and bi-nitrogen oxide ($N_2O$)
    - indirect global warming through the emission of particulate matter, where the ratio of elementary carbon and organic carbon (EC/OC) plays an important role
    - depletion of the ozone layer caused by emission of $N_2O$

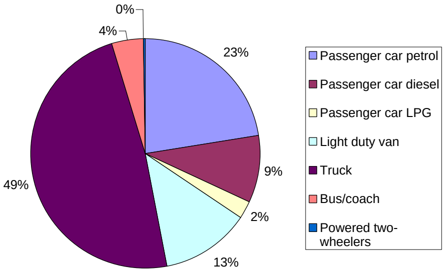
From the above it can be concluded that there are a lot of exhaust emission components that have an impact on the environment. However, emissions of $NO_x$, PM and $CO_2$ have been identified by the Dutch Ministry of Spatial Planning and the Environment as the most important contributors to the Dutch environmental problems [21]. On several locations next to highways the $NO_2$ concentrations (caused by amongst other the emission of $NO_x$ from road transport) and PM concentrations are exceeding the EU limits for 2010. Also, the total Dutch emission of $NO_x$ will exceed the National Emission Limit (NEC) for 2010. The problem of $CO_2$ emissions has a more long term character and also has to do with issues of energy security.

Although carbon monoxide (CO) and hydrocarbons (HC) are no longer major environmental problems anymore, they still have an important role in environmental policy making. As such they are still part of the European exhaust gas emission legislation (see Section 4.2). Figure 23 shows the contribution of these components to the total Dutch emissions for each component as well as the subdivision into the separate road transport modes.

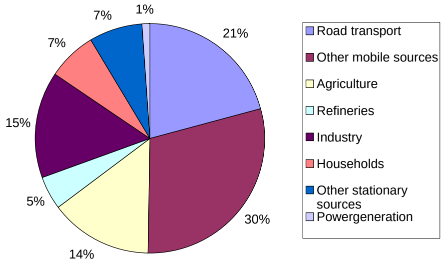
**Total NOx emissions in The Netherlands [2003]**



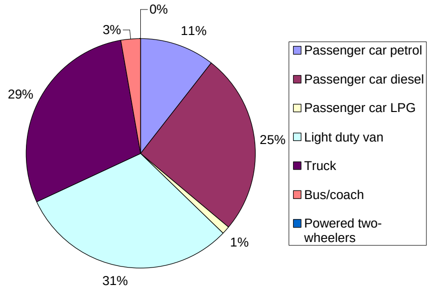
**NOx emissions by road transport in The Netherlands [2003]**



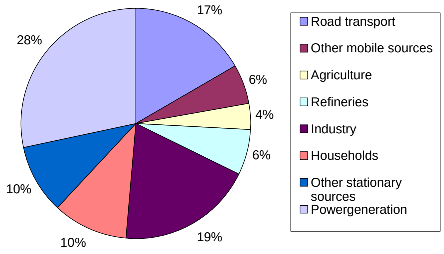
**Total PM emissions in The Netherlands [2003]**



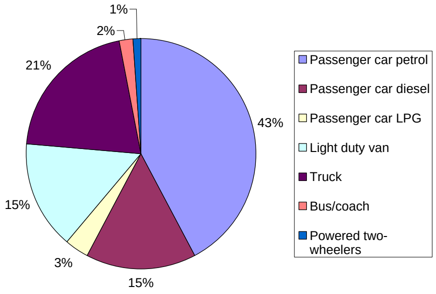
**PM emissions by road transport in The Netherlands [2003]**



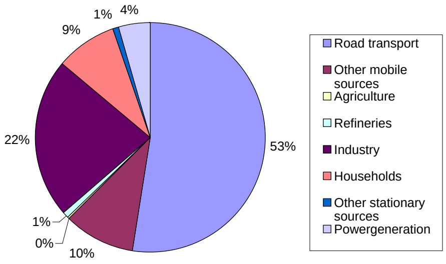
**Sources of CO2 emissions in The Netherlands [2003]**



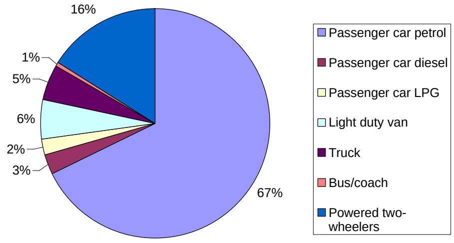
**CO2 emissions by road transport in The Netherlands [2003]**



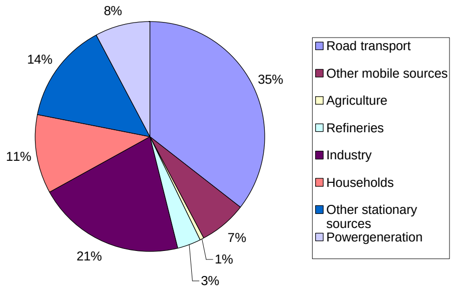
**Total CO emissions in The Netherlands [2003]**



**CO emissions by road transport in The Netherlands [2003]**



**Total HC emissions in The Netherlands [2003]**



**HC emissions by road transport in The Netherlands [2003]**

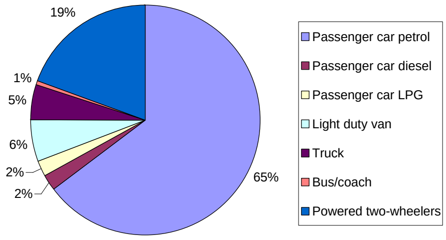


*Figure 23 – Overview of sources for emissions to the air in The Netherlands [17]*

## 4.2 Legislation for passenger cars

In order to address the problems described in Section 4.1, the European Union has set up legislation with the aim of reducing exhaust emissions, for the components CO, HC and $NO_x$ for petrol cars and CO, HC, $NO_x$ and $PM_{10}$ for diesel fuelled cars. This legislation [22] has initially been set up in the early seventies. Since the nineties the 'Euro-class' system has been used, starting with Euro 1 in 1993, followed by Euro 2 in 1997. At the moment of writing, all newly sold vehicles fall into the Euro 3 (since 2000) and Euro 4 (from 2005) categories.

Within the emission legislation several vehicle classes are defined. Passenger cars are designated as M1 vehicles. N1 vehicles are the so called light duty trucks. The N1 legislation is applicable to vehicles with a Gross Vehicle Weight (empty weight plus maximum payload) of less than 3500kg. The N1 legislation is subdivided in three groups, based on the empty weight:

- Class I : = 1305kg;
- Class II : > 1305kg, but = 1760kg; and
- Class III : > 1760kg, but <3500kg.

The vehicles that qualify as N1 class II or III have higher limits and thus are allowed to produce more emissions. The emission legislation thus does not discriminate vehicles on the basis of size, yet it differentiates only on the basis of weight. Table 25 below shows the corresponding emission limit-values for passenger cars (M1) and N1 Class III vehicles.

Table 21 Mandatory Euro3 and Euro4 emission limits in the European Union

| | | | Limit values | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Reference Mass (RW) | Mass of carbon monoxide (CO) | | Mass of hydrocarbons (HC) | | Mass of nitrogen oxides ($NO_X$) | | Combined mass of hydrocarbons and nitrogen oxides ($HC + NO_X$) | | Mass of particulates[1] (PM) |
| | | [kg] | [g/km] | | [g/km] | | [g/km] | | [g/km] | | [g/km] |
| Category | Class | | Petrol | Diesel | Petrol | Diesel | Petrol | Diesel | Petrol | Diesel | Diesel |
| A $M_1$[2] | | All | 2.3 | 0.64 | 0.20 | - | 0.15 | 0.50 | - | 0.56 | 0.05 |
| (2000) $N_1$[3] | I | RW ≤ 1305 | 2.3 | 0.64 | 0.20 | - | 0.15 | 0.50 | - | 0.56 | 0.05 |
| Euro 3 | II | 1305 < RW ≤ 1760 | 4.17 | 0.80 | 0.25 | - | 0.18 | 0.65 | - | 0.72 | 0.07 |
| | III | 1760 < RW | 5.22 | 0.95 | 0.29 | - | 0.21 | 0.78 | - | 0.86 | 0.10 |
| B $M_1$[2] | | All | 1.0 | 0.50 | 0.10 | - | 0.08 | 0.25 | - | 0.30 | 0.025 |
| (2005) $N_1$[3] | I | RW ≤ 1305 | 1.0 | 0.50 | 0.10 | - | 0.08 | 0.25 | - | 0.30 | 0.025 |
| Euro 4 | II | 1305 < RW ≤ 1760 | 1.81 | 0.63 | 0.13 | - | 0.10 | 0.33 | - | 0.39 | 0.04 |
| | III | 1760 < RW | 2.27 | 0.74 | 0.16 | - | 0.11 | 0.39 | - | 0.46 | 0.06 |

1. For compression ignition engines.
2. Except for vehicles of which the maximum mass exceeds 2500 kg.
3. And those Category M vehicles which are specified in note 2.

An important comment needs to be made with respect to heavy passenger cars. Passenger cars with a GVW of more than 2500 kg automatically are classified as N1 class vehicles. These mainly are the (what used to be just) terrain vehicles and the larger SUVs. SUVs with a GVW of more than 2500 kg will have (in most cases) an empty weight of 2000 kg and higher (loading capacity of 500 to 600 kg). Based on the various models that are sold in The Netherlands, it is found that almost 50% (sales weighed) of the SUVs qualify for the N1 class III category.

The test that is used for measuring the exhaust emissions is the European Driving Cycle (EDC) that consists of a low speed Urban Driving Cycle (UDC) and medium to high speed Extra Urban Driving Cycle (EUDC). The complete cycle is shown in Figure 24.

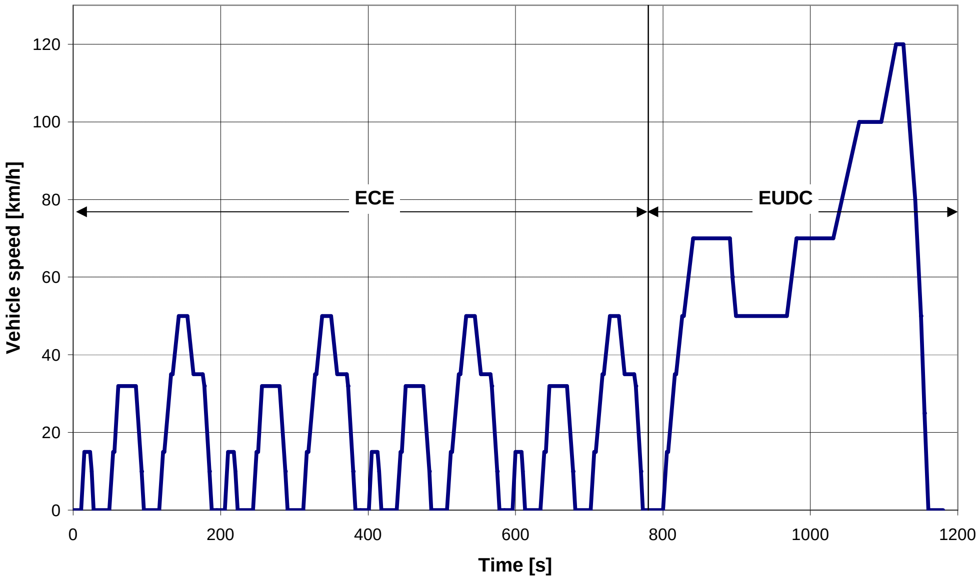


*Figure 24 – European Driving Cycle*

No legislation on fuel consumption or $CO_2$-production exists. Instead a covenant between the EU commission and the vehicle manufacturers has been agreed upon that includes a vehicle fleet average for newly sold vehicles of class M1 (‘regular’ passenger cars) for $CO_2$-emission of 140 g/km by the year 2008. N1 class vehicles thus are not included in this covenant.

## 4.3 TNO facilities, test programme and test vehicles

As part of the project four SUVs are tested in TNO’s Engine and Emission Laboratory. These tests are used for comparing actual measurements with the results from the database models (see textbox on page 50). Due to the small number of vehicles tested as well as some practical limitations of the test facilities, these vehicles can only be regarded as some examples of SUVs out on the road. They cannot be used as a statistically accountable sample.

### *4.3.1 Engine and Emission Laboratory*

TNO Automotive has its own OEM[2] level laboratory facility in Delft for testing of engines, vehicles and components as well as validation of new concepts and performing

---

[2] OEM: Original Equipment Manufacturer, often used as indication for vehicle manufacturer.

type approval tests for engines and vehicles. These activities are key aspects in the development, application and production in the automotive industry. The facilities provide engine test benches and chassis dynamometers for light-duty (passenger cars, Figure 25) and heavy-duty (buses, trucks) vehicles.

*Figure 25 – Examples of vehicles on the chassis dynamometer*

The chassis dynamometers that are available are for two-wheel drive (2WD) vehicles. Although many of the SUVs are permanent four-wheel drive (4WD) vehicles, it is often possible to make a small change to the vehicle so that it can be tested on a 2WD roller bench. For the purpose of testing it may, for instance, be possible to remove two drive shafts and put the differential in a locked position. A second option may be to disconnect a sensor for the differential. These actions need to be carried out well thought and with care and it needs to be tested whether it influences normal vehicle operation. From experience it is known that some of the SUV models may be adapted for the test, but also that some systems cannot be tackled. Many of the newest 4WD vehicles with electronically controlled differentials cannot be tested, at least not without support from the manufacturer.

### 4.3.2 *The test programme*

The tests that are carried out are the official type approval test as well as various real-world driving cycles. The test contains a speed pattern that needs to be followed, and a shift strategy that is to be used. During the test all tail-pipe emissions are sampled and collected in a bag. After the test the contents of the bag are analysed and the emission and fuel consumption results are calculated. Emissions are expressed in g/km, fuel consumption in l/100km.

The following tests are carried out:

1. European Driving Cycle (EDC):
   The official European type approval test for vehicles of class N1-M1, as explained in section 4.2. A shift pattern is defined for vehicles with a manual transmission.

2. Common Artemis Driving Cycles (CADC – [23]):
   The CADC cycles have been developed in the European 5th Framework project Artemis in which all prominent European road traffic research institutes participate. As a result, these cycles are considered representative for average European real-world driving. These driving cycles consist of a separate urban, rural and highway part.

3. TNO Congestion Cycles [24]:
   On behalf of the Transport Research Centre of the Dutch Ministry of Transport (V&W) and the Dutch Ministry of Housing, Spatial planning and the Environment (VROM), TNO carried out a research programme in order to determine the effects of traffic congestion on exhaust gas emissions and fuel consumption of road vehicles when used on motorways. The need for information on this topic occurred when policy makers wanted to know what the benefits for emissions could be of decreasing traffic congestion by using traffic management measures. As a result an extensive research programme was executed in 1999 and 2000. Important milestones in this project were the development of test cycles that represent Dutch motorway traffic and a measurement programme in which nineteen (19) vehicles were tested in the TNO laboratory on these test cycles. Table 22 shows the congestion categories and characteristics used in the project.

Table 22 Congestion categories as used in the “Emissions and Congestion” study [24]

| Congestion category | Definition |
|---|---|
| 1aa | Speed <10 km/h; ‘stop and go’ |
| 1ab | Speed between 10 and 25 km/h |
| 1a | 1aa and 1ab combined, speed between 0 en 25 km/h |
| 1b | Speed between 25 and 40 km/h |
| 1c | Speed between 40 and 75 km/h |
| 2a | Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h |
| 2b | Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 120 km/h |
| 2c | Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 100 km/h |
| 2d | Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 120 km/h |
| 2e | Speed over 120 km/h, independent of traffic volume |
| 3 | Traffic jam ‘avoidance’ route |

4. TNO Driving Style Cycles [25]:
   In order to gain more insight into the effects of different driving styles on fuel consumption, some additional test cycles that focus on driving styles were added to the test programme as well. These driving style test cycles were developed during a research programme executed in 1999. Each of the cycles consists of an urban, a rural and a highway part.

A. Defensive driving style

This style can be characterised as the style people learn during their initial driver's courses. It does not involve any kind of sporty driving. This style could be expected to be the average way of driving, almost automatically implicating that this style would be used during a large majority of the driving performance. Although there are no actual data available regarding the actual average Dutch driving style, it has become clear during the driving style project that the average Dutch driving style will most probably differ from the defensive style used in this project. This average Dutch driving style will be situated somewhere in between defensive and sporty. This means the average driver will not be as defensive as expected, because he will drive sporty from time to time, use higher engine speeds and anticipate less than expected.

The instructions to the driver for use of the defensive driving style was accelerating with a maximum of 50% accelerator pedal position, shifting at medium engine speeds and driving in traffic with fairly constant distances to the other cars in traffic (following the traffic flow).

B. Sporty driving style

This driving style used during the investigation can be described as a style, using the performance of the car that is driven, without driving on the absolute limit (which would be dangerous and therefore punishable). It is a style people use whenever they are eager to get somewhere on time, or when they are irritated in some way. It is a driving style, which some people use incidentally, because of certain circumstances, while 'sporty' drivers use it more commonly.

The instruction to the driver for this type of driving style has been: accelerating with a maximum of 75% accelerator pedal position (if possible), shifting at high engine speeds (80% at the maximum, for petrol typically around 4500 rpm). The distances to the other traffic should be kept as short as reasonably possible (shorter than advised by the authorities, but not critically dangerous).

