SARAC II

CEA
Insurers of Europe

**Quality Criteria for the Safety Assessment of Cars Based on Real-World Crashes**

# Car Occupant and Fleet Effects

Report of Sub-Task 3.3



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Quality Criteria for the Safety Assessment of
Cars based on Real-World Crashes

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# CAR OCCUPANT AND FLEET EFFECTS

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# Abstract

Driver populations, car fleets, car use and traffic cultures are changing continuously, but different way in different countries. This report examines how do the results of car safety ratings in different countries correlate with the characteristics of changing car fleets and driver populations.

Because the ratings are always individual relative analyses regardless the chosen methods, the results present the situation only based on the certain analysed data set. This means that it is not possible directly to compare the results even between two consecutive ratings from two different data sets in the same country. Comparisons between different countries are still more unreliable because of typically different methodologies and data recording systems. Of course the calculated ratings are indicative and they give only hints about some possible tendencies and possible variables behind them. Therefore this report is focused more on showing examples from different kind of progresses in driver and fleet distributions of different countries during the past 15 years

All car manufacturers have developed the structures, control techniques and safety restraints of their products actively. This has increased the mass of the cars in an average with almost 200 kilograms since 1990. At the same the relative mass difference between "large" and "small" car has diminished. New car models seem to be even 40-50 per cent safer than their predecessors some 15 years ago. Especially strong has been the decrease of injury severity rates. Very positive issue is also that newer models are less aggressive compared to the older ones regardless the increased average mass.

Differences between new and old models or between small and large models depend strongly on their mass and design but also their different driver and owner populations, different mileages, distributions between urban and rural use. With time the driver populations and the use by car models change very different way, which reflects also to the fleet level and may cause remarkably pronounced values for individual models.



### Keywords

OCCUPANT EFFECT, FLEET EFFECT, ACCIDENT RISK, INJURY RISK, SAFETY RATINGS, MILEAGE



**<u>The views expressed are those of the authors and do not necessarily represent those of CEA, or any of the participants of the SARAC 2 committee</u>**

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# EXECUTIVE SUMMARY

## General

Car safety ratings have been done over 15 years in several countries. During the years driver populations, car fleets, car use and traffic cultures have changed a lot and in different way in different countries. This report examines how do the results of car safety ratings in different countries correlate with the characteristics of changing car fleets and driver populations

Large samples of accidents are always needed for safety ratings and other safety analyses by car models. This leads to a long observation period that the sample would be large enough for the ratings. However, the time period can not be too long because several time-dependent factors like driving habits, driver populations, traffic volumes and regional car use, car mass and design, safety devices and developing traffic environment, for example, are influencing on the results. The length of inspection period has in most car safety ratings been from 5 to 8 years.

Because each rating is an individual analysis regardless the chosen method, also the results present only a certain cross-section based only on the analysed data set. This means that it is not possible directly to compare the results even between two consecutive ratings from two different data sets in the same country. Comparisons between different countries are still more unreliable because of typically different methodologies and data recording systems. Some of the calculated results in this report are only indicative and they give only hints about some tendencies and possible variables behind them. Therefore this report is focused more on showing examples from different kind of progresses in driver and fleet distributions of different countries during the past 15 years. These examples will describe more or less the phenomena and their directions affecting on changing fleets and occupant populations and furthermore on safety ratings.  This perspective offers a possibility to consider occupant and fleet effects on rating results more versatile using also smaller data sets.

It is essential to remember that the presented examples which are calculated based, for example on Finnish data sets, may not influence as strongly in the whole Europe. A purpose of the examples is to point out new unapplied variables which would improve and internationally commensurate the rankings. This report also concerns briefly the problems in the interpretations of different ratings.

## Occupant effect

The occupant effect is polarized to the occupants of different age and gender and their different propensities to involve in certain types of accidents and to injure in those. The owner profiles vary significantly between the car models. Female favour small cars and in general a proportion of females as car owner grow when the car gets older. As an example some about 38% of cars are owned by females in Finland. However, there are large differences between car models. Some 60% of certain car model owners are females and old females can be the largest owner group. On the other hand there are some new large car models which are owned practically only by middle-aged men. Some models are very popular among young drivers. This type of variations can be seen in each European country but the differences vary between car models and user age groups. Large departures from the average fleet reflect also to the results of ratings, but the absolute extent of the bias is impossible to calculate from accident data.