**The Dutch In-Use Compliance Programme**

The passenger car in-use compliance programme, that is carried out on behalf of the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM), was started in 1987 in order to obtain objective relevant data on the environmental performance of the then sold first generation of “clean” vehicles. These vehicles received a tax incentive based on the expected environmental benefits, but these benefits still had to be proven in real-world use. This basic concept of vehicles proving their actual environmental performance in real-world use, is still utilised in the ongoing programme, but with evolving vehicle technology and legislation over the years, the set-up of the in-use compliance programme has changed also. A major point that has gained importance over the years is real-world driving conditions during testing. In this respect the European Type Approval Procedure proves to be insufficiently representative for real-world driving. Therefore next to testing vehicles on the type approval procedure, additional tests are conducted to gain insight into the real-world emission behaviour of passenger cars. The data gained from testing have proved to be very useful for emission modelling purposes. Therefore gathering information on the real-world emission behaviour of passenger cars has become one of the basic targets of the Dutch in-use compliance programme.

During the seventeen years of the In-Use Compliance programme on average 150 vehicles have been tested annually.

The European type approval test, the Artemis cycles (CADC) and the Congestion cycles have been included in the Dutch In-Use Compliance programme since 2002. Therefore a fairly large database exists of emission results on these test cycles for the Dutch best selling vehicle types.

The results of the test programme will provide information on the vehicle performance in different situations. These results will also be included in the In-Use Compliance database, so that it will become even more representative for a larger part of the total Dutch vehicle fleet. If it is known in what type of application (i.e. what type of roads and speeds) the SUV is mainly used, it is possible to apply weighting factors to create a better estimation of the actual environmental effect of these SUVs.

For each vehicle, the measurements are carried out for all the mentioned test cycles, resulting in a large number of emission and fuel consumption figures for different driving conditions.

### *4.3.3 The SUVs used for the tests*

A large list of available vehicles is made and presented in Appendix A. From this list only four (4) vehicles could be selected for tests in this project (limited budget).

Due to the low number of vehicles that could be tested (also due to time and technical constraints, see Section 4.3.1), it has been decided to create SUV classes so that sufficient insight over the entire range of vehicles is obtained, rather than just selecting the top four best selling vehicles. These classes have no statistical background, but are based on matching vehicle specifications. Vehicles within the same class are assumed to have roughly the same effect on the environment, while the different classes are expected to show more distinct results. Sales figures show that the ‘smaller’ SUVs are larger in number, yet the bigger (and stronger) SUVs are expected to show a larger individual effect. The balance for the SUV fleet is to be drawn on the basis of the individual performance in combination with the number of that specific vehicle on the road.

Sales information is available from the 'Rijksdienst voor het Wegverkeer (RDW)' [26] with detailed information on the specific vehicle models that are sold. This database provides additional information on the engine and transmission types. This database contains both passenger cars and light duty commercial vehicles (according to Dutch ‘yellow’ and ‘grey’ registrations). Because it is much more detailed than for example the Autoweek car-base, it is decided only to look at the information for the years 2003 and 2004.

The environmental impact is determined by the type of SUVs in combination with the number of SUVs. It is common knowledge that petrol and diesel engines have different effects. This information specifically is distilled from the RDW sheets.

The SUVs are equipped with manual as well as automatic transmissions. The larger, more powerful and more expensive ones have an automatic (or automated) transmission. Almost all of these vehicles are equipped with permanent four-wheel drive (abbreviated with 4WD, 4x4, AWD).

Table 23 lists the vehicle models available in the RDW database. It clearly depends on the vehicle model whether it is sold more as petrol or diesel, or in both versions. When these results are averaged according to sales numbers it becomes clear that a 55-45% distribution for petrol versus diesel is present. This is also shown in Figure 26. The distribution for individual SUV models can be found in Appendix C.

Table 23 Distribution of petrol and diesel vehicles [%]

| Year → | 2003 | | 2004 (forecast) | | Total 2003 + 2004 | |
|---|---|---|---|---|---|---|
| Vehicle sales ↓ | petrol | diesel | petrol | diesel | petrol | diesel |
| Total | 79 | 21 | 77 | 23 | 78 | 22 |
| Total SUVs | 55 | 45 | 53 | 47 | 54 | 46 |

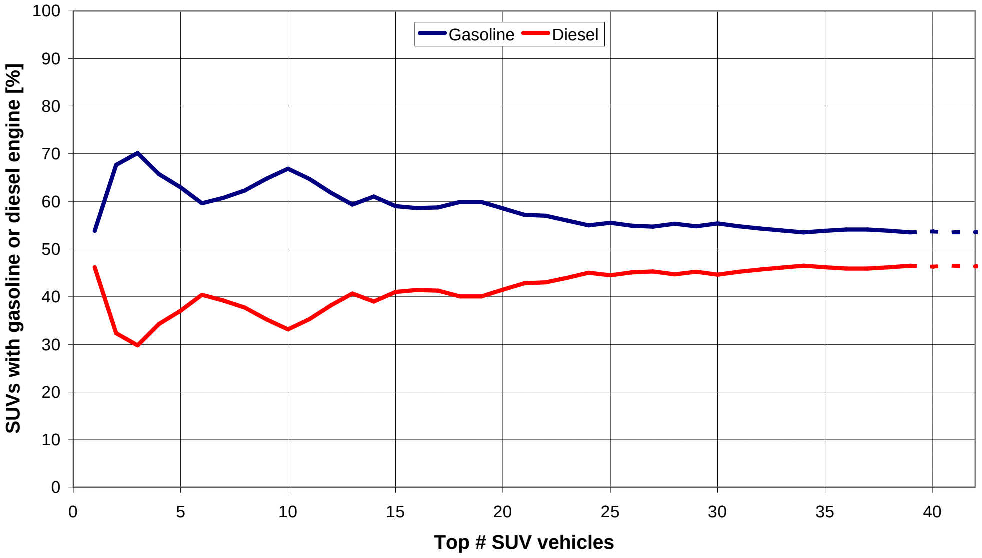


*Figure 26 – Sales weighed distribution of petrol and diesel versions*

On the basis of the technical specifications used to define and identify the SUVs in Chapter 2, the following SUV-like classes have been defined. These classes are defined primarily to have a guideline for selecting vehicles for the test. Different versions of a SUV may be placed in different classes due to the various available engine and transmission options. This especially is valid for some of the class 3 and 4 vehicles below.

1. Small SUV
Vehicles that are placed in this class have a SUV-like exterior, but are much like the average passenger car with respect to technical specifications. One might not directly regard these vehicles as a SUV due to their friendly and playful appearance. Typically these SUVs weigh about 1200 to 1500kg and their (4-in-line cylinder petrol) engine has a displacement of around 2.0L. SUVs in this class are all M1 vehicles. A few examples of these vehicles are the Honda CR-V and HR-V, Mitsubishi Pajero Pinin, Subaru Forester, Suzuki (Grand) Vitara and Toyota RAV4 (#2 best selling).
2. Medium SUV
These vehicles are regarded as a genuine SUV by appearance. Their technical specifications usually are not very excessive. Typically, they weigh about 1700 to

2000kg and have a (4 to 6 cylinder) engine with a displacement of about 2.5 to 3.5L. Most of these SUVs are category M1 vehicles, a few may be class N1 vehicles. The best selling SUVs are included in this class. Examples are the Kia Sorento (#1 best selling), Hyundai SantaFe (#3 best selling), Jeep Cherokee and LandRover Freelander.

3. Large SUV
Luxury SUVs with a more eye-catching appearance than the Medium SUV. These SUVs weigh about 2000-2300 kg with a 3.0 to 4.0 L engine (usually 5 or 6 cylinders). Most of these SUVs are N1 vehicles, only a few may still classify as M1 car. Examples are the BMW X5 (#5 best selling), Mercedes M, Chrysler Pacifica, Volkswagen Touareg and Volvo XC90 (#4 best selling).
4. Extra Large SUV
Very large and powerful SUVs are placed in this class. The weight of these vehicles is above 2000 kg, starting at the same level as class 3 SUVs. Typically, the engines have higher displacement than those of class 3 vehicles. It usually is an 8-cylinder engine with a displacement of more than 4.0L, even up to almost 7L. All of these vehicles classify as N1 vehicles. Some examples are the Chevrolet Tahoe, Ford Expedition, LandRover RangeRover, Hummer, Porsche Cayenne S or Turbo.

One vehicle from each of these classes has been selected. Because the research concentrates on the total impact of SUVs on the Dutch environment, it has been decided not to use brand and model names to identify the SUVs that have been used. Instead, the vehicles are labelled according to the vehicle class (Table 24).

Only petrol vehicles are selected to be able to make a comparison between the classes and because powerful diesel engines are likely to give a problem in the facilities at this moment (will be possible in 2005).

The vehicles that are used for the tests are not new. It is chosen to use vehicles that have been used for about 10.000 to 30.000 kilometres so that the catalyst has passed the initial ageing effect and operates normally.

Table 24 Indicative specifications of SUVs used for the testing (values are rounded)

| | SUV1 | SUV2 | SUV3 | SUV4 |
|---|---|---|---|---|
| Origin | Asia | Asia | EU | US |
| Model year | 2004 | 2003 | 2003 | 2003 |
| Mass | 1200 kg | 1800 kg | 2100 kg | 2500 kg |
| GVW | 1800 kg | 2450 kg | 2800 kg | >3000 kg |
| Size | 4.0 x 1.75 x 1.70 m | 4.5 x 1.85 x 1.70 m | 4.8 x 1.90 x 1.70 m | 5.6 x 2.0 x 1.90 m |
| Emission class | Euro 3 | Euro 3 | Euro 3 (N1 Class III) | US EPA MY2003 |
| Engine configuration | 4L | 4L | 6L | V8 |
| Engine displacement | 2 L | 2.5 L | 3 L | 5 L |
| Engine power | 90 kW | 100 kW | 200 kW | 220 kW |
| Transmission | manual 5-speed | manual 5-speed | automatic 4-speed | automatic 4-speed |

## 4.4 Test results and analyses

In this section the results of the measurement programme are presented and analysed. First the results on the European type approval test are given, and then the results on the real-world cycles per emission component are displayed. In the last section the effects on fuel consumption and $CO_2$-emission will be analysed.

Since only four cars were tested it is not possible to do a statistical analysis of the performance of these cars. It is known that the individual results may spread a lot. Instead, it was chosen to give an impression on how the individual SUV results compare to the individual ‘other cars’ results. These ‘other cars’ are regular passenger cars selected for the In-Use Compliance programme on the basis of sales numbers.

### *4.4.1 Results on the European type approval test*

Because all passenger cars sold in 2003 and 2004 are from the Euro 3 and Euro 4 legislation category, the results of the SUVs will be compared with the results from these vehicles as obtained in the Dutch In-Use compliance programme.

Figures 27 and 28 show the results of the SUVs tested on the EDC. The SUVs have been subdivided into Euro 3 M1 type approved cars and Euro 3 N1 Class III[3] type approved cars.

As can be concluded from these figures, all SUVs complied very well to the Euro 3 limits. Two SUVs complied with Euro 4 on HC and $NO_x$, and one SUV complied with Euro 4 on all three emission components. In order to maintain readability of these figures, the Euro 3 N1 Class III limits were not visualised.

These figures also show that the values measured for the SUVs are slightly on the outside of the range of the Euro 3 passenger cars that have been tested in the In-Use Compliance programme in recent years. From this sample, it cannot be concluded however that the less strict emission limits for the heavy petrol SUVs (N1 class III/3) result in increased emissions on the European type approval test.

---

[3] Although the ‘grey import’ SUV with US origin did not have an official EU Euro 3 type approval, it was added to the Euro 3 N1 Class III SUV (GVW > 2500 kg) throughout this section for reasons of clarity.

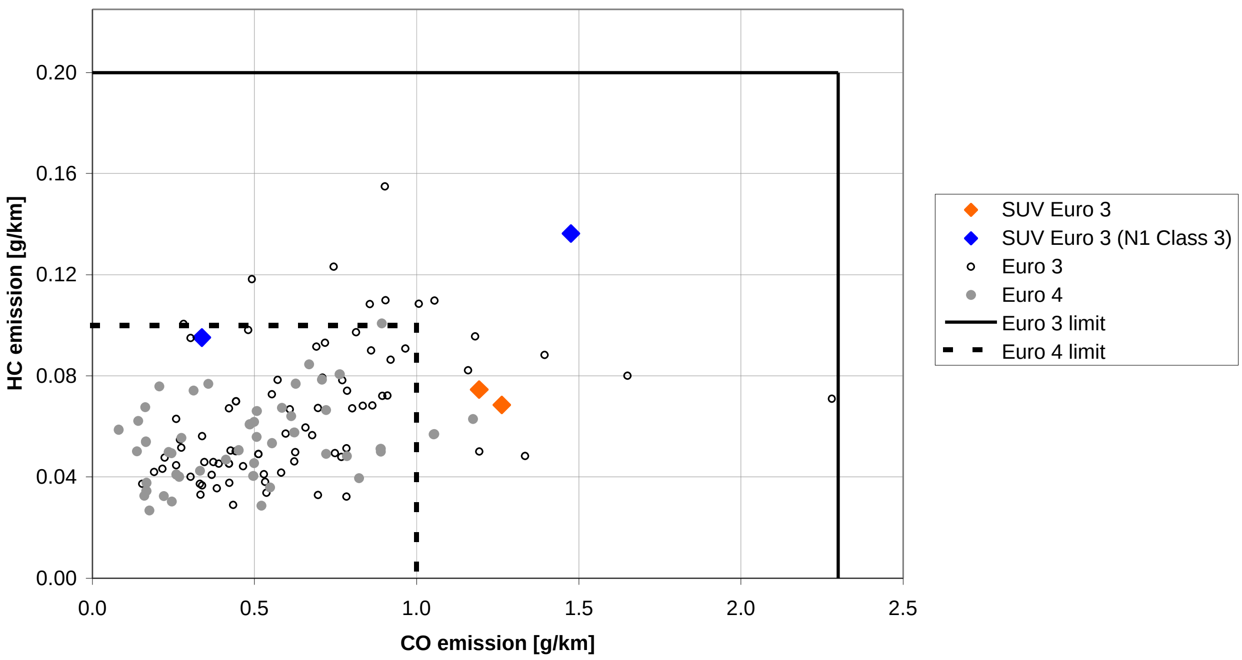


*Figure 27 – Results of SUVs, Euro 3 and Euro 4 passenger cars on the European Driving Cycle: CO vs. HC*

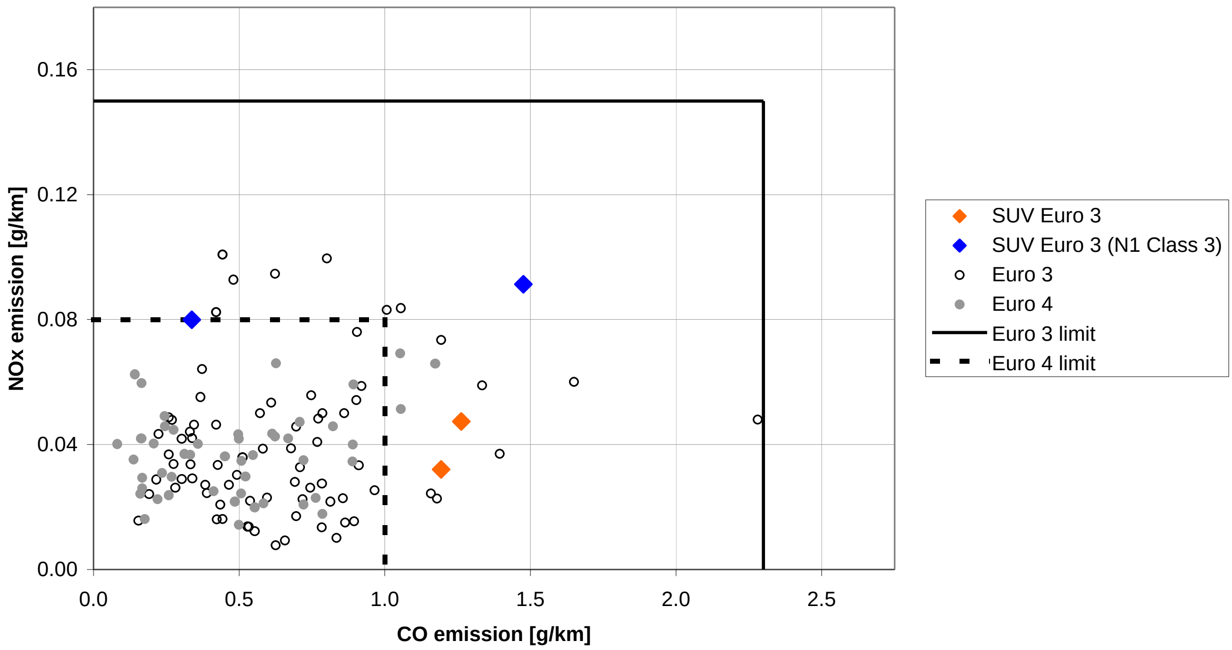


*Figure 28 – Results of SUVs, Euro 3 and Euro 4 passenger cars on the Eurotest: CO vs. NO$_x$*

### 4.4.2 NO$_x$, HC and CO emission results on real-world driving cycles

This section presents the results for the three regulated exhaust gas components: NO$_x$, HC and CO. The fourth regulated component PM is not applicable for petrol vehicles and therefore not present in the analyses.

Figures 29 through 34 show the results for the three types in the Artemis (CADC) and Congestion driving cycles (Table 25). Each of the figures contains the values for the following:

- SUV Euro 3 : SUV 1 and 2
- SUV Euro 3 (N1 class 3) : SUV 3 and 4
- Euro 3 : Euro 3 vehicles in In-Use Compliance database
- Euro 4 : Euro 4 vehicles in In-Use Compliance database
- Euro 3 average and deviation : The average value ±½ standard deviation for the Euro 3 vehicles in the In-Use Compliance database (included to give an impression on the statistical variation around the measured averages)

Table 25 $NO_x$, HC and CO results figures

| Figure number | Emission component | Driving cycle |
|---|---|---|
| 29 | $NO_x$ | Artemis |
| 30 | $NO_x$ | Congestion |
| 31 | HC | Artemis |
| 32 | HC | Congestion |
| 33 | CO | Artemis |
| 34 | CO | Congestion |

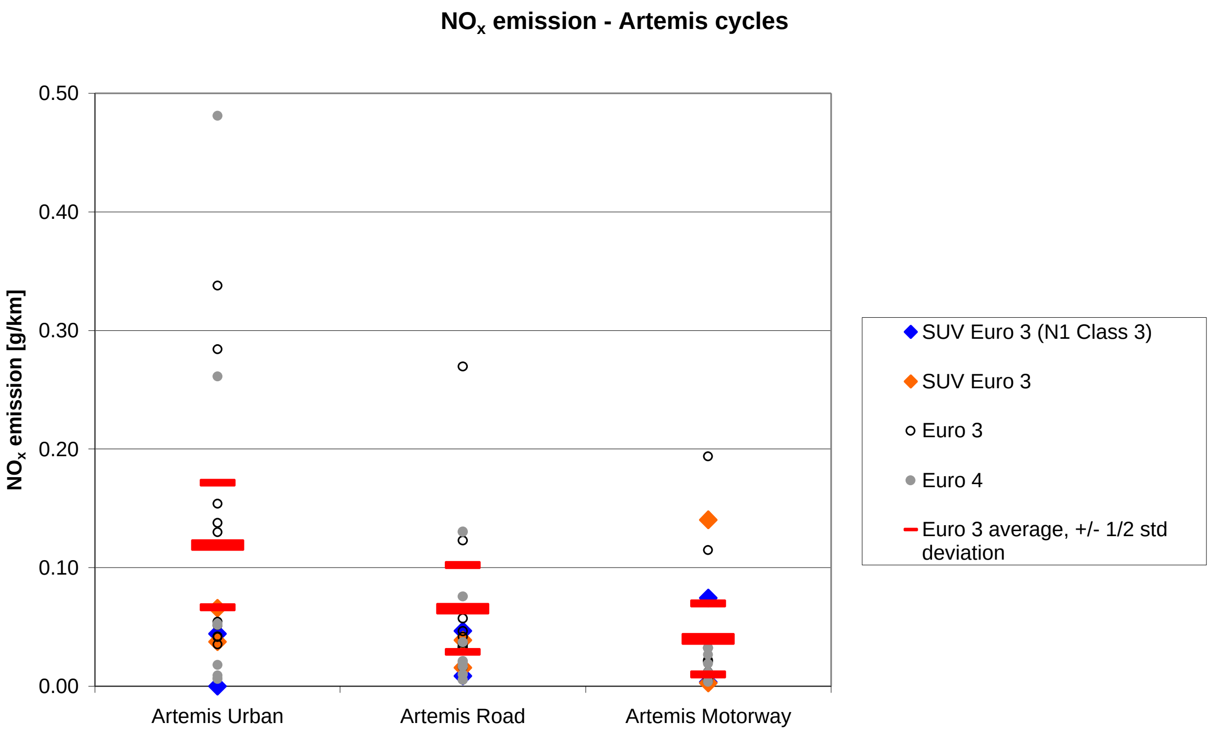


*Figure 29 – $NO_x$ results of SUVs, Euro 3 and Euro 4 passenger cars on the Artemis cycles compared to the Euro 3 average (±½ standard deviation)*

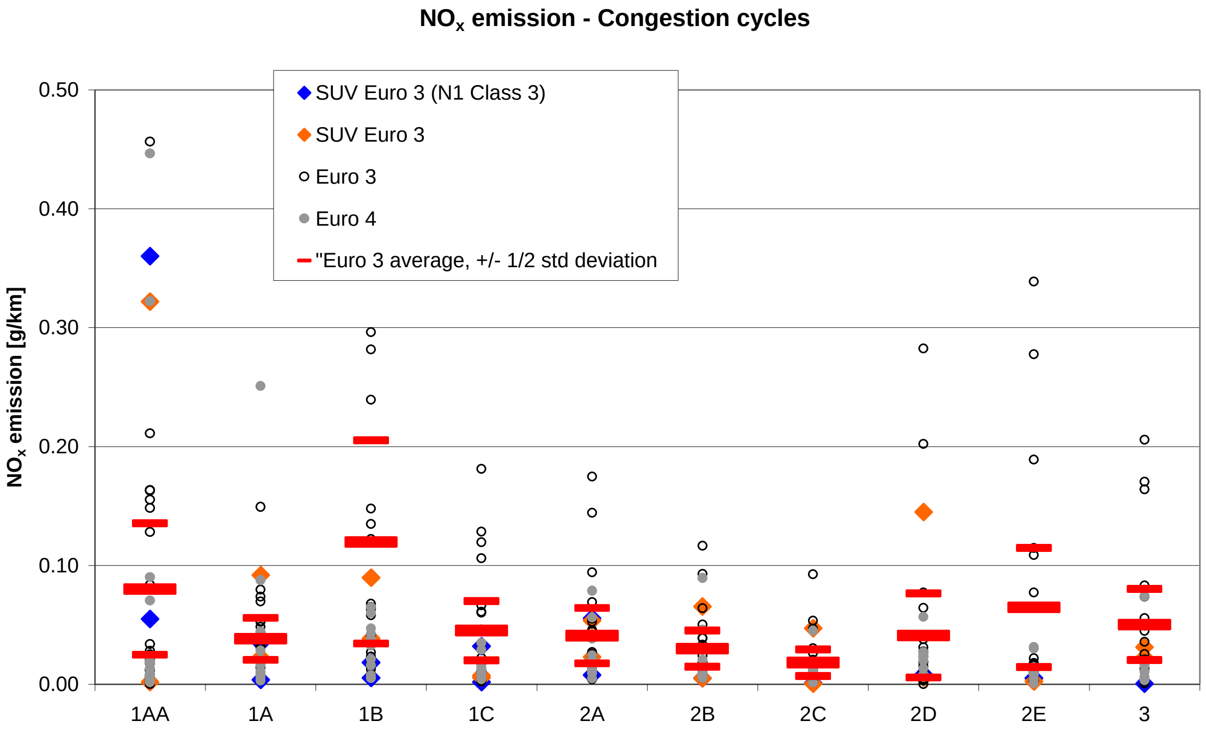


*Figure 30 – NO$_x$ results of SUVs, Euro 3 and Euro 4 passenger cars on the Congestion cycles compared to the Euro 3 average (±½ standard deviation)*

These figures show that, for each of the exhaust gas components, the tested SUVs perform well within the same range as the other cars that are tested. Hence, no exceptional behaviour is found for these SUVs. Compared to the Euro 3 averages, these four SUVs produce both more and less emissions, making them no worse (nor better) than other cars.

A few outliers can be distinguished in some of the figures. These can be explained though and form no extraordinary peaks.

NO$_x$ emissions

In Figure 30, two of the tested SUVs (one from each class) show values well outside the Euro 3 deviation bandwidth. On the other side, their values are still considerably lower than several regular passenger cars, so no alarm bells necessary.

HC emissions

On the Artemis highway cycle (Figure 31) one vehicle shows a value that is outside the range of measured values. The variation on this cycle is quite high in general already.

CO emissions

On the Artemis road and highway cycles (Figure 33) as well as on the Congestion 2E driving cycle (Figure 34), one vehicle showed an emission result that was well outside of the range of measured values. The plausible cause for these results is full load fuel mixture enrichment as this SUV has little or no power reserve anymore at several moments on these driving cycles. In other words, the engine had to ‘work’ very hard to deliver the power needed on these driving cycles.

Especially vehicles that have a low power-to-mass ratio (as does this one) may suffer from these enrichment effects, causing the combustion process to become more polluting. This occurs for many vehicles on cycles with highly dynamic driving at medium and higher speeds or whenever the accelerator pedal is completely pushed down.

Although the value is exceptionally high, it is considered to be an occasional outlier, as the other (tested) SUVs and (database) passenger cars do not show this behaviour.

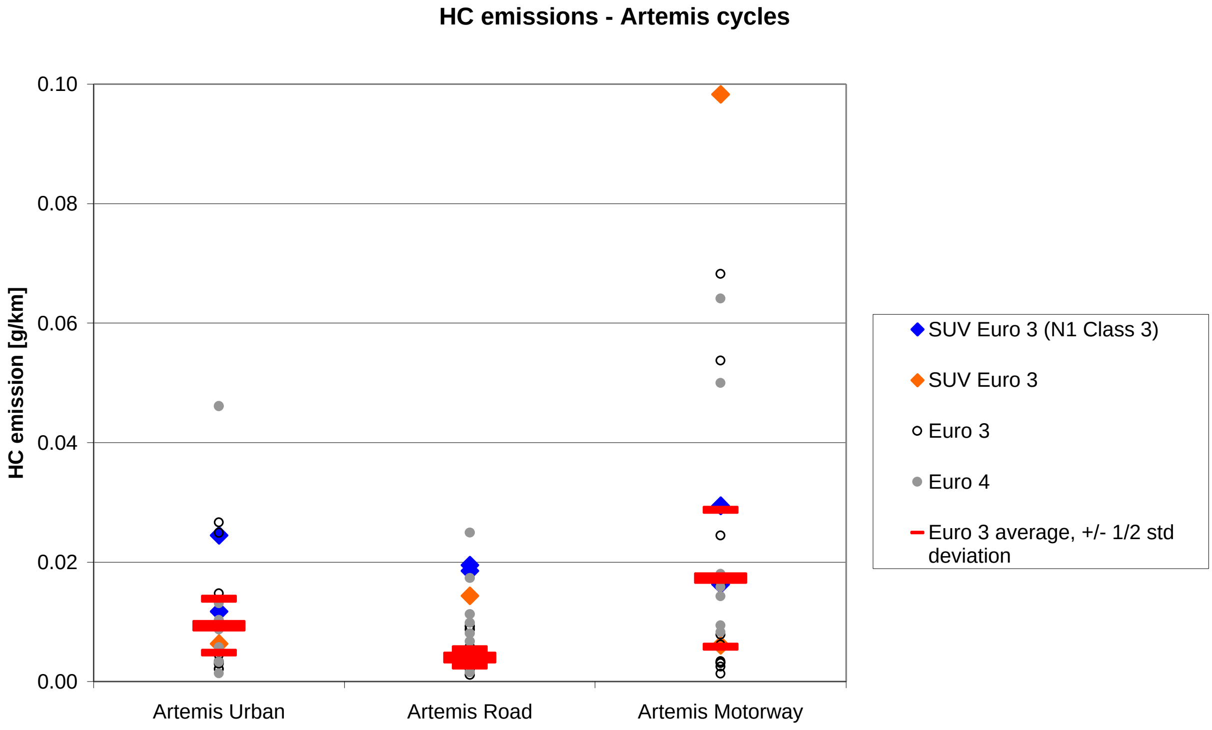


*Figure 31 – HC results of SUVs, Euro 3 and Euro 4 passenger cars on the Artemis cycles compared to the Euro 3 average (±½ standard deviation)*

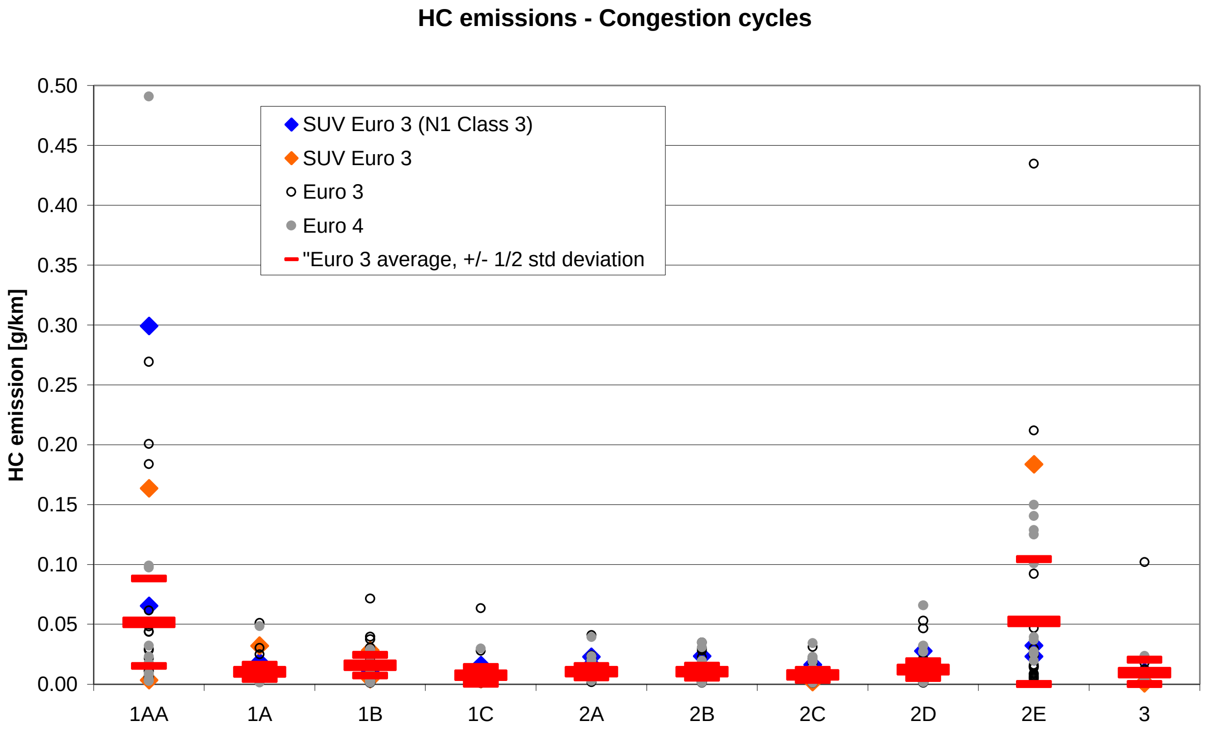


*Figure 32 – HC results of SUVs, Euro 3 and Euro 4 passenger cars on the Congestion cycles compared to the Euro 3 average (±½ standard deviation)*

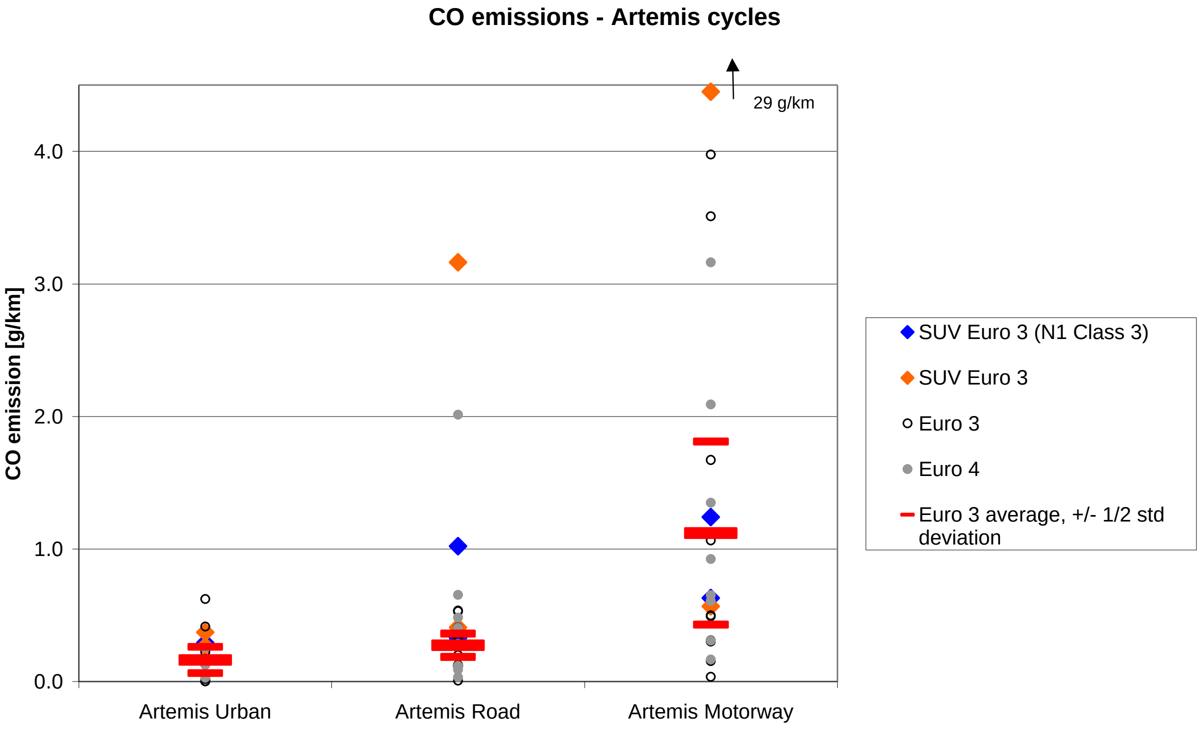


*Figure 33 – CO results of SUVs, Euro 3 and Euro 4 passenger cars on the Artemis cycles compared to the Euro 3 average (±½ standard deviation)*