A difficult problem in safety ratings is to identify the real car drivers in the traffic, their mileage and their experience in the traffic. In accident statistics we often have only the information of injured occupants available, but seldom any complementary pieces of information. Again as an example in Finland males from 18 to 24 years own 6% of all driving licenses and 5% of all registered passenger cars. However, they have been involved in 17% of accidents compensated by insurance companies when concerning guilty drivers only. Furthermore 17% of all drivers injured in those accidents have been males from 18 to 24 years. However, 40 % of injured drivers did not own the vehicles they were driving.

It can be suggested that some car models have larger proportion of risky drivers than the others. For example a majority of owners of small car are female who have higher injury and injury severity risk than male. Furthermore, a high proportion of young drivers increase the accident risk and injury risk of old cars. The increasing proportion of female owners increases the computational injury risk of old cars.

Over 65 years old occupants are more vulnerable than younger ones. A person 65 or older who is involved in a car accident is more likely to be seriously injured, more likely to require hospitalization, and more likely to die than younger person. If the vulnerable drivers use old and small cars, like in this study shown, it is quite obvious that the drivers will get injuries in accidents.

The average age of car drivers in EU is increasing. Especially rapid the ageing is in the countries with high car ownership rate and high rate of driving licence holders. This will obviously increase both injury and injury severity risks in Europe if we cannot compensate them with still safer cars, with quicker renewing of European car fleets, with softer road environments and with advanced accident preventive technologies.

## Fleet effect

Fleet effect describes the influence of renewing and safer car fleet changes and how they influence on the risk rates in traffic accidents. Typical variables affecting on the safety level of the vehicle fleet are the changing mass, age, mileage, operation regions and driver populations of the fleet and its sub-groups.

During the previous 15 years investigation period all car manufacturers have developed the structures, control techniques and safety restraints of their products actively. Especially the planning activities of new structures which are able to absorb better the crash energy in frontal and side crashes have been beneficial. These have increased the mass of the cars in an average with almost 200 kilograms since 1990. At the same the relative mass difference between "large" and "small" car has diminished. It is interesting that for example in France and Spain where the average mass of the fleet has all the inspection period been much lower compared to Sweden, Germany or Finland, the average mass has increased also roughly with those 200 kilograms. New car models seem to be even 40-50 per cent safer than their predecessors some 15 years ago according several analyses done in different countries. Especially strong has been the decrease of injury severity rate. Very positive issue is also that newer models are less aggressive compared to the older ones regardless the increased average mass.

In Europe relative size differences of the car fleets have become smaller, which has influenced positively on occupant safety in both vehicles in two-car crashes. This kind of positive trend of car compatibility should be continued also in the future. Thought the consumers tend to replace their smaller cars with larger and heavier cars, the narrowed dispersion of mass in car fleet has also helped to reach the safety targets. However, there are already some signals of less harmonious fleet from USA and Australia where the proportions of pick-ups, vans and large SUV and MPV are increasing. Therefore we should try in Europe to avoid the re-polarization of the fleet. In the U.S. and in Australia there already are observations about increasing proportions of large SUV, MPV and pick-ups but also smaller city cars in the fleet.

A certain time-depended regional movement among car fleet can be seen. New cars are often registered to large cities and regional centres from where they slowly move to smaller municipalities and rural areas. The car fleet is older on rural areas. This is problematic for the traffic safety because the major part of mileage of older vehicles takes place on rural roads. Older fleet, higher speed limits and older driver population is a very bad and unrewarding combination, which also increases the risk rate of older fleet. At the same time the most mileage of the newest fleet is accumulated on urban areas and driven by middle-aged male drivers which improve the risk rates of newer models in relation to the older ones. Unfortunately it is not possible to calculate the absolute deviations of these phenomena by car models based on actual data bases.

The annual mileage varies by model and age of the car. The mileage of the smallest size class is typically 20-25% lower than the average mileage of the whole fleet. The annual mileages of new cars are the highest and the drop of the mileage for older cars seems almost linear after third year of use. 10 years old vehicles tend to have mileages of 60-65 per cent and 20 years old only 30 per cent compared to corresponding new cars. If the risk calculations are made per driven mileage the differences of risk rates between small and large as well as between new and older cars grow. The cars which are classified to professional or company use are younger and they do have much higher mileage compared to privately owned ones. There are large differences in average mileages between different European countries.