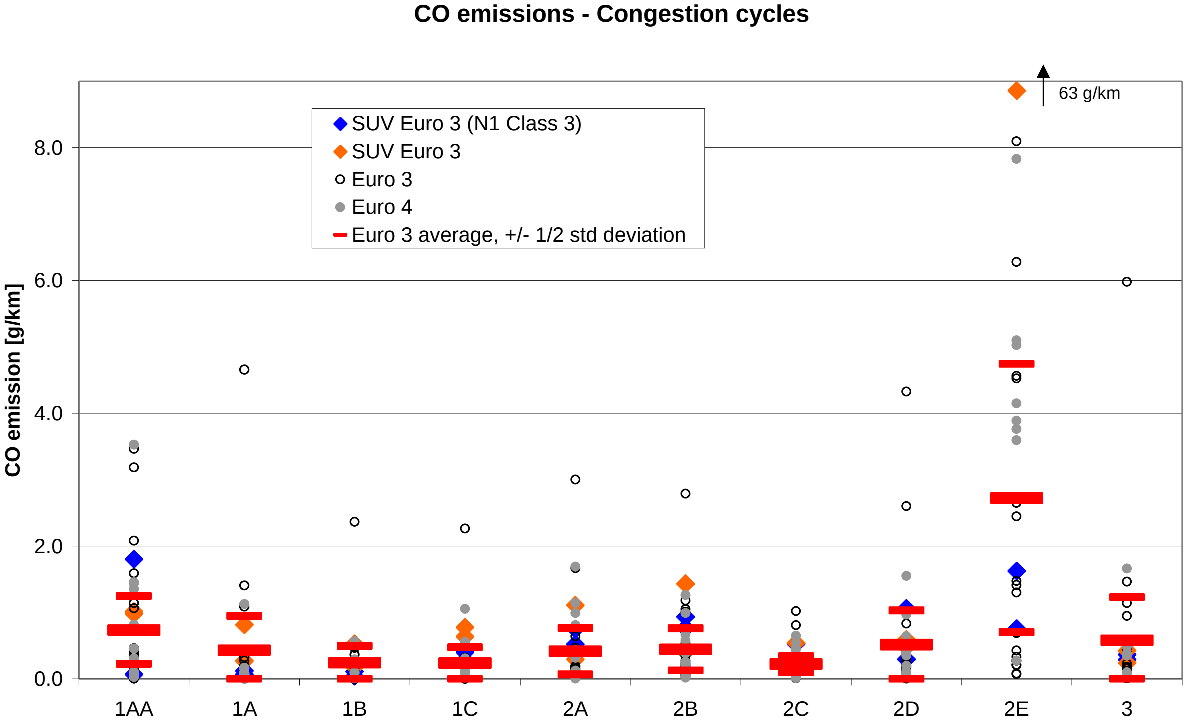


*Figure 34 – CO results of SUVs, Euro 3 and Euro 4 passenger cars on the Congestion cycles compared to the Euro 3 average (±½ standard deviation)*

### 4.4.3 $CO_2$ *and fuel consumption results on real-world cycles*

The $CO_2$ emission and fuel consumption of a certain vehicle are directly related to each other. Therefore, the results on both aspects are described in this section. The main question to be answered here is:

*How do fuel consumption and CO2 emissions of SUVs compare to those of vehicles that are a realistic non-SUV alternative for the user?*

Because fuel consumption and $CO_2$ emission are also directly related to specific characteristics of a vehicle, such as weight, frontal area and the air drag coefficient, it is impossible to compare the results of the SUVs directly to the vehicles that are already tested in the In-Use Compliance programme. In the In-Use Compliance programme the vehicle selection is based on sales volume, and as a result no vehicles are present in the database that are directly comparable to SUVs. That is why the comparison has been based on the results of model runs (simulation) for the calculation of $CO_2$ emissions for cars that are a realistic non-SUV alternative for the SUVs that have been tested here. Examples of alternatives for the SUVs are shown in Table 26. The choice of these examples is arbitrary, but the aim here is to obtain an impression of the characteristics (especially weight) that possible alternatives would have, and not to identify the exact alternative.

Table 26 Overview of possible alternative passenger cars for the SUVs tested

| | Non-SUV alternative (examples) | Version | Catalogue starting price [Euro] |
|---|---|---|---|
| SUV 1<br>list price: 25.000 Euro<br>weight: 1200 kg | Audi A3 | 1.6 litre | 24.000 |
| | BMW 1-series | 116i | 25.000 |
| | Mini | Cooper | 21.000 |
| | Peugeot 206 CC | 2.0 litre | 24.000 |
| | average weight: | 1150 kg | |
| SUV 2<br>list price: 29.000 Euro<br>weight: 1800 kg | Ford Mondeo Wagon | 1.8 125 HP | 27.000 |
| | Toyota Avensis Wagon | 2.0 litre | 29.000 |
| | Opel Zafira | 2.2 litre | 27.000 |
| | Volkswagen Touran | 2.0 litre | 30.000 |
| | average weight: | 1400 kg | |
| SUV 3<br>list price: 65.000 Euro<br>weight: 2100 kg | Audi A6 Avant | 3.0 Quattro | 64.000 |
| | BMW 5-series Touring | 525i | 61.000 |
| | Mercedes E-class Combi | E320 | 67.000 |
| | Volvo V70 | 2.5 T5 | 57.000 |
| | average weight: | 1600 kg | |
| SUV 4<br>list price: 55.000 Euro<br>weight: 2500 kg | Chrysler Grand Voyager | 3.3 litre | 54.000 |
| | Renault Grand Espace | 3.5 litre | 56.000 |
| | Mercedes Viano | 3.0 litre | 52.000 |
| | Volkswagen Multivan | 3.2 litre | 59.000 |
| | average weight: | 2000 kg | |

As can be seen in this table, apart of SUV 1, the weight increase of ‘large SUVs’ ranges from 400 to 500 kg. SUV 1, which is more closely based on a passenger car, only has a weight increase of about 50 kg.

Artemis cycles

To compare the effect on fuel consumption, the fuel consumption and $CO_2$ emission of the reference cars (Euro 3 passenger car) have been modelled using the empty weights of 1150, 1400, 1600 and 2000 kg. The differences between the modelled passenger car values and the measured SUV values on the Artemis test cycles are displayed in Figure 35.

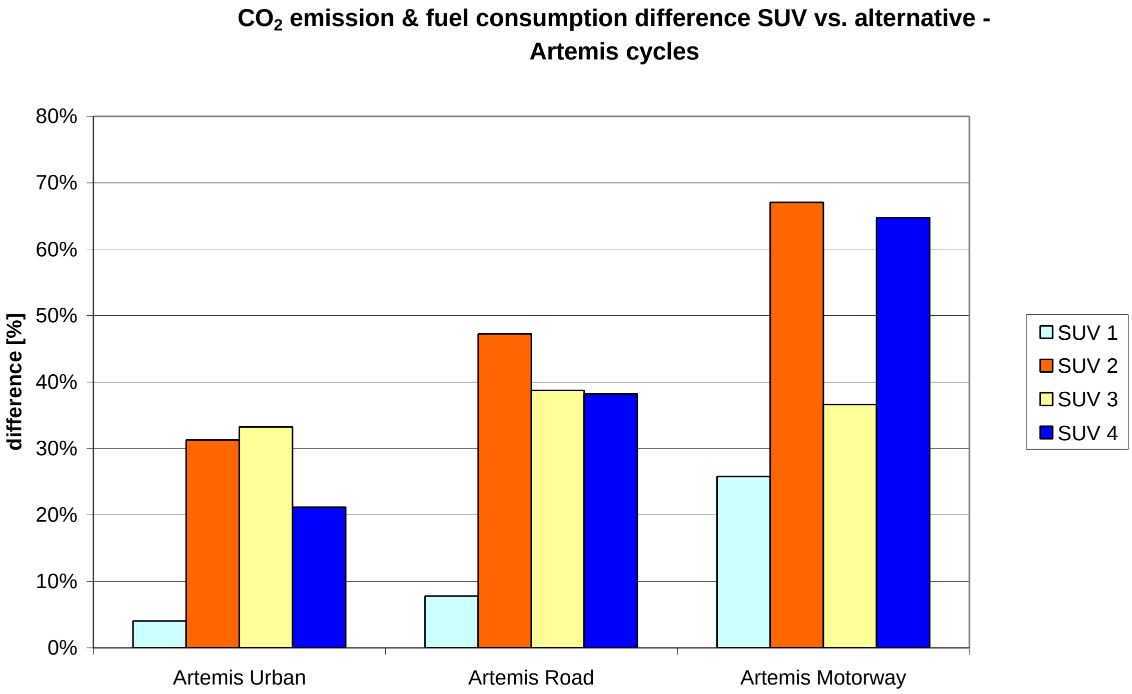


*Figure 35 – $CO_2$ and fuel consumption difference of SUVs versus alternative passenger cars, Artemis cycles*

For the small SUV 1, which has a small weight difference compared to the ‘alternative’ and is two wheel drive only, the increase under urban low speed conditions remains relatively small. On test cycles with higher vehicle speeds (road and motorway) the difference increases, which can be explained by the fact that SUVs generally have a larger frontal area and a worse air drag coefficient than passenger cars. These parameters are strong determinants for fuel consumption at higher speeds.

The same is valid for SUVs 2, 3 and 4 that have a larger weight difference compared to their alternatives. These SUVs have a fuel consumption increase ranging from 20 to 35%. At higher speeds, the differences are 35 up to 65%. It is remarkable though that the increases for SUV 3 remain at a relatively constant level between 30 and 40%.

Congestion cycles

Fuel consumption has also been measured on the Congestion test cycles. Three different typical Dutch highway traffic situations have been composed that consists of the individual congestion driving cycles:

1. Situation with strong congestion
2. Peak hour average composition for the Dutch ‘Randstad’
3. Daily average composition for all Dutch highways

These compositions, see table below, have been derived from the ‘Emissions and Congestion’ research [24].

Table 27 Compositions of Dutch highway traffic in various situations

| Congestion cycle | strong congestion | peak hour average 'Randstad' | Dutch highway average |
|---|---|---|---|
| 1AA & 1A | 9.4% | 4.7% | 0.9% |
| 1B | 6.9% | 5.0% | 1.1% |
| 1C | 21.1% | 17.2% | 5.3% |
| 2A | 32.3% | 22.9% | 1.4% |
| 2B | 2.8% | 35.1% | 1.2% |
| 2C | 27.5% | 4.3% | 26.2% |
| 2D | 0.0% | 9.5% | 60.7% |
| 2E | 0.0% | 1.3% | 3.2% |

The differences between the modelled passenger car values and the measured SUV values on these traffic/congestion compositions are displayed in the Figure 36.

Basically the same picture emerges here as for the Artemis driving cycles, SUV 1 shows the lowest increases, SUV 2, 3 and 4 show differences in the range of 25 to 55% and the differences increase at higher speeds. Again, SUV 3 remains remarkably stable.

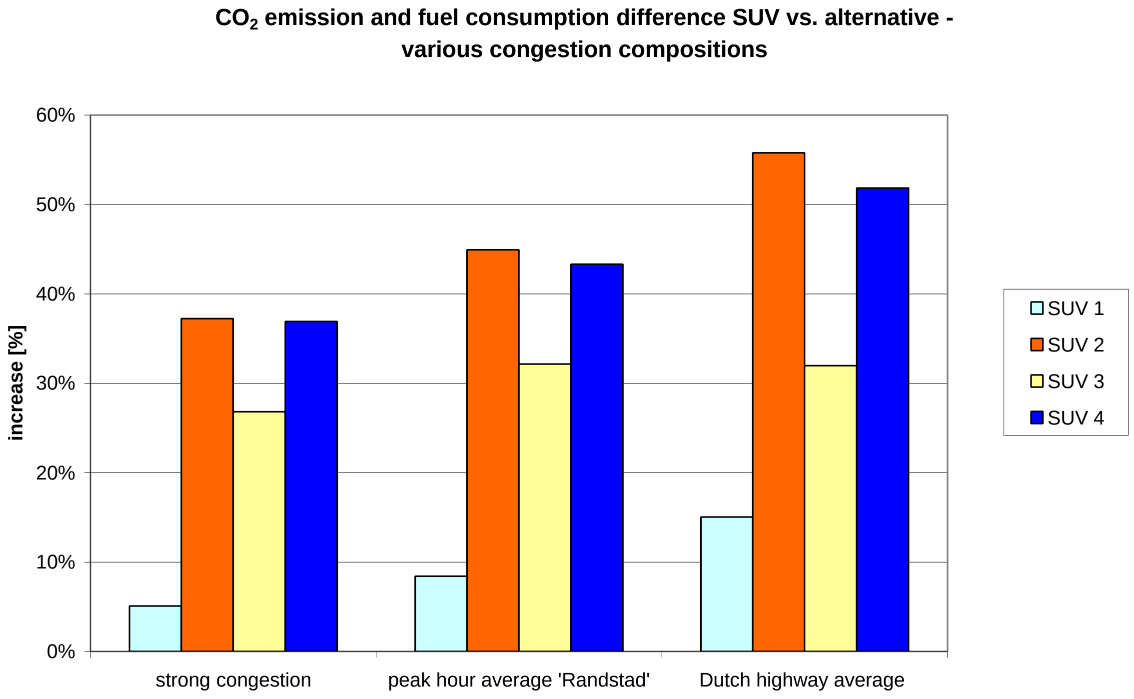


*Figure 36 – $CO_2$ and fuel consumption difference for SUVs versus alternative passenger cars; various compositions of Dutch highway traffic*

<u>Driving Style cycles</u>

The SUVs have also been tested on a set of driving cycles representing ‘defensive’ and ‘sporty’ driving behaviour. In Figure 37, the increase of fuel consumption and $CO_2$ emission of the sporty driving style compared to the defensive driving style is shown.

This figure shows that the effects of a sporty driving style on fuel consumption are the strongest in urban situations, where the increase varies between 35 and 90%. Under rural conditions the increase is also quite high, ranging from 20 to 35%. The smallest effects were observed under highway conditions, with increases of only 2 to 10%.

Because of the large variety of SUVs and non-SUV alternatives and also the conditions under which SUVs are used it is very difficult to draw general conclusions about the fuel consumption (and $CO_2$ emissions) of SUVs in comparison to a non-SUV alternative. Two observations can be made however:

- at low vehicle speeds, the increased weight and the, in most cases, four wheel drive system of SUVs can increase the fuel consumption up to about 40%
- at higher vehicle speeds, the fuel consumption increase can add up to 65% due to the larger frontal area and worse air drag coefficient.

In Appendix D some additional aspects of the difference and large variety of issues that may affect the comparisons of different types of vehicles are discussed.

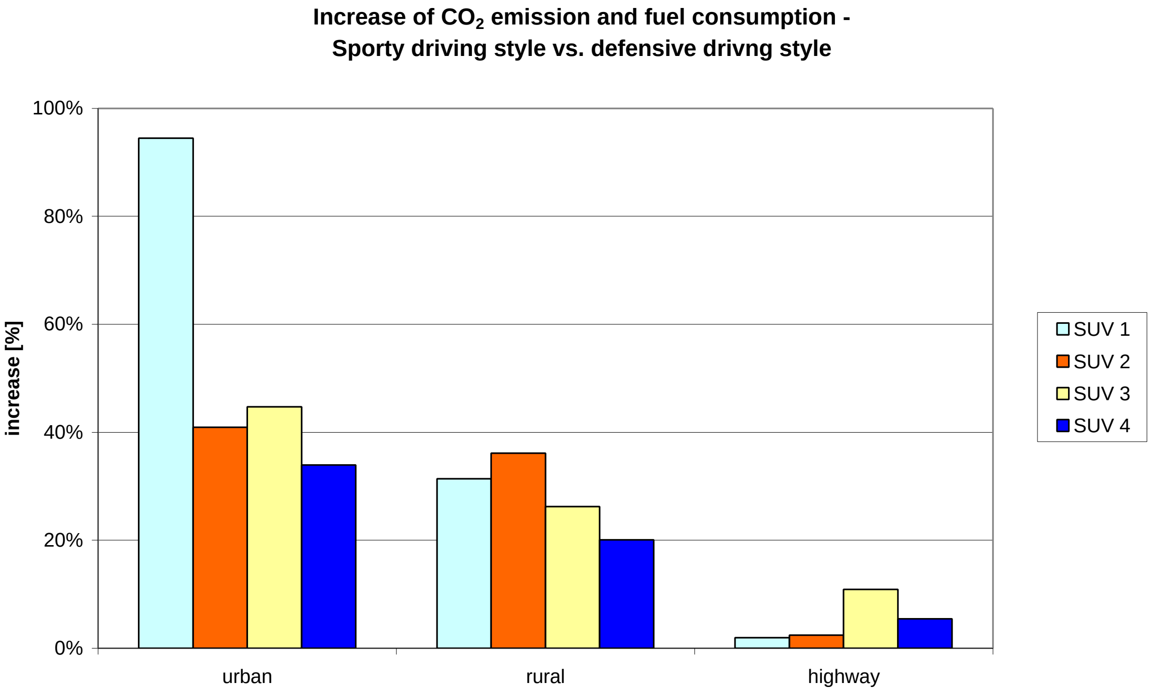


*Figure 37 – $CO_2$ and fuel consumption increase of SUVs on sporty driving style compared to defensive driving style*

## 4.5 Advanced powertrains

Advanced powertrains are being developed for or are already applied in many types of transportation means today, varying from bicycles to passenger cars and trucks to boats. Most of these powertrains incorporate an electric motor, but also e.g. mechanical and hydraulic hybrids are under investigation. Currently the most widely used advanced powertrains for vehicles are based on full electric, hybrid electric or fuel cell technology. In this report a brief overview, with advanced powertrain technology and recent applications that already have been or will soon be introduced to the market, is given on the basis of [26].