## Conclusions

This study supports strongly a general hypothesis that newer car model generations vehicle model would have much better safety performance than the previous generation of the same vehicle model. This seems to reflect strongly on the average safety of the whole fleet in each investigated country. Based on car safety ratings and other safety analyses the injury risk rate has decreased roughly 40 - 50 % or even more from the model generations of late 1980´s up to the newest models of early 2000´s. Especially the injury severity rates of new models have decreased.

Car mass influences clearly on injury risk, which is clearly detectable in ratings from UK, France and Germany. The influence of car mass on injury severity risk, however, is not necessarily obvious. The severity risk rates do not seem to differ by the size of the car model, even though single differences between car models can be seen. One possible explanation might be the different use of small and large cars. Smaller cars have accumulated their most mileage in safer urban traffic but heavier cars do have higher proportion of long distance traffic.

From the traffic safety research point of view, it would be important to harmonize internationally the transportation data recording methods. One major problem, for example, is the lack of relevant mileage information by individual cars. The harmonizing would be possible to execute because in many countries only small amounts of the data is recorded. In most countries such data is not currently recorded at all. However, usually the problem is not the availability of the data but the co-ordinated recording practise. Continuous co-operation between researchers, car manufacturers and different administrations is therefore essential.

# 1 INTRODUCTION

## 1.1 GENERAL

A purpose of car safety ratings is to produce information which is purely focused on safety issues of cars. Therefore the results of safety ratings are often tried to commensurate with help of information on several variables influencing on accidents. This ensures the high level of validity. In ratings the indicators for car safety are usually the numbers of injured or fatal occupants in relation to the total number of accidents or mileage. Proportions of different injury severities in relation to suitable denominator are also used.

For ratings, the safety analyses of car models are usually based on large amount of accidents. Long observation period is needed to get a sample of accidents which is large enough for the ratings. However, the time period can not be very long because of several time-dependent variations influencing on research targets. New car models are introduced, old cars are scrapped and also the ownership, the use and the environment of use of the cars are changing. Time period for observations used in car safety researches is typically 5-8 years, which allows analysing only a few "internal changes" in the car fleet.

When calculating accident risks, the most essential variables are driver’s age and gender, accident type, operating environment and its speed level and the interaction between these variables. Concerning the severity of the accidents, the year of accident is an important variable due to influence of fleet changes on safety.

We have to underline that the internal changes in the car fleet are always concerning only the particular country but in all countries the car fleets are changing different ways. This report analyses the changes of the car fleets and driver populations and their influence on car safety ratings generally. Different kind of data sets from Germany, France, Sweden, Great Britain, Spain, Australia and Finland has been used in the analyses. Unfortunately the lack of uniform data acquisition systems and the different data contents in each national statistics have made the international comparisons more difficult. Therefore in the analysis it was often used in the investigations the Finnish data sets to describe the phenomenon. Finland land is a good "laboratory" with fairly old car fleet, clear regional fleet differences and good distribution of car size classes.

The accident data is usually based on compensated insurance claims or police reported accidents. Those information sources vary a lot in reliability of recorded injury data. The main problem in the data is the grading of injury severities. In accident data based on insurance compensations, the grading is often done afterwards by the insurance company. In cases of minor injuries the injury type is not typically recorded. However, the accident data based on insurance compensations is still useful with its high number of observations because it gives information on different trends. Information on guilty driver is included in the data quite often as well.

Age and gender of the driver or car holder are often used in commensuration of research objects. Variables related to driving environment like urban /rural, speed limit and intersection / straight road are often taken into account as well. When concerning involved cars, for example mass, age, mileage and mass ratio of collided cars are usually taken into account.

Information on drivers' activities could be examined from detailed accident investigation reports, but they are usually done only in fatal cases. Therefore the number of those investigation reports is not sufficient to be used on car model level.

It is generally known that young drivers have significantly higher accident risk than experienced drivers. When the driver is getting older, like more than 65 years, the accident risk increases again but the proportions of accident types are different. The same variation of accident types comes out when comparing accidents of young and middle-aged drivers.

It is also generally known that different drivers prefer different car makes and models due to differences in transportation needs, financial positions and importance of car imago, for example. Effect of these variables in the results of ratings is inexplicable so far. However, several studies (eg. SARAC 1) have proved that the newest cars are the safest ones.

On national level, the results of the ratings depend for example on proportions of high class motorways, types of junctions and proportion of heavy vehicles. When concerning longer time periods or when comparing safety ratings from different years, it is obvious that general changes happened in traffic environment during those periods impairs the comparability of the results. Changes can happen for example in speed limit system, in traffic mode separation and in junction arrangements.

Making detailed numerical analyses based on international databases is impossible because information on drivers and the vehicles are recorded in different ways. For example, in Great Britain, cars involved in accidents are classified only according to motor volume and in France the classification is made by vehicle mass. In Finland for example, information on mass and motor volume of every single car is available for traffic accident research. When concerning the outcome of accident, it is more reasonable to analyse the cars based on mass information than motor volume information.

General trends in ratings are quite similar internationally. However, there may be small differences in rankings of single car models because of differences in rating methods and accident databases. This makes the international comparison of rankings more difficult. For example, results of SARAC I indicated some remarkable differences between car models in safety ratings. The results seemed to depend on different mass and age distributions of the car fleet. Therefore the rankings illustrate the performance of cars in home countries of the ratings. Consumers may feel the differences in rankings quite confusing which may also decrease the high value of ratings.

Car safety ratings have been made as long as 15 years in several countries. Driver populations and car fleets have went through significant changes during that time. There is no end for the changing in sight. A purpose of this report is to examine the most important effects of changes in driver populations and car fleets on ratings.

## 1.2 METHOD OF THE RESEARCH

The aim was to investigate in more detail how the fleet itself and the changes in the fleet influence the risk rates based on data from car-to-car and single vehicle accidents. Another interesting problem is how drivers' age and gender influence on ratings of car models.

There is a lack of internationally harmonized variables in the research data. For example, the classification of car age classes is different in different countries. This makes the comparison inexact. Furthermore, the low number of cases is a problem especially in Finnish data. Therefore the effects of selected variables on safety ratings and safety in general are mainly presented in form of variable-sensitive examples from different countries.

Many of the examples are based only on observations of one country and those examples may not take place in the same extent everywhere in Europe. A purpose of the examples is also to point out such explanatory variables which are affecting on rating results, but which have not been recorded at the moment in the accident data bases. The variables having the most significant influence on ratings and rankings may vary between different countries.

The research is, however, primarily a literature review. As supporting information sources for the study have been the data sets of Finnish car fleet, insurance years, accidents and injuries based on insurance compensations and data of vehicle technical specifications. **The car fleet** data set contains three cross-sections of the whole Finnish car fleet; in the years 1996, 1999and 2002 including the information of technical characteristics of each individual car and its owner details. Each data set consists of more than 2 million registered cars. The data of the **insurance years** reveal more detailed information about the use of the vehicles because only active insured years of the car models are recorded in this data set. Traffic **accidents** from 1994 to 2002 have been collected from yearly data set prepared by Traffic Safety Committee of Insurance Companies (VALT). Information on i**njured** persons is from the same source as accidents.

## 1.3 STRUCTURE OF THE STUDY

The study consists of three different parts. The first part discusses about occupant effect i.e. important driver variables from safety ratings' point of view. The first part presents the effects of drivers' age and gender on accident risks and accident profiles. Selected examples of car selection depending on drivers' characteristics are also presented.

The second part of the report is focused on the car fleet and its changes. The part presents the technical changes of car fleet and their safety effects of past 10-15 years. The phenomenon of geographical moving of car fleet according to car age is also presented.

The third part is about accident risks for different car models. In that chapter the risk figures from different countries are compared to each other. In different countries the studies are made from different basis and the results of the comparison are more or less describing the overall situation. This part of the study is describes the problems of the comparison.

# 2 OCCUPANT EFFECT

## 2.1 GENERAL

Car safety ratings are based on large accident data sets. When we try to explain different factors affecting on accidents or injuries, we are obliged to use average values or characteristics of occupants and vehicles. In advance, we know that there are great differences inside the sub-groups of analyses. Additionally, occupant and vehicle populations are continuously changing over the time. Sometimes it is very difficult to say whether the variables influences through driver or vehicle.