### *4.5.1 Why advanced powertrains are being developed*

Worldwide the population and total energy use are increasing. The use of world resources therewith also increases and the (known) available supplies decrease rapidly. High energy use as well as high production of emissions are reasons to investigate options that can reduce the total environmental load. These reasons not necessarily need to be averaged in the worldwide perspective. Local conditions like in densely populated communities or industrial areas also need to remain well below health risk levels.

The transportation sector is (regarded) one of the largest contributors to energy use and pollution. Much effort is put into research to decrease the total energy demand of transportation means. The application of advanced powertrains results in an increase of system efficiency and thus lowers the energy use. The basic principles that account for this result are:

- (more) optimal operation of individual components; it is possible to prevent (extremely) low efficiency operation
- regenerative braking; recuperate the energy otherwise lost during braking (friction brakes) and store it for later use (e.g. acceleration)

Many different systems are being investigated, yet a winning technology has not been found yet. Hybrid technology (see Appendix E for more detailed descriptions) that combines the conventional powertrain with electric propulsion seems to be the most promising technology for the short and near term period. Currently developed systems often are more expensive and not ready for large-scale production. The (renewable) hydrogen economy that is regarded to be the solution requires a completely improved infrastructure on top of the technological developments that rapidly take place.

### *4.5.2 SUVs and hybrid technology on the market*

In Appendix E some examples of hybrid technology in applications are already given. Among these, some vehicles can be found that clearly classify as SUV. It can easily be concluded that SUVs being popular models and the large space available for alternative systems, make the SUV a suitable platform for demonstrating technologies.

Several manufacturers have announced the market introduction of some hybrid SUVs, mainly in the United States. The first are the Chevrolet Silverado Hybrid [28] and GMC Sierra Hybrid, the Ford Escape Hybrid [29] and the Lexus RX400h [30] (see Figure 38 for specifications).

| | | |
|---|---|---|
| Chevrolet Silverado (General Motors) | Ford Escape (Ford) | Lexus RX400h (Lexus/Toyota) |
| mild parallel hybrid | combined hybrid | combined hybrid |
| 5.3L V8 petrol engine | 2.3L L4 petrol engine | 3.3L V6 petrol engine |
| 10kW electric machine | 65kW electric machine | 123kW electric motor (front) |
| | | 50kW electric motor (rear) |
| $30.000,= | $28.000,= | price estimate not available |
| SULEV rating | SULEV&AT-PZEV rating | SULEV&AT-PZEV (expected) |

*Figure 38 – Chevrolet Silverado Hybrid, Ford Escape Hybrid, and Lexus RX-400h Hybrid system specifications*

#### *4.5.2.1 Emissions*

Hybrid powertrains are installed in new vehicles. Current emission legislation for new vehicles already demands that exhaust emissions are very clean. In the United States of America, two organisations have defined the standards: the Environmental Protection Agency (full US coverage) and the California Air Resources Board (CARB, mainly California and some other North-eastern states). These organisations have defined various classes to qualify the emissions of new vehicles.

In Figure 38, it is shown that all three vehicles qualify as SULEV (Super Ultra Low Emission Vehicle). This is a classification according to the CARB standards and corresponds to the Tier 2 bin2 from the EPA standards. The Ford and Lexus even qualify as AT-PZEV (Advanced Technology – Partial Zero Emission Vehicle), which indicates that emission are even lower than SULEV and that (even more) special technology has been applied.

Concluding, these emission ratings mean that these SUVs produce extremely low emissions and that they are (among) the cleanest vehicles available. Only one more additional rating is defined: Zero Emission Vehicle (currently applies to battery electric vehicles and -hydrogen- fuel cell vehicles only).

#### *4.5.2.2 Fuel consumption*

The conventional SUVs are quite often referred to as ‘gas guzzlers’ and it is true that they consume more fuel than the average passenger car (as is found in Section 4.4.3). Basically, two hybrid systems can be distinguished in the (available) SUV models. The parallel hybrid configuration as used in the General Motors models and the combined hybrid system as used by Ford and Toyota/Lexus.

The hybrid powertrain in the SUVs is guaranteed to lower the fuel consumption with respect to the conventional counterpart. The potential gain depends on the applied system. Mild hybrids have lower potential than full hybrids.

For the Chevrolet Silverado Hybrid, General Motors (GM) claims a fuel consumption reduction of 10-15% over the conventional petrol version (in actual use). The combined city and highway test results in a combined fuel economy improvement of 7-9% according to the EPA Green Vehicle Guide [11]. GM’s design philosophy here is that uncompromised performance needs to be at hand in this market segment (light trucks). Downsizing of the engine would for instance result in decreased towing performance.

According to the same database, a fuel economy improvement is found for the (smaller SUV) Ford Escape Hybrid of around 60 to 70 and 25 to 30% for the city and highway cycles respectively, giving a combined result of 45-55%. No rating is available for the Lexus RX model, but it can be assumed that it corresponds to the Ford numbers (because of similar powertrain systems). The fuel economy results for the Ford Escape Hybrid even show values that are better than the values for regular conventional passenger cars. The Toyota Prius and the hybrid version of the Honda Civic are the only already commercially available hybrid vehicles on the market. These both show significant reductions in fuel consumption with respect to their conventional alternatives.

Table 28 US EPA Fuel consumption ratings [miles per gallon (mpg)]

| | Chevrolet Silverado | | | | Ford Escape | | | |
|---|---|---|---|---|---|---|---|---|
| | 2WD | | 4WD | | 2WD | | 4WD | |
| | Conv. | Hybrid | Conv. | Hybrid | Conv. | Hybrid | Conv. | Hybrid |
| City | 16 | 18 | 15 | 17 | 22 | 36 | 19 | 33 |
| Highway | 20 | 21 | 19 | 19 | 25 | 31 | 22 | 29 |
| Combined | 17.6 | 19.2 | 16.6 | 17.8 | 23.3 | 33.6 | 20.2 | 31.1 |
| Increase | +9.1% | | +7.2% | | +44.2% | | +54.0% | |

With respect to fuel consumption it can be concluded that SUV hybrids can significantly reduce the energy requirement and thus limit or even eliminate the negative effect of a larger and heavier vehicle with respect to a more common (non-hybrid) passenger car model. A hybrid passenger car can and most likely will have a lower fuel consumption than a hybrid SUV.

### 4.5.2.3 *Availability and market share*

At this moment it is unknown whether the Chevrolet and Ford models will become available in Europe. Currently, the high end Lexus SUV is expected in 2005. Several more hybrid SUV models have been announced for 2005 and after. Most of these are US models and it remains to be seen whether these will be made available in Europe.

A very low number of hybrid SUVs therefore will probably be available on the European market. In The Netherlands, vehicles like the Ford Escape and Lexus RX are more likely to get market share than a Chevrolet Silverado. This is based upon the size of the vehicles, where the latter according to Dutch measures might sooner be qualified as a truck rather than a SUV.

In The Netherlands the regulations are currently set up so that no BPM-tax[4] needs to be paid for hybrid vehicles. This positive stimulation is done because of the environmentally friendly performance of these hybrids in comparison to similar

---

[4] BPM = Belasting Personenauto’s en Motorrijwielen

conventional vehicles. During the past years, no road tax was required either. The latter now has been changed so that the somewhat heavier vehicles are taxed according to their conventional version weight class.

A large market share for hybrid SUVs cannot be expected, basically as there is very little offer. This makes it basically even less plausible that hybrid SUVs might obtain an effective market share.

## 4.6 Conclusions and recommendations

The impact of SUVs on the Dutch environment is discussed in detail in the previous sections. This section presents the overall conclusions and recommendations with respect to this part of the research.

The impact of vehicles on the environment results from the cumulative value of exhaust gas emissions and fuel consumption of all individual vehicles. For every type of vehicle, its emissions are related to applied engine technology, driving behaviour, total distance travelled and location of emission (urban area, highway, etceteras).

The most harmful, and regulated, emission components are carbon-oxide (CO), hydrocarbon (HC), nitrogen oxides ($NO_x$) and particulate matter (PM). These components effect local air quality and have direct influence on human health and ecological situation. Another major component is the output of carbon-dioxides ($CO_2$) that is a greenhouse gas and as such has a global effect. $CO_2$-emissions and fuel consumption are directly related to one another.

With respect to the regulated emissions CO, HC, $NO_x$ and PM (human health and ecological condition) the following conclusions are drawn:

1. On the basis of current regulations for vehicles, no worse emission behaviour is expected of SUVs as compared to other passenger cars (M1 class vehicles). All vehicles have to meet the same emission regulations. However, the heavier vehicles with a Gross Vehicle Weight (GVW, empty weight plus maximum payload) above 2500 kg (N1 class II and III) are subject to wider limits. This class can possibly emit more than ‘regular’ passenger cars.
2. The test results of four SUVs with petrol engines show that the N1 vehicles also easily satisfy the legislative emission limits for M1 vehicles. In real-world driving cycles, no increased emissions are observed when compared to ‘regular’ passenger cars. A few outliers are present, but these can also occur when testing a ‘regular’ passenger car. The SUVs (tested) thus do not pollute more than ‘regular’ passenger cars.
3. The statistical value of the SUV test results is very limited due to the low number of vehicles in comparison to the spread that is known to occur.

With respect to fuel consumption and $CO_2$-emissions (climatic effect) the conclusions are:

1. No legislation on fuel consumption or $CO_2$-production exists. Instead a covenant between the EU commission and the vehicle manufacturers has been agreed upon that includes a vehicle fleet average for newly sold vehicles of class M1 (‘regular’ passenger cars) for $CO_2$-emission of 140 g/km by the year 2008. N1 class vehicles thus are not included in this covenant.

2 $CO_2$ and fuel consumption are strongly related to vehicle parameters like mass and air drag resistance (combination of frontal area and coefficient of drag). In SUVs the (usually present) four-wheel drive system also contributes to additional energy use. These parameters show a negative influence for comparisons of SUVs and their non-SUV alternatives. Consequently, a higher fuel consumption and $CO_2$-emission can be expected for SUVs.
3 The test results for the four petrol SUVs confirm that fuel consumption and $CO_2$-emission are higher than those of the non-SUV alternatives. The increase clearly depends on the test cycle and driving style. At relatively low speeds (urban area) fuel consumption and $CO_2$ are up to 40% higher, while at higher speeds (motorway operation) up to 65% increase can be found. The latter mainly results from the increased effect of high air drag resistance due to a larger frontal area and air drag coefficient.

One important note that has to be made here is on diesel SUVs. The experience of the Dutch In-Use Compliance programme is that Euro 3 diesel fuelled cars generally tend to produce emissions that are close to the applicable emission limits for $NO_x$ and $PM_{10}$. The emission limits for diesel cars are set rather tight so that it is more difficult (and expensive) to meet these limits. As vehicles with a GVW above 2500 are subject to less stringent limits (N1 class III), it is expected that manufacturers will make use of the window that is allowed in order to save costs or obtain lower fuel consumption ($CO_2$). It is not known at this point to what extent the emissions can be higher compared to Euro 3 diesel passenger cars under real-world conditions. However, it needs to be taken into account that a considerable increase might be possible. Since almost 50% of the SUVs sold in The Netherlands (Table 23) are diesel fuelled, the effect on total Dutch emissions could be significant.

Due to the lack of sufficient, statistically significant and accountable information it is not possible to draw general and reliable conclusions on the impact of all SUVs with respect to the Dutch environment. It therefore is recommended that a more extensive research programme is defined, or included in an existing programme, to investigate the SUV fleet as well as their alternatives. Several points of attention are the following:
1 The number and type of vehicles in the test needs to be representative for the entire SUV fleet. Limited knowledge of petrol SUVs has been gained in this project. Very little experience with diesel fuelled SUVs is already available.
2 Additional statistical information is required in order to determine the actual effect of SUVs. This would include, for instance, data on the number of kilometres that are driven with SUVs, the location where those kilometres are driven and more details on the SUVs and their non-SUV alternatives.
3 An unambiguous definition for SUV thus is necessary in order to be able to carry out statistical analysis on the SUV issue. SUV seems to be a term for a collection of vehicles with a trendy appeal to the public.

With respect to advanced technologies, hybrid SUVs may give significant fuel consumption and emission reductions with respect to the conventional SUV. Fuel consumption may be lowered to a level that corresponds to a normal passenger car, yet the potential reduction clearly depends on the applied (hybrid) technology. The difference between hybrid SUVs and hybrid passenger cars however will remain similar to the difference between conventional SUVs and conventional passenger cars.

# 5 Conclusions and recommendations

The purpose of this study is to investigate the impact of Sport Utility Vehicles on traffic safety and the environment in The Netherlands.

‘Sport Utility Vehicle (SUV)’ seems to be a term for a collection of vehicles with a trendy appeal to the public. An unambiguous definition for SUV is necessary in order to be able to carry out statistical analysis on the SUV issue, but such a clear definition for a SUV is very difficult to write down. The vehicles compatibility or actually ‘height and bumper height’ may justify the difference between SUV and a passenger car. The average bumper height of a SUV is around 20% higher related to a passenger car.

For this study the definition of a SUV is set to:

> ***A SUV is a vehicle with a nose type front-end, a bigger geometry and an increased: mass, front and rear bumper height, overall ground clearance and higher centre of gravity, in comparison to normal passenger cars. Terrain (off-road) vehicles and so called ‘pickup-trucks’ are also included in this definition.***

The SUV sales related to the total vehicle sales is 4.5%, but the number has doubled over the last five years from 11600 to 23800 SUVs per year, while the total vehicle sales numbers is stable over the last three years with around half a million sales per year. Over the last five years the total vehicle sales is 14% lower. SUV sales in 2010 are estimated (linear trend) to be around 7.0% of the total vehicle sales. The latter is estimated to stay more or less the same.

The conclusions on traffic safety impact of SUVs are written in Section 5.1 followed by the recommendation in Section 5.2. The conclusions on the impact on the environment are given in Section 5.3. followed by the recommendations in Section 5.4

## 5.1 Conclusions related to traffic safety

From the VOR database 650 SUV accidents and 44559 passenger car accidents have been analysed. The latter group was used as the so called ‘control group’ in the analysis. In addition, a limited set of 32 accidents from the TNO Automotive In depth Database were investigated.

Regarding accidents with injurious outcome, SUVs are generally involved in the same kind of crashes as normal passenger cars. Side impacts and ‘head – tail’ impacts are most frequent, followed by frontal impacts. Collisions between SUVs and passenger cars are relatively more frequent on 80 km/h roads, for SUV’s against trucks however this trend could not be observed. For accidents that happen on 80 km/h roads, involvement of an SUV proved to be a solid indicator for serious injury and fatality to the occupant(s) in the struck vehicle.

Mass of the striking vehicle is a factor in the prediction of accident severity. The accident data used in this study did not allow to distinguish whether this 'mass' aspect contains hidden stiffness and geometrical aspects such as bonnet height and bumper height.

For aggressiveness it was found that striking vehicle mass is the main predictor for the accident severity. A higher vehicle mass as such increases the accident severity, whatever the type of vehicle (SUV or passenger car). From the 32 in-depth cases studied, the resulting injuries of car occupants observed were mainly to head and face and at maximum AIS 3 (serious). SUV are significantly more aggressive towards pedestrians and powered two-wheeler riders than passenger cars, even when compensated for the mass differences. The in-depth data showed that the injury of powered two-wheeler riders were mainly bone fractures. The level varied from AIS 1 (light) to AIS 4 (fatal). With under-run accidents by passenger cars the difference in the height of structural parts, but also other external geometric features of the SUV may play an important role in the damage and injury sustained.

With respect to fatality there is tendency towards a slightly better crash protection for the SUV driver and his passengers, than for the driver and passengers of a ‘normal’ passenger car. SUV occupants seem to be more frequently not injured in a crash. This might indicate a safer environment for the SUV occupant but it is most probably due to the higher vehicle mass, less absorbed energy and resulting intrusions in a crash.

With respect to the gender of the driver, SUVs are more frequently driven by males than by females. In the analysed accidents males are also found to generally drive heavier vehicles and for that reason they are found to be a significant factor in the prediction of fatality and serious injuries for the occupant(s) in the struck vehicle. In this respect, female SUV drivers significantly decrease the probability at fatal or serious injuries for struck car occupants. This effect might be partly due to the fact that in general women involved in accidents drive significantly lighter cars than males that are involved in accidents.

In summary, it can be concluded that SUV’s are significantly more aggressive against vulnerable road users. Problems with SUV crashes to other vehicles on the road are related amongst others to compatibility, except for commercial vehicles. However in this study no difference is found between heavy passenger cars and SUVs. SUVs are about as heavy as the average full-size passenger car. So the same mass difference occur within passenger car classes (e.g. full-size and small cars). Although the bumper height is about 20% higher compared to passenger cars, this difference could not directly be related to an increase in injury severity in this study due to the lack of data. Nevertheless, based on accident pictures in this study and other investigations, it is believed that mass, frontal stiffness and geometry factors play a role in the compatibility between SUVs and other road users.