Variables influencing on accident or injury risks have many complex correlations. For example, driving environment influences on car selection and severity of accidents. Growing annual mileages and higher traffic volumes in urban areas increase the general risk to be involved in an accident. Mileage depends on the driver itself and his needs. The risk of injuries is higher when the impact speed is higher. The chosen speed depends on the driver and the environment. The injury outcomes depend on the driver itself (age, sex, use of safety restrains) but also about the opponent car and its aggressivity. High aggressivity in an accident, however, doesn't depend only on the opponent vehicle (mass, design, speed), but also the behaviour of the driver of the opponent vehicle (speeding, alcohol, inexperience). We know generally at least: the newer is the fleet the safer it should be, the older persons are the weaker are their bodies, more experienced drivers have less accidents.

## 2.2 DRIVER PROFILES

The results of car passive safety analyses based on accident databases may be quite skewed if certain variables related to the car occupants (i.e. drivers) have not been taken into account. Contorting influence of occupant variables may be high especially when comparing safety results of different cars models. Primary occupant variables discussed in this chapter are gender and age. Those variables influence more or less on driving behaviour, accident consequences and car selection, for example.

There are few ways how to estimate profiles for driver populations. The estimation can be done on traffic system level or on car model level. One method for estimating the potential influence of age and gender is to use the information on the numbers of driving licence holders. Those statistics give a general picture of distributions of different driver profiles but they don't tell anything about the driver's real life performance, like driving amounts or car model.

It has to take into account in international comparisons that there may be differences between national driving licence practices. In Finland, for example, a driver licence is valid until the driver reach age 70. After that a positive medical statement is needed if the driver wants to renew the licence. This may not be a common practice in all countries and therefore there may be significant differences in proportions of old driving licence holders. An example of statistics concerning British and Finnish driving licence holders is presented in Table 1.

According to Table 1 Finns have more driving licences per population than the British when concerning all licence holders. The proportion of driving licence holders is growing continuously in both countries. Especially, the proportion of female licence holders is growing very fast. However, it is detectable in both countries that the proportion of young licence holders is slowly descending. There is a big difference between countries in proportions of the oldest licence holders, but this may be explained by different national practises.

**Table 1. Proportion of driving license holders in Great Britain and in Finland related to the total population by age groups. Sources: Transport Statistics of Great Britain 2004, Statistics Finland**

| **Great Britain** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Age, all adults [%] | | | | | | | |
| Year | **17-20** | **21-29** | **30-39** | **40-49** | **50-59** | **60-69** | **70 or over** | **All** |
| 1975/1976 | 28 | 59 | 67 | 60 | 50 | 35 | 15 | 48 |
| 1985/1986 | 33 | 63 | 74 | 71 | 60 | 47 | 27 | 57 |
| 1995/1997 | 42 | 73 | 81 | 82 | 74 | 64 | 39 | 68 |
| 2002 | 32 | 67 | 82 | 84 | 81 | 70 | 45 | 71 |
| | Age, male [%] | | | | | | | |
| 1975/1976 | 36 | 78 | 85 | 83 | 75 | 58 | 32 | 69 |
| 1985/1986 | 37 | 73 | 86 | 87 | 81 | 72 | 51 | 74 |
| 1995/1997 | 48 | 79 | 89 | 89 | 88 | 83 | 65 | 81 |
| 2002 | 34 | 74 | 88 | 91 | 89 | 85 | 68 | 81 |
| | Age, female [%] | | | | | | | |
| 1975/1976 | 20 | 43 | 48 | 37 | 24 | 15 | 4 | 29 |
| 1985/1986 | 29 | 54 | 62 | 56 | 41 | 24 | 11 | 41 |
| 1995/1997 | 36 | 67 | 74 | 74 | 61 | 46 | 22 | 57 |
| 2002 | 31 | 60 | 77 | 79 | 74 | 56 | 28 | 61 |

| **Finland** | Age, all adults [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | **18-19** | **20-29** | **30-39** | **40-49** | **50-59** | **60-69** | **70-** | **All** |
| 1990 | " | 89 | 88 | 83 | 69 | 47 | 15 | 71 |
| 1996 | 74 | 88 | 91 | 87 | 80 | 61 | 23 | 75 |
| 2000 | 70 | 87 | 93 | 90 | 84 | 70 | 29 | 77 |
| 2003 | 74 | 85 | 93 | 91 | 86 | 74 | 33 | 79 |

| | **Male, all [%]** | **Female, all [%]** |
|---|---|---|
| 1993 | 88 | 60 |
| 1997 | 90 | 64 |
| 2002 | 92 | 68 |

Information on car ownership and occupant profiles can be found from car registration records. In Finland it is possible to have for research use information on car owners' home municipality, year of birth and gender. All registered cars are included in the dataset. However, quite often the recorded owner of the car is not the actual user of the car. Comparison between Finnish accident and registration databases revealed some 60% match between drivers involved in accidents and the owners of cars.

Information on driver populations and on their car selection can also be examined by analysing only accident databases. On some level, accident databases can be seen as an expression of drivers' real life driving behaviour and car selection. Of course, there are many limitations in this supposition, like over representing of risky drivers in the accident database.

Table 2 and Figure 1 illustrate the interactions of different Finnish information sources. For example, males from 18 to 24 years have 6% of all driving licences and 5% of all registered passenger cars. However, they have been involved in 17% of accidents compensated by insurance companies when concerning guilty drivers only. Furthermore, some 17% of all drivers injured in those accidents have been males from 18 to 24 years.

Young male drivers but also young females have been involved in larger number of accident than it can be expected according to their driving licence and car ownership numbers. However, accident proportion of middle-aged males is quite small in comparison to the volume of their car owning. This phenomenon comes out quite well from the Table 2.

**Table 2. Licences: proportion of driving licence holders by gender and age related to all driving licence holders. Average 2001-2003. Car owners: proportions of passenger cars by owners' gender and age. End of year 2002. Accidents: proportions of drivers involved in accidents as guilty. Injured drivers: proportions of injured drivers in all accidents. Accident data from years 2001-2003.**

| | Male | | | | Female | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | 18-24 [%] | 25-44 [%] | 45-64 [%] | 65-84 [%] | 18-24 [%] | 25-44 [%] | 45-64 [%] | 65-84 [%] | All [%] |
| Licences | 6 | 21 | 21 | 7 | 5 | 19 | 17 | 3 | 100 |
| Car owners | 5 | 27 | 28 | 10 | 2 | 12 | 12 | 3 | 100 |
| Accidents* | 17 | 23 | 17 | 7 | 6 | 12 | 8 | 2 | 100 |
| Injured drivers | 17 | 20 | 17 | 9 | 8 | 13 | 10 | 3 | 100 |