## 5.2 Recommendations related to traffic safety

Design recommendations

Concerning the aggressiveness, the front and rear ladder chassis construction should be redesigned to be less aggressive during an impact with a passenger car. The height of the bumper and other load bearing components of SUVs should be made more compatible to other road vehicles.
Ornaments and fog lights should be integrated in the front and the spare wheel should be placed within the vehicle, in a similar way as the spare wheel of the passenger cars.

The use of a winch needs to be considered for strictly limited or no admittance on public roads (e.g. vehicle use, area driven). An easily demountable version of the winch needs to be developed.
Attention must be paid to the bull-bar. A bull-bar is of no use in road traffic. In principle the bull-bar is an add-on structure and was not part of the safety considerations by the manufacturer. A closer bull-bar construction, allowing less space in between the bars and not protruding the width of the vehicle should be designed. Another way to tackle the problem is a more restricted regulation, which would allow the use of a bull-bar only if they have no negative effect on the safety of other road-users.
With respect to lethality, a less deformable SUV roof and upper pillars have to be designed, to prevent the roof to collapse during rollover accidents.

Recommendations to improve the analyses

The effect of mass needs further investigation with a study in which passenger cars and SUVs in identical mass-classes are compared. The two groups need to be of equal mass-distribution. Difference between the two categories could then be explained by geometry (e.g. bumper height) or stiffness characteristics.
The effect of gender needs to be further investigated with a control group. Video shots at random locations should be able to give information about the frequency of male and female drivers in passenger cars and SUVs. Compared with accident data, this information could give valuable information about driving behaviour differences between men and women, and information about average vehicle mass in these categories.

## 5.3 Conclusions related to environmental impact

The impact of vehicles on the environment results from the cumulative value of exhaust gas emissions and fuel consumption of all individual vehicles. For every type of vehicle, its emissions are related to applied engine technology, driving behaviour, total distance travelled and location of emission (urban area, highway, etceteras).

The most harmful, and regulated, emission components are carbon-oxide (CO), hydrocarbon (HC), nitrogen oxides ($NO_x$) and particulate matter (PM). These components effect local air quality and have direct influence on human health and ecological situation. Another major component is the output of carbon-dioxides ($CO_2$) that is a greenhouse gas and as such has a global effect. $CO_2$-emissions and fuel consumption are directly related to one another.

With respect to the regulated emissions CO, HC, $NO_x$ and PM (human health and ecological condition) the following conclusions are drawn:

- On the basis of current regulations for vehicles, no worse emission behaviour is expected of SUVs as compared to other passenger cars (M1 class vehicles). All vehicles have to meet the same emission regulations. However, the heavier vehicles with a Gross Vehicle Weight (GVW, empty weight plus maximum payload) above 2500 kg (N1 class II and III) are subject to wider limits. This class can possibly emit more than ‘regular’ passenger cars.
- The test results of four SUVs with petrol engines show that the N1 vehicles also easily satisfy the legislative emission limits for M1 vehicles. In real-world driving cycles, no increased emissions are observed when compared to ‘regular’ passenger cars. A few outliers are present, but these can also occur when testing a ‘regular’

passenger car. The SUVs (tested) thus do not pollute more than ‘regular’ passenger cars.

- The statistical value of the SUV test results is very limited due to the low number of vehicles in comparison to the spread that is known to occur.

With respect to fuel consumption and $CO_2$- emissions (climatic effect) the conclusions are:

- No legislation on fuel consumption or $CO_2$-production exists. Instead a covenant between the EU commission and the vehicle manufacturers has been agreed upon that includes a vehicle fleet average for newly sold vehicles of class M1 (‘regular’ passenger cars) for $CO_2$-emission of 140 g/km by the year 2008. N1 class vehicles thus are not included in this covenant.
- $CO_2$ and fuel consumption are strongly related to vehicle parameters like mass and air drag resistance (combination of frontal area and coefficient of drag). In SUVs the (usually present) four-wheel drive system also contributes to additional energy use. These parameters show a negative influence for comparisons of SUVs and their non-SUV alternatives. Consequently, a higher fuel consumption and $CO_2$-emission can be expected for SUVs.
- The test results for the four petrol SUVs confirm that fuel consumption and $CO_2$-emission are higher than those of the non-SUV alternatives. The increase clearly depends on the test cycle and driving style. At relatively low speeds (urban area) fuel consumption and $CO_2$ are up to 40% higher, while at higher speeds (motorway operation) up to 65% increase can be found. The latter mainly results from the increased effect of high air drag resistance due to a larger frontal area and air drag coefficient.

One important note that has to be made here is on diesel SUVs. The experience of the Dutch In-Use Compliance programme is that Euro 3 diesel fuelled cars generally tend to produce emissions that are close to the applicable emission limits for $NO_x$ and $PM_{10}$. The emission limits for diesel cars are set rather tight so that it is more difficult (and expensive) to meet these limits. As vehicles with a GVW above 2500 are subject to less stringent limits (N1 class III), it is expected that manufacturers will make use of the window that is allowed in order to save costs or obtain lower fuel consumption ($CO_2$). It is not known at this point to what extent the emissions can be higher compared to Euro 3 diesel passenger cars under real-world conditions. However, it needs to be taken into account that a considerable increase might be possible. Since almost 50% of the SUVs sold in The Netherlands (Table 23) are diesel fuelled, the effect on total Dutch emissions could be significant.

With respect to advanced technologies, hybrid SUVs may give significant fuel consumption and emission reductions with respect to the conventional SUV. Fuel consumption may be lowered to a level that corresponds to a normal passenger car, yet the potential reduction clearly depends on the applied (hybrid) technology. The difference between hybrid SUVs and hybrid passenger cars however will remain similar to the difference between conventional SUVs and conventional passenger cars.

## 5.4 Recommendations related to environmental impact

Due to the lack of sufficient, statistically significant and accountable information it is not possible to draw general and reliable conclusions on the impact of all SUVs with respect to the Dutch environment. It therefore is recommended that a more extensive research programme is defined, or included in an existing programme, to investigate the SUV fleet as well as their alternatives. Several points of attention are the following:

- The number and type of vehicles in the test needs to be representative for the entire SUV fleet. Limited knowledge of petrol SUVs has been gained in this project. Very little experience with diesel fuelled SUVs is already available.
- Additional statistical information is required in order to determine the actual effect of SUVs. This would include, for instance, data on the number of kilometres that are driven with SUVs, the location where those kilometres are driven and more details on the SUVs and their non-SUV alternatives.

# 6 References

[1] Summers S.M., Prasad A., Hollowell W.T., 2002, NHTSA'S Research program for Vehicle aggressivity and fleet compatibility, Paper #249

[2] U.S. Department of Transportation National Highway Traffic Safety, 2000 AdministrationTraffic Safety Facts 2000

[3] Jocks H.C., 1998, Vehicle Aggressivity: Fleet Characterisation Using Traffic Collision Data, report number DOT-VNTSC-NHTSA-98-1

[4] Gabler and Hollowell W.T., 2000, SAE paper 980908 The aggressivity of Light Trucks and Vans in traffic crashes

[5] Ross M.,Wenzel T., 2002, An analysis of traffic deaths by vehicle type and model, Report prepared for the U.S. department of Energy, report number T021

[6] Parenteau C., Thomas P., Lenard J., 2001, US and UK Field rollover Characteristics, SAE paper 2001-01-0167

[7] Deutermann W., April 2002, Characteristics of fatal rollover crashes, report number DOT HS 809 438

[8] Autoweek, *Internet database*, www.autoweek.nl

[9] Autovisie, *Autovisie Jaarboek 2004*

[10] Kraftfahrt-Bundesambt, *Kraftstoffverbrauchs- und Emissions- Typprüfwerte von Kraftfahrzeugen*, database 2003

[11] U.S. Environmental Protection Agency, *Green Vehicle Guide*, www.epa.gov/greenvehicles

[12] Hollowell, W.T., and Gabler, H.C., 1996, *NHTSA's Vehicle Aggressivity and Compatibility Research programme*, 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, Australia, May 13-17

[13] Evans, L., and Frick, M.C., 1991, *Driver fatality risk in two-car crashes -- dependence on masses of driven and striking cars*, Proceedings of the 13th ESV Conference, paper no. 91-S1-O-10, Paris, France

[14] Mooi H. G., Nastic T., Huibers J. H. A. M., 1999, *Modelling and Optimization of Car-to-Car compatibility*, VDI Berichte NR 1471 (ISBN 3-18-091471-8), pages 239-255, Delft, The Netherlands

[15] Shearlaw, A., and Thomas, P., 1996, *Vehicle to vehicle compatibility in real-world accidents*, Proceedings of the 15th ESV conference, paper no. 96-S4-O-04

[16] Zobel, R., 1997, *Barrier impact tests and demands for compatibility of passenger vehicles*, VDI Tagungsbericht 1354, Innovativer Insassenschutz im PKW, pp. 209-225, Düsseldorf, Germany

[17] Centraal Bureau voor de Statistiek, *Statline*, via www.cbs.nl

[18] Ministry of Transport, Public Works and Water Mamagement; Van A naar Beter; http://www.vananaarbeter.nl/NotaMobiliteit

[19] SPSS, 1999, SPSS Base 12.0 Application Guide

[20] Ministerie van VROM, 2004, *Beleidsnota Verkeersemissies*, VROM 4079 06-04

[21] Burgwal, H.C. van der, Hendrikse, P., Bremmers, D.A.C.M., 2002, *Environmental and human health effects of exhaust gases from passenger cars*, TNO report 02.OR.AT.014.1/HvdB

[22] European Union, *Directive 70/220/EEC*, http://europa.eu.int/comm/enterprise/automotive/directives/vehicles/index.htm

[23] Artemis website, www.trl.co.uk/artemis

[24] Gense, N.L.J., Wilmink, I.R., Burgwal, H.C. van de, *Emissions and Congestion – Estimation of emissions on road sections and the Dutch motorway network,* TNO-report 01.OR.VM.044.1/NG, Delft, May 2001

[25] Gense, N.L.J., *Driving style, fuel consumption and tail pipe emissions*, TNO report 00.OR.VM.021.1/NG, Delft, March 2000

[26] Rijksdienst voor het Wegverkeer, Verkoopaantallen 2003 (Q1 t/m Q4) en 2004 (Q1 t/m Q3)

[27] Smokers, R.S.M., et.al., 2003, *Quickscan 2003*, TNO report 03.OR.VM.032.1/RW, Delft, September 2003

[28] General Motors, http://www.gmbuypower.com/vehicleHomePage.bp?make=Chevrolet&model=Silverado&makeId=001&sellingSource=13&modelId=003&year=2005&subModelId=260&subModel=Hybrid&lowerPrice=&higherPrice=

[29] Ford, http://www.fordvehicles.com/suvs/escapehybrid/

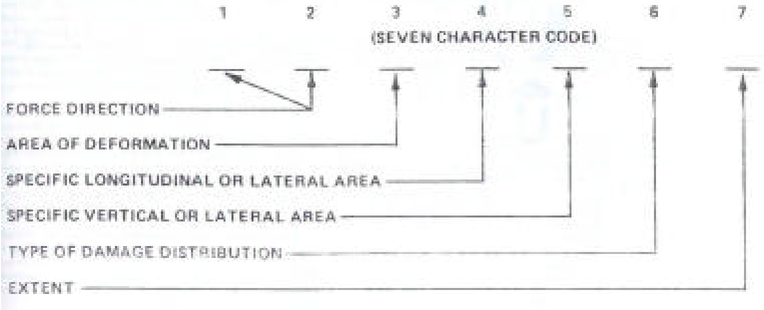
[30] Lexus, http://www.lexus.com/models/hybrid/

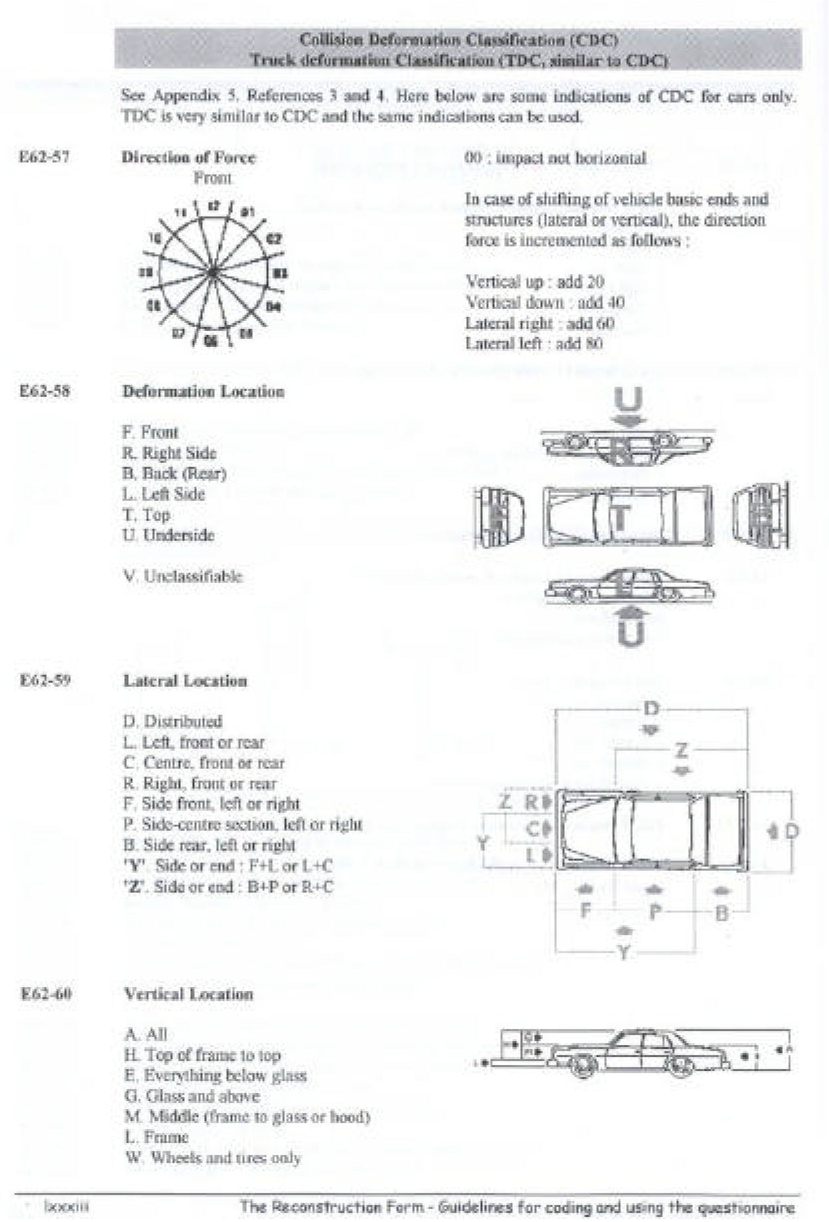
# A SUV(-like) vehicles and specifications

This appendix contains an extensive list of vehicle models and versions that may qualify as SUV. Vehicles that are included are selected on the basis of exterior impressions only, without taking into account any other technical specifications. Most common vehicles available in The Netherlands are expected to be present. By no means is it expected that this list contains all vehicles in the world that would classify as SUV, pickup, light truck or other similar styles. Vehicles that are available in The Netherlands through the parallel import also may not all be included. The latest models newly introduced to the market may also not be present.

# B CDC coding information

The pictures are taken from the EACS coding manual.





**Collision Deformation Classification (CDC)**
**Truck deformation Classification (TDC, similar to CDC)**

See Appendix 5, References 3 and 4. Here below are some indications of CDC for cars only. TDC is very similar to CDC and the same indications can be used.

E62-57 **Direction of Force**

00 : impact not horizontal

In case of shifting of vehicle basic ends and structures (lateral or vertical), the direction force is incremented as follows :

Vertical up : add 20
Vertical down : add 40
Lateral right : add 60
Lateral left : add 80

E62-58 **Deformation Location**

F. Front
R. Right Side
B. Back (Rear)
L. Left Side
T. Top
U. Underside

V. Unclassifiable

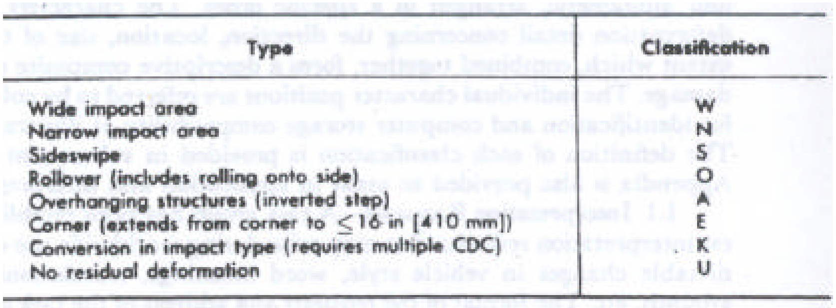
E62-59 **Lateral Location**

D. Distributed
L. Left, front or rear
C. Centre, front or rear
R. Right, front or rear
F. Side front, left or right
P. Side-centre section, left or right
B. Side rear, left or right
**'Y'**. Side or end : F+L or L+C
**'Z'**. Side or end : B+P or R+C

E62-60 **Vertical Location**

A. All
H. Top of frame to top
E. Everything below glass
G. Glass and above
M. Middle (frame to glass or hood)
L. Frame
W. Wheels and tires only

lxxxiii The Reconstruction Form - Guidelines for coding and using the questionnaire



| Type | Classification |
|---|---|
| Wide impact area | W |
| Narrow impact area | N |
| Sideswipe | S |
| Rollover (includes rolling onto side) | O |
| Overhanging structures (inverted step) | A |
| Corner (extends from corner to ≤ 16 in [410 mm]) | E |
| Conversion in impact type (requires multiple CDC) | K |
| No residual deformation | U |

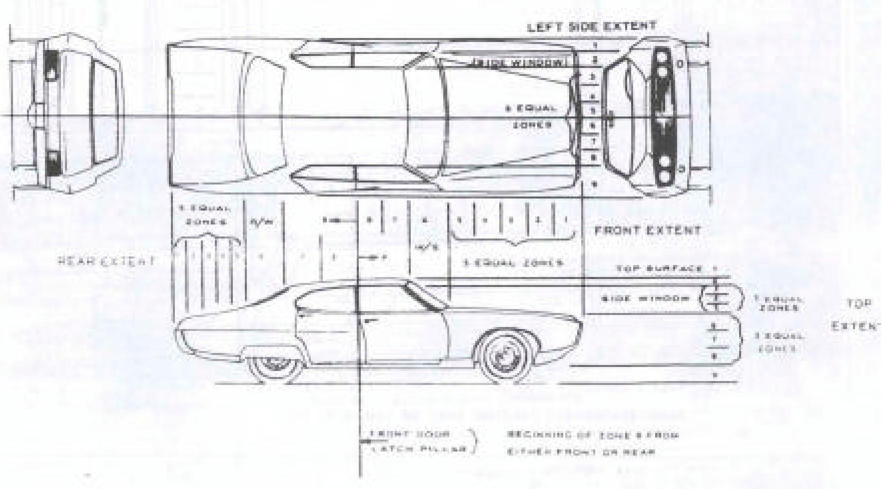


FIG. 6 · DEFORMATION EXTENT ZONES (FOR PASSENGER CARS)

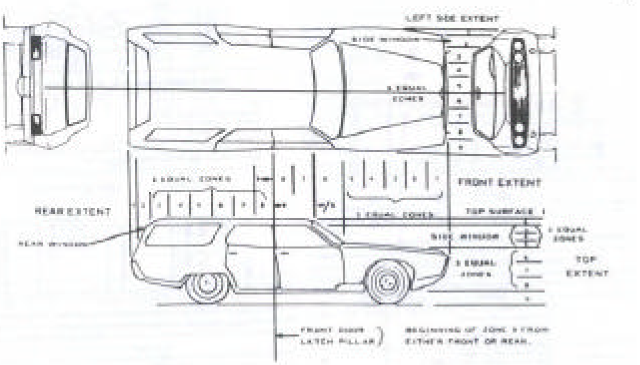


FIG. 3—DEFORMATION EXTENT ZONES (FOR STATION WAGONS)

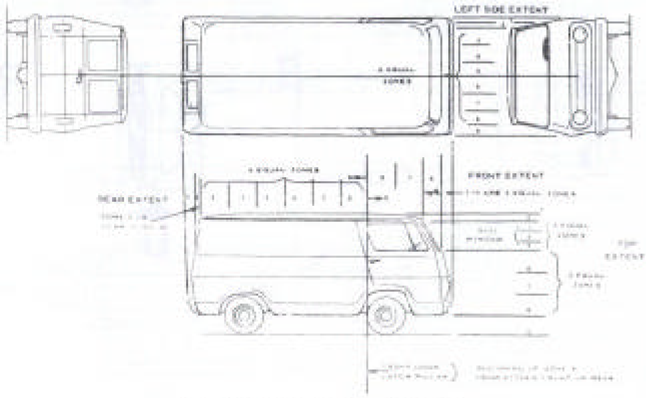


FIG. [illegible]—DEFORMATION EXTENT ZONES (FOR VANS)

# C Sales distribution [%] of petrol and diesel SUVs

| Year → | 2003 | | 2004 (forecast) | | Total 2003 + 2004 | |
|---|---|---|---|---|---|---|
| Vehicle sales ↓ | petrol | diesel | petrol | diesel | petrol | diesel |
| Total | 79 | 21 | 77 | 23 | 78 | 22 |
| Total SUVs | 55 | 45 | 53 | 47 | 54 | 46 |
| Model ↓ | | | | | | |
| Kia Sorento | 64 | 36 | 42 | 58 | 54 | 46 |
| Toyota RAV4 | 78 | 22 | 87 | 13 | 84 | 16 |
| Hyundai SantaFe | 81 | 19 | 75 | 25 | 78 | 22 |
| Volvo XC90 | 43 | 57 | 49 | 51 | 47 | 53 |
| Nissan X-Trail | 50 | 50 | 47 | 53 | 48 | 52 |
| BMW X5 | 39 | 61 | 28 | 72 | 33 | 67 |
| Chrysler PT Cruiser | 74 | 26 | 72 | 28 | 73 | 27 |
| Suzuki (Grand) Vitara | 85 | 15 | 77 | 23 | 81 | 19 |
| Honda CR-V | 100 | 0 | 100 | 0 | 100 | 0 |
| Mitsubishi Outlander | 100 | 0 | 100 | 0 | 100 | 0 |
| Landrover Freelander | 20 | 80 | 31 | 69 | 27 | 73 |
| Toyota Landcruiser | 0 | 100 | 0 | 100 | 0 | 100 |
| Dodge RAM Van | 6 | 94 | 2 | 98 | 4 | 96 |
| Subaru Forester | 100 | 0 | 100 | 0 | 100 | 0 |
| Mercedes ML | 6 | 94 | 4 | 96 | 5 | 95 |
| Volvo XC70 | 58 | 42 | 45 | 55 | 48 | 52 |
| BMW X3 | 0 | 0 | 61 | 39 | 61 | 39 |
| Suzuki Jimny | 100 | 0 | 100 | 0 | 100 | 0 |
| Volkswagen Touareg | 89 | 11 | 47 | 53 | 60 | 40 |
| SsangYong Rexton | 0 | 100 | 0 | 100 | 0 | 100 |
| Landrover Discovery | 3 | 97 | 1 | 99 | 2 | 98 |
| Jeep Cherokee | 45 | 55 | 53 | 47 | 49 | 51 |
| Nissan KingCab pickup | 0 | 100 | 0 | 100 | 0 | 100 |
| Landrover Defender | 0 | 100 | 0 | 100 | 0 | 100 |
| Hyundai Tucson | 0 | 0 | 84 | 16 | 84 | 16 |
| Jeep Grand Cherokee | 15 | 85 | 12 | 88 | 14 | 86 |
| Landrover RangeRover | 45 | 55 | 42 | 58 | 43 | 57 |
| Porsche Cayenne | 100 | 0 | 100 | 0 | 100 | 0 |
| Mitsubishi Pajero Sport | 23 | 77 | 19 | 81 | 21 | 79 |
| Lexus RX300 | 100 | 0 | 100 | 0 | 100 | 0 |
| Nissan Patrol | 0 | 100 | 0 | 100 | 0 | 100 |
| Mitsubishi Pajero | 0 | 100 | 0 | 100 | 0 | 100 |
| Hyundai Terracan | 0 | 100 | 0 | 100 | 0 | 100 |
| SsangYong Korando | 0 | 100 | 0 | 100 | 0 | 100 |
| Honda HR-V | 100 | 0 | 100 | 0 | 100 | 0 |
| Daihatsu Terios | 100 | 0 | 100 | 0 | 100 | 0 |
| Opel Frontera Wagon | 50 | 50 | 54 | 46 | 52 | 48 |

# D Differences between SUVs and passenger cars

By appearance SUVs and common passenger cars are easily distinguished. This appendix describes or tries to explain various factors that have some influence on the environment. Often it is not possible to give an adequate quantification of the effect. The effect is addressed qualitatively and only some quantification to get a basic understanding for the mutual relation is given.

## D.1 Vehicle types

The effect of SUVs on the Dutch conditions depends on the total number of vehicles, individual performances, etceteras. SUVs are not just extra vehicles out on the road. They replace a vehicle that would have been chosen otherwise. The SUV can be used in many different applications. This means that it may replace many different kind of vehicles. Being a large vehicle, the SUV may provide a modern alternative to a large sedan or wagon, off-road vehicle, distribution van or it might just be an alternative for a luxury vehicle. It seems unlikely that a SUV would replace an average family car as both initial and running costs are not in line.

Considering the price range of SUVs, a normal family saloon is not the alternative for consumers in this market segment. These consumers are most likely to by a high-end sedan model in the same price range. These high-end models also have a high mass. The difference therefore is not that great, but remains 200 – 500 kg higher than a comparable high-end sedan model. For an estimate of weights and price range see the table below.

Restricting options to the passenger classes, three basic references are defined. The average family car, a high end luxury car and the SUV. Note that these are only used to create a better understanding of the issues. This line may easily be extended to other types.

Table D.1 Vehicle class estimates

| | SUV | High-end sedan | Average family car |
|---|---|---|---|
| Average weight [kg] | 2000 | 1700 | 1400 |
| Price range [Euro] | 40.000 – 100.000 | 40.000 – 100.000 | 25.000 – 50.000 |

## D.2 Fuel consumption

### *D.2.1 Fuel consumption versus $CO_2$-emissions*

Emission of the green house gas $CO_2$ is directly linked with fuel consumption. The fuel consumption value is calculated from the emission components through the carbon balance method of Equation D.1 (for petrol). Fuel consumption is expressed in l/100km. The emission factors are expressed in g/km.

$$FC = \frac{fuel\_factor}{D} \cdot [(0.866 \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)] \qquad \text{(D.1)}$$

The parameters fuel_factor and D (density) depend on the used fuel:

| Fuel | fuel_factor | D [kg/m$^3$] |
|---|---|---|
| petrol | 0.1154 | 0.74 |
| diesel | 0.1155 | 0.84 |

Consuming twice as much fuel will cause twice as much $CO_2$-emissions. The amount of $CO_2$-emissions per litre fuel depends on the type of fuel. Diesel gives lower $CO_2$-emissions than petrol. There are a lot of factors influencing fuel consumption. Those that relate to SUVs are shortly discussed.

### D.2.2 *Mass*

Mass has a clear influence on fuel consumption. The higher the mass, the higher the fuel consumption. In city traffic a large part of the required energy is used to overcome the inertia of the vehicle, in other words accelerating the vehicle. Compared to the average family passenger car the SUV has a (much) higher mass, resulting in a higher fuel consumption. Table D.2 lists some examples in the different classes.

Table D.2 Fuel consumption [l/100km] for (petrol) vehicle classes [8]

| | | Urban [l/100km] | Highway [l/100km] | Combined [l/100km] | $CO_2$ [g/km] |
|---|---|---|---|---|---|
| SUV | BMW X5 3.0i | 18.1 | 9.9 | 12.9 | 312 |
| | Mercedes ML 350 | 19.4 | 11.0 | 14.1 | 338 |
| | Volvo XC90 2.9T | 18.5 | 9.6 | 12.9 | 309 |
| High-end sedan | BMW 530i | 14.1 | 7.5 | 9.9 | 240 |
| | Mercedes E240 | 14.8 | 7.8 | 10.3 | 247 |
| | Volvo S80 2.5T | 14.1 | 7.7 | 10.0 | 234 |
| Family car | Ford Focus 1.6 | 8.7 | 5.5 | 6.7 | 161 |
| | Opel Astra 1.6 | 8.4 | 5.4 | 6.5 | 156 |
| | Volkswagen 1.6FSI | 8.5 | 5.3 | 6.4 | 154 |

### D.2.3 *Air resistance*

A second important resistance that needs to be overcome during driving is the air resistance. The air resistance basically is determined by vehicle geometry and is defined by its frontal surface area (A) and the air drag coefficient ($C_d$). Furthermore, it depends on vehicle speed and air density.

The $C_d$-value of SUVs is in the range of 0.35 – 0.39. Compared to a high-end sedan car this is about 25% higher. Also because of its height, the frontal surface of a SUV is bigger than a sedan car (about 15-30%). In total this will cause for a higher air resistance (drag) of the vehicle. In steady state high-speed operation this can cause up to 30% increase in fuel consumption. This is mainly an issue while driving on the highway, in city traffic the air resistance plays only a less significant role.

Table D.3 Air resistance values for vehicle classes [various Internet sources]

| | | A [$m^2$] | $C_d$ [-] |
|---|---|---|---|
| SUV | BMW X5 | 3.0 | 0.35 |
| | Mercedes ML | 3.1 | 0.39 |
| | Volvo XC90 | 3.1 | 0.36 |
| High-end sedan | BMW 5-series | 2.7 | 0.28 |
| | Mercedes E-class | 2.6 | 0.27 |
| | Volvo S80 | 2.6 | 0.28 |
| Family car | Ford Focus | 2.4 | 0.31 |
| | Opel Astra | 2.3 | 0.29 |
| | Volkswagen | 2.5 | 0.32 |

### *D.2.4 Rolling resistance*

The third major resistance during driving is the rolling resistance of the tires. At low vehicle speeds the rolling resistance is more significant than the air resistance. The rolling resistance has a direct link with the load of the tire; twice as much load is approximately twice as much rolling resistance. SUVs tend to have bigger tires and a higher load of the tire. This may give an increased rolling resistance.

The rolling resistance force depends on the tyre rolling resistance coefficient and the vehicle mass.

The coefficient of rolling resistance depends on various factors like the aspect ratio, rubber compound, profile pattern, etceteras. Many SUVs have normal tread patterns, optimised for road use. Even the original terrain vehicles are equipped with tyres that are more suitable for on-road than off-road driving. It is not expected that a distinctive difference exists between the smaller regular passenger car tyres and larger SUV tyres.

Most SUVs are heavier which results in a higher tire load compared to a normal passenger car. The rolling resistance force will thus be higher as a result of higher vehicle mass. Because SUVs are such a diverse group it is not possible to make a general statement on the size of the tire and its influence on fuel consumption. The table below shows some examples for different vehicles. A vehicle model may be equipped with different tyres for different versions (e.g. engine).

A larger tyre does not automatically mean that it will have a bad influence on the vehicle. A tyre with a wider contact area will give better traction performance. This actually means that the vehicle has increased vehicle dynamics behaviour, which is good from a safety point of view.

Table D.4 Tyre size for vehicle classes [8]

| | | Tyre size |
|---|---|---|
| SUV | BMW X5 3.0i | 235/65HR17 |
| | Mercedes ML 350 | 255/60HR17 |
| | Volvo XC90 2.9T | 235/65R17 |
| High-end sedan | BMW 530i | 225/55R16 |
| | Mercedes E240 | 205/60VR16 |
| | Volvo S80 2.5T | 215/55R16 |
| Family car | Ford Focus 1.6 | 195/65R15 |
| | Opel Astra 1.6 | 195/65R15 |
| | Volkswagen 1.6FSI | 195/65R15 |

### D.2.5 *Driveline friction losses*

The powertrain losses are internal losses that are present due to, mainly, friction. The total driveline friction of SUVs is higher than for an average family car or big sedan vehicle. There are several factors causing this. Shortly discussed are (permanent) four wheel drive and the automatic transmission.

The transmission for a 4WD vehicle is more complex than that for a 2WD vehicle. Two additional differential gears are required to transfer the power from the transmission to the wheels. Additional losses are present in the powertrain and the transmission is larger and also a little heavier (making the vehicle heavier). Consequently, a 4WD has a higher fuel consumption than a 2WD. From experience it is known that this is about 15-20% (as a result of additional transmission loss and increased weight). Table D.5 shows the effect of 4WD on the fuel consumption.

Table D.5 Fuel consumption for 2WD versus 4WD versions [8]

| | Transmission | Mass [kg] | Urban [l/100km] | Highway [l/100km] | Combined [l/100km] | |
|---|---|---|---|---|---|---|
| Golf 2.0 16V FSI | manual | 1254 | 10.1 | 5.6 | 7.2 | |
| Golf 2.0 16V FSI | automatic | 1289 | 11.8 | 6.0 | 8.1 | 12.5% |
| Golf 2.0 16V FSI 4motion | manual | 1375 | 11.6 | 6.6 | 8.4 | 16.7% |
| Audi A4 2.0T FSI | manual | 1425 | 10.9 | 5.8 | 7.7 | |
| Audi A4 2.0T FSI | automatic | 1450 | 11.2 | 6.3 | 8.1 | 5.2% |
| Audi A4 2.0T FSI Quattro | manual | 1490 | 12.6 | 6.6 | 8.8 | 14.3% |

The automatic transmission as opposed to the manual transmission traditionally causes higher losses in the powertrain. Developments in transmission technology have improved the efficiency of the automatic transmission significantly. Still the automatic transmission has higher losses and depending on the specific technology, a 5-15% higher fuel consumption is found.

SUVs are more often equipped with automatic transmission than the average family car, especially when it is a powerful or luxury SUV. This is also valid for the high-end sedan vehicles. So in absolute figures, the manual transmission is better than the automatic. When comparing the SUV with a high-end vehicles that it replaces, then the transmission type is not a big issue.

An advantage of automatic transmissions is the lower request for driver attention. The driver does not have to control the shift lever. Consequently he has more time to focus on traffic conditions outside of the vehicle.

### *D.2.6 Engine displacement*

Because SUVs have a higher mass it takes more power to give them the same performance as a regular passenger cars. The fun and luxury marketing require that these SUVs are at least as powerful as a normal car and the manufactures therefore put big engines in these cars. A problem with these big engines is the efficiency at part load, making these cars less fuel efficient during steady state operation (high way). It is not possible to assign a percentage to the influence on fuel consumption. It is just observed that some influence is present here. High end luxury saloons are also equipped with these large engines, yet the vehicle is a little lighter and has lower air resistance. It is a race for more horsepower in all vehicles, not only SUVs.