*guilty

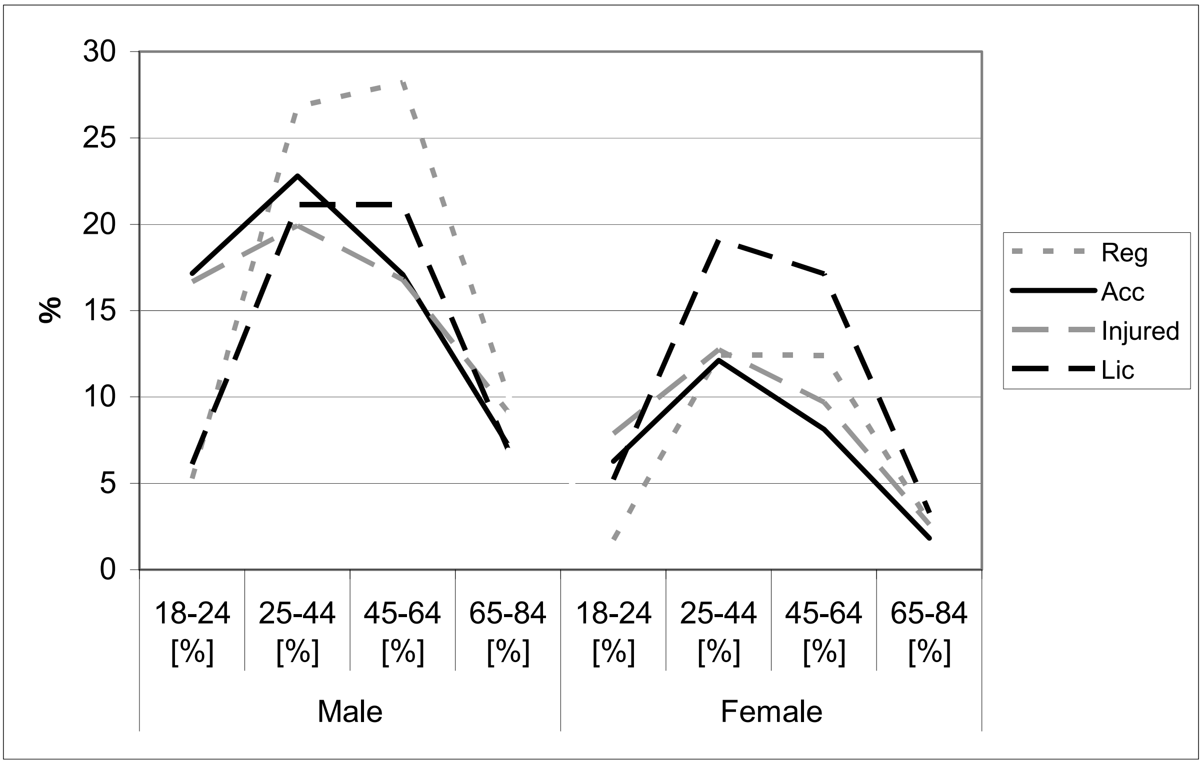


**Figure 1. Reg: proportions of passenger cars by owners' gender and age in Finland at the end of year 2002. Acc: proportions of drivers involved in accidents as guilty. Injured: proportions of injured drivers in all accidents. Finnish accident data from years 2001-2003. Lic: Finnish driving licence holders by gender and age in proportion to all driving licence holders, average 2001-2003.**

According to Figure 1 there are many middle-aged female licence holders i.e. potential drivers who are not car owners. On first hand, small accident proportion of female drivers in relation to their driving licenses suggests that a remarkable part of females do not drive a lot. On the second hand, female drivers seem to have relatively high number of accidents and injuries related to the female owned cars. This suggests that many female drivers use cars registered to middle-aged males. The same relates with young drivers, who often use cars owned by their parents, relatives or friends.

## 2.3 DRIVER GROUPS AND THEIR CAR MODELS

Some of the differences in accident types and accidents amounts between different car models can be explained by differences in their driver populations. That is, driving habits and routines varies between driver profiles. Also, physiological dimensions vary between drivers. However, cars and locations of safety equipments are designed to "average drivers" so that the suitability of cars is good for majority of the potential car users. Therefore the protective effect of safety equipments may not be as perfect as possible for marginal group of drivers.

It can be said on certain level that the use of cars depends on driver profiles. For example, driving for fun is more typical to young than old drivers and to males than females. When excluding professional driving, night time accidents are very typical to young drivers due to their high night time mileages. Mileages driven annually vary between driver profiles as well. Middle-aged males have the highest mileages and old females have the lowest ones. Consequently, car models preferred by much driving profiles are highly exposed to the accidents.

Generally, the car selection in terms of car's age and size depends also on driver profiles. Different profiles have different needs. Families with children require a lot of passenger and luggage capacity and that is why they prefer for example large station wagons. Young drivers drive often by quite old and small cars because usually they can not put much money in their first cars. However, they don't usually require a lot of loading capacity. Old drivers seem to select quite often smaller car models. This kind of estimations has been presented in most European countries.

In safety ratings we are obliged to use "average populations" both for the drivers, their age and sex, their car use and the distributions of driven mileages, for example. In this paper it is not possible to show any results about the numerical comparisons how much different factors really influence on rating results by make and model. The following examples picked from Finnish car fleet will describe those remarkable differences we can find among some selected car models. It is clear that this kind of differences can be seen in any countries, but not necessarily within the same models.

Table 3 illustrates as an example the proportions of car owners for 8 general car models based on the Finnish Vehicle Register. The table shows roughly that the larger the car is the often they are owned by middle-aged males. Smaller cars, like Micra and Clio are more owned by females.

**Table 3. Proportion of owners for 8 selected car models in Finland at the end of year 2002. Example: 8% of all Nissan Micra cars are registered to males from 25 to 44 years.**

| | Male [%] | | | | Female [%] | | | |
|---|---|---|---|---|---|---|---|---|
| **Car model** | **M18_24** | **M25_44** | **M45_64** | **M65_84** | **F18_24** | **F25_44** | **F45_64** | **F65_84** |
| Nissan Micra | 1 | 8 | 14 | 14 | 2 | 18 | 32 | 10 |
| Renault Clio | 4 | 15 | 15 | 8 | 3 | 21 | 27 | 6 |
| VW Golf | 4 | 30 | 24 | 8 | 1 | 15 | 15 | 3 |
| Toyota Corolla | 2 | 17 | 32 | 17 | 1 | 10 | 19 | 3 |
| Ford Mondeo | 2 | 38 | 33 | 8 | 0 | 10 | 7 | 1 |
| Opel Vectra | 5 | 34 | 31 | 9 | 1 | 10 | 8 | 1 |
| Volvo 850,70 | 2 | 41 | 35 | 5 | 0 | 10 | 7 | 1 |
| MB E-series | 1 | 24 | 52 | 8 | 0 | 5 | 9 | 1 |