The trend in normal passenger cars is downsizing, getting the same or higher performance from a smaller engine, more and more using turbochargers. This trend is not as strong among SUVs. There still are a lot of SUVs with large displacement engines without turbochargers. These big engines are also part of marketing the powerful image of SUVs. Furthermore, it seems that manufacturers increase displacement of the large engines, creating an even larger engine with more power. At the same time, vehicles are equipped with more and more luxury electronics (like video screens) making them heavier and requiring more power.

### *D.2.7 Bull bars and sports packages*

Bull bars and sports packages are external decoration of the vehicle. As they are positioned on the outside of the car they influence the aerodynamics around the car. This influence is known to be present, yet it is difficult to quantify the effect.

Bull bars can be found on the typical terrain vehicles. In general, bull bars are robust and large. Usually made of metal and therefore add some weight to the car. The aerodynamics ($C_d$-value) are influenced negatively. A terrain vehicle already having bad aerodynamic behaviour will feel only little change. The air resistance for the vehicle will increase though and consequently a little higher fuel consumption will be found.

Sports packages contain spoilers and side skirts. These are used to give the car a more sportive appearance. Again aerodynamic flow is affected. Depending on size and shape of the spoiler, fuel consumption may be influenced negatively or positively. Usually some kind of synthetic material is used for these sports packages so that relatively very little extra weight may be involved.

## D.3 Life cycle construction and disposal costs

SUVs tend to have a higher mass, so more materials are used to build the vehicle. The total energy use associated with producing these materials therefore will be higher. These vehicles are not produced in The Netherlands though, so (maybe only a little) extra environmental penalty (e.g. in the production and transportation of steel) associated with the extra energy used will contribute to Dutch environment.

Disposing the vehicle will also take more energy and will produce more waste material. It is not possible to predict more specific figures on the environment. A complete life cycle analysis would have to be carried out. Some of this influence will be felt in The Netherlands, because the vehicle will be disposed here. Note that the additional effect is only found when more material is involved. In other words, if the SUV replaces a high end luxury sedan with the same weight, then no difference would be found.

## D.4 Grey registration plate

In The Netherlands currently a BPM-tax is used, which is to be paid for most vehicles. Cars which apply to several special standards (‘grijs kenteken’, grey registration plate) are excluded from this tax. At the moment, a reduction on road tax is arranged as well. Part of the SUV population is sold in this grey registration plate legislation.

The Dutch government is planning to stop the tax advantages of (light duty) grey registration vehicles. This will result in a price increase of about 50% for these vehicles. Also the running costs will go up because the road tax reduction is no longer applicable. The government is considering other measures to compensate business owners, but it is not expected to fully compensate the loss of the grey registration.

It is possible that there will be a shift in sales of SUVs by business owners. The prediction is that they will buy a cheaper and lighter vehicle that fits their needs. Business owners who need the transportation space of a SUV may continue to buy one or buy a delivery van. Delivery vans have about the same properties as SUVs, but more cargo space: high mass, high air resistance and high fuel consumption.

# E Definitions of advanced powertrains

This appendix gives an overview of various advanced powertrain technologies and examples of vehicles in which these have been applied.

Various categories are used to identify a vehicle's powertrain [27]. One represents the commonly applied conventional system. The others are for advanced technology concepts. The following categories are used to classify most frequently applied systems.

1. Internal Combustion Engine Vehicle (ICEV)
2. In general, these vehicles are powered by a petrol or diesel fuelled engine that drives the wheels through a manual or automatic transmission.
3. Battery Electric Vehicle (BEV)
4. An electrically powered vehicle with electric energy storage in a battery.
5. Hybrid Electric Vehicle (HEV)
6. A vehicle using both a (conventional) internal combustion engine and one or more electric motors for propulsion.
7. Fuel Cell Vehicle (FCV)
   An electrically powered vehicle with a fuel cell for on-board electric power generation, often also equipped with a small energy storage system.

Figure E.1 shows a schematically representation of these propulsion configurations. Corresponding to the applied components, advanced vehicles often are distinguished by multiple types of energy conversion. In a conventional vehicle the main power flows are chemical (fuel) and mechanical energy. In an advanced vehicle, chemical, mechanical and electrical energy are present. These processes can be clearly identified by looking at the various components in the powertrains.

- Engine: converts chemical energy from fuel (fluid or gas) to mechanical energy
- Transmission: mechanical energy transfer
- Battery: stored chemical energy is converted to electrical energy (and vice versa)
- Electric Motor/Generator: electrical energy is converted to mechanical energy (Motor operation) or from mechanical to electrical energy (Generator mode)
- Fuel Cell: converts chemical energy (fuel, usually hydrogen) to electricity

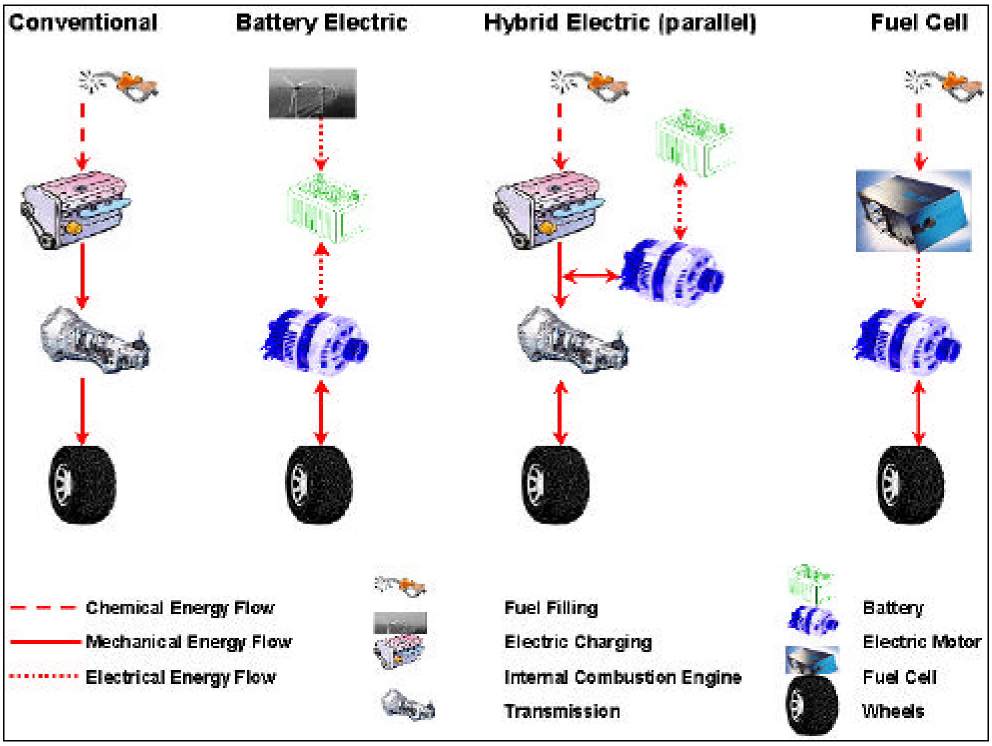


*Figure E.1 – Various main propulsion system configurations*

## E.1 Battery Electric Vehicle

In a Battery Electric Vehicle, an electric motor drives the wheels and energy is provided by a battery.

Many of these vehicles have been developed and made commercially available in the past decades. A breakthrough in the main area of road transportation, however, has not occurred nor is expected in the near to mid term future. The major problem is the limited driving range due to the limited storage capacity. In many other applications where driving range is not the main issue, but local emissions may be, battery electric powertrains are successfully applied. Some examples, see figure below) are forklifts, golf karts and some neighbourhood vehicles.

*Figure E.2 – Electric forklift and Th!nk City*

## E.2 Hybrid Electric Vehicle

Depending on the exact components and driveline design, it is possible to expand these schematics with new or more components or, especially for the hybrid electric option, connect them in different ways. Performance and powertrain design of hybrid vehicles may have been optimised for a dedicated application. Basically, three different Hybrid Electric Vehicle configurations can be discerned (see also E.3):

1. Series
2. Parallel
3. Combined Series/Parallel

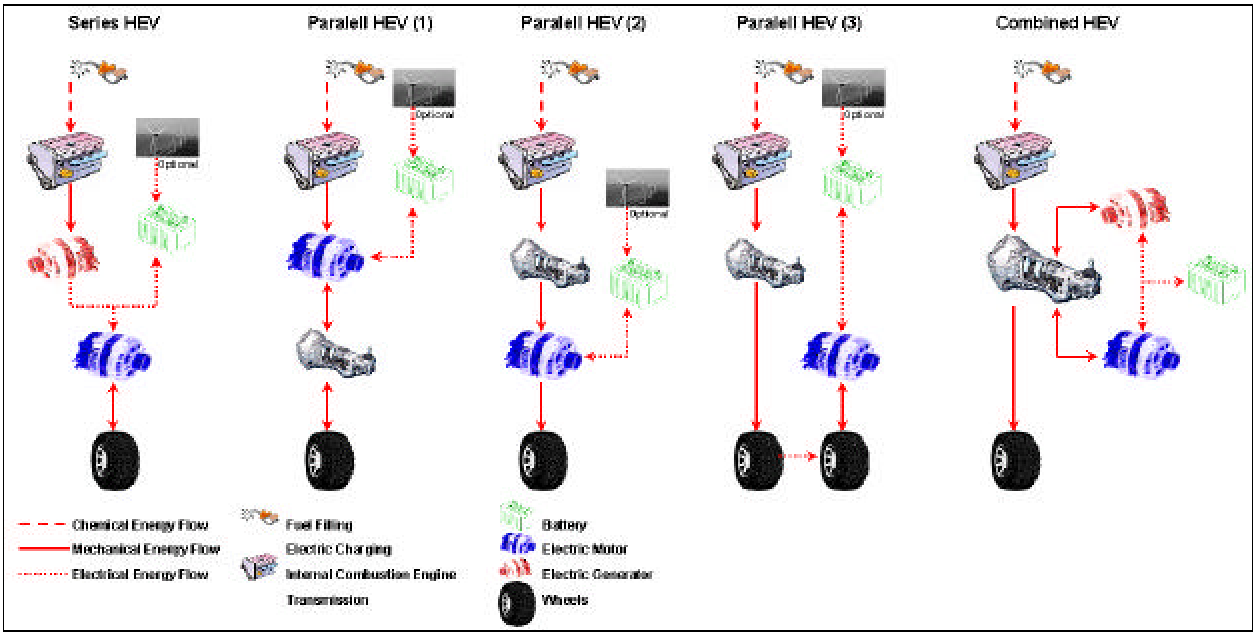


*Figure E.3 – Hybrid Electric Vehicle configurations (series, 3x parallel, combined)*

### E.2.1 *Series Hybrid*

In a Series HEV, the wheels are driven by one or more electric motors (similar to the BEV). Electrical power is provided either by a battery or engine-generator set (or the fuel cell system in a FC-HEV) or by both simultaneously. Depending on the energy demand the (master) control system will decide which component has to provide what amount of energy. Because the engine is no longer mechanically connected to the wheels, it can be run in a restricted range of optimal operating points. The battery (or super capacitor) unit usually provides low power when the engine-generator set is turned off and operates as a peak power shaving device limiting transient operation and maximum power output from the genset.

This type of powertrain is most popular for very dedicated applications with high dynamic driving conditions like urban traffic. Worldwide various test fleets with SHEV city buses are running in daily practise. In The Netherlands, the Dutch companies E-traction (prototype) and APTS (Phileas) have developed series hybrid buses. TNO Automotive has developed a SHEV test platform called Hybrid CarLab to investigate and gain knowledge of operational characteristics of various hybrid technologies (component and system level). These vehicles are shown in Figure E.4.

*Figure E.4 – Examples of Series Hybrid Vehicles in The Netherlands: E-traction bus, TNO’s Hybrid CarLab, APTS’s Phileas)*

### *E.2.2 Parallel Hybrid*

In a Parallel HEV, the mechanical energy from the engine is transferred to the wheels by a mechanical transmission. Depending on the exact parallel configuration, an electric motor is used to assist the engine or to propel the vehicle on its own (electric driving). Based on the ratio of electric motor to total power, the degree of hybridisation is called ‘mild’ or ‘full’ hybrid, even ‘lite’ or ‘micro’ are sometimes used for vehicles with powerful engines (usually V6 or V8).

This powertrain configuration is very popular for vehicles like passenger cars. The system presented as Parallel HEV (1) in Figure E.3 is applied most often. Some example are the commercially available Honda Insight and Civic (Honda Integrated Motor Assist -IMA- system), the Citroen C3 (Valeo belt-driven Starter Alternator system, market introduction recently announced) or the Chevrolet Silverado HEV (Continental ISAD system, available in the US). In these systems the conventional starter and generator have been replaced with one more powerful electric machine (about 10kW). In the Honda and Chevrolet (Figure E.5) this machine is placed directly on the engine crankshaft, in the Citroen it is coupled to the crankshaft using a belt. The machine’s functionality in these systems is the same. They allow for engine stops during standstill and fast engine restarts before driving off. Furthermore, they allow regenerative braking and torque assist (during acceleration). Commonly used names for these systems are (crankshaft mounted) ‘Integrated Starter Generator (ISG)’ or (belt-driven) ‘Starter Alternator (SA)’. In these systems, no electric driving is possible, a more powerful electric machine would be required as well as more changes to the powertrain.

*Figure E.5 – Honda Civic Hybrid, Chevrolet Silverado Hybrid, BMW X5 Hybrid (proto) and Audi DUO (left-to-right)*

### *E.2.3 Combined Hybrid*

The Combined Hybrid Electric Vehicle system is the most complex of the three configurations. As its name indicates it combines the advantages of series and parallel hybrid powertrains. A mechanical connection between engine and wheels is present like in the parallel hybrid, yet the system with two electric motors and electronically controlled continuously variable transmission (planetary gear) allows for free control of the engine operating points (like the series hybrid). This requires a very complex and intelligent control system.

Although being the most complex, Toyota introduced it to the market already in 1997 in the first commercially available hybrid vehicle: the Prius. In 2000 the system was further optimised and the vehicle was introduced in Europe and North America. In 2004 the second generation Prius was presented.

Lexus, Toyota’s luxury division, and Ford have announced the introduction of SUVs with this type of powertrain. These are the Ford Escape and Lexus RX. The Lexus RX will even create 4WD by adding an electric motor to the rear axle.

These vehicles are shown in Figure E.6.

*Figure E.6 – Toyota Prius generation I and II, Ford Escape HEV and Lexus RX*

## E.3 Fuel Cell Vehicle

The layout of a Fuel Cell Vehicle is much similar to that of a BEV. An electric motor (or several) drive the wheels. A fuel cell converts chemical power to electricity to feed the electric motor. Nowadays, a small electric energy buffer, usually a super capacitor system, is used to create better transient behaviour of the vehicle. Most fuel cell vehicles therefore actually have a series hybrid configuration. At this moment, infrastructure and state-of-technology are not ready for large scale introduction of fuel cells in the road transportation sector. The expected shift to a hydrogen economy requires a lot of research. All vehicle manufacturers therefore are involved in the developments of fuel cell vehicles. Again the city bus application is one of the favourites at this moment. Some examples are given in Figure E.7.

*Figure E.7 – Opel Hydrogen3, Hyundai SantaFe, Mercedes Necar5 and Fuel Cell Bus*

## E.4 Expected market introduction of hybrid models

Table E.1 list the (announced) introduction years for several hybrid models.

Table E.1 Hybrid vehicle introduction

| Manufacturer | Model | Configuration | Vehicle class | Introduction year |
|---|---|---|---|---|
| Toyota | Prius I | combined | family sedan | 1997 (Japan) |
| Honda | Insight | parallel, mild | 2-seater | 2000 |
| Toyota | Prius Ia | combined | family sedan | 2000 (US,EU) |
| Honda | Civic | parallel, mild | family sedan | 2002 |
| Ford | Escape | combined | SUV | 2004 |
| Ford | Futura | combined | sedan | 2004 |
| General Motors | Chevrolet Silverado | parallel, mild | SUV/pickup | 2004 |
| General Motors | GMC Sierra | parallel, mild | SUV/pickup | 2004 |
| Honda | Pilot SUV | parallel, mild | SUV | 2004 |
| Lexus | RX400h | combined | SUV | 2004 |
| Toyota | Highlander | combined | SUV | 2004 |
| Toyota | Prius II | combined | family sedan | 2004 |
| DaimlerChrysler | Dodge RAM | parallel, mild | SUV/truck | 2005 |
| Honda | Accord | parallel, mild | family sedan | 2005 |
| Toyota | Alphard/Sienna | combined | MPV/Minivan | 2005 |
| DaimlerChrysler | Mercedes S-class | parallel, mild | family sedan | 2006 |
| General Motors | Chevrolet Equinox | parallel, mild | SUV | 2006 |
| General Motors | Saturn Vue | parallel, full | SUV | 2006 |
| Lexus | Hybrid V8 | combined | family sedan | 2006 |
| Toyota | Camry | combined | family sedan | 2006 |
| Ford | Mercury Mariner | combined | SUV | 2007 |
| General Motors | Chevrolet Malibu | parallel, mild | family sedan | 2007 |
| General Motors | Chevrolet Tahoe | parallel, full | SUV | 2007 |
| General Motors | GMC Yukon | parallel, full | SUV | 2007 |
| Nissan | Altima | combined | family sedan | 2007 |