Figure 2 illustrates the development of car ownership within the same 8 models by owners' age and gender. The cars observed in the Figure 2 have been taken in use during years 1993–1995. It can be seen that the older small cars get the more they are registered to females. Large cars are registered all the time to males. Figure 2 shows also for young males and females that the number of registered cars is the higher the older are the cars.

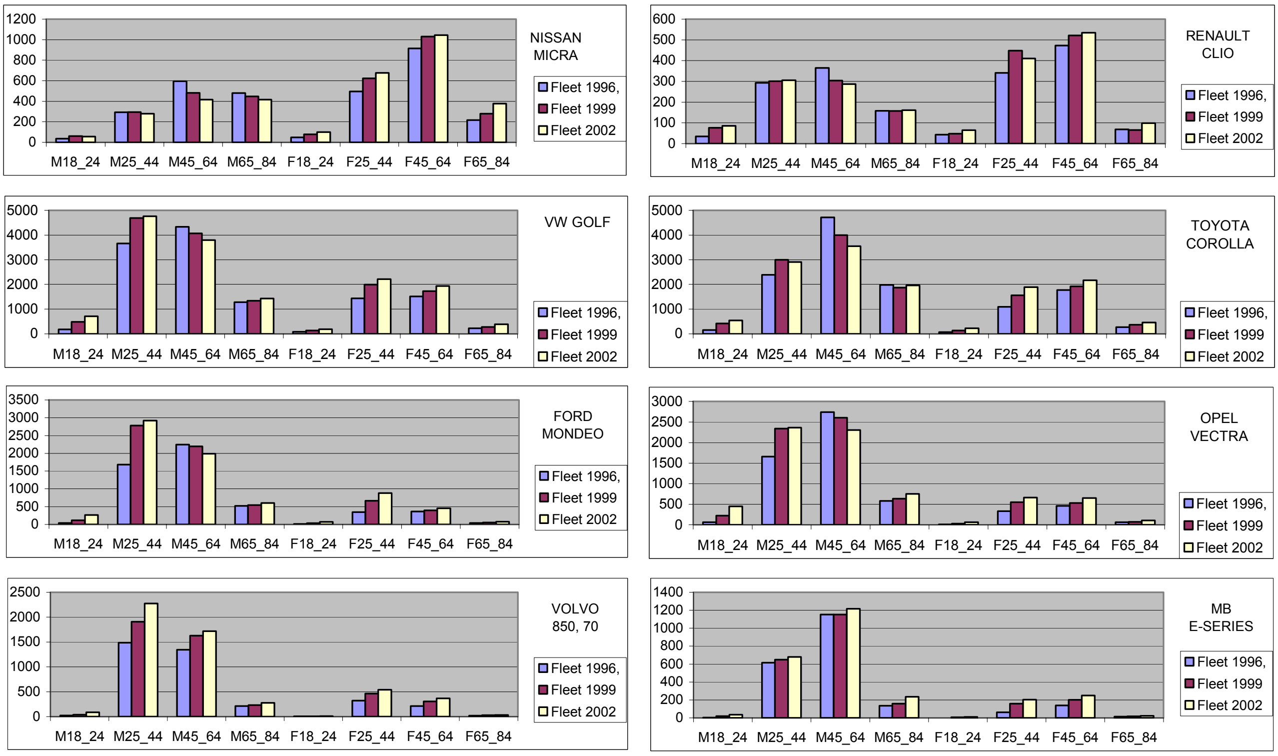


**Figure 2. Development of the numbers of cars registered to different owner profiles. The cars have been registered first time during the years 1993–1995. Finnish car fleet data 1996, 1999 and 2002.**

This occurrence of car selection influences in results of passive safety analyses based on real-life accidents. The influence of car selection is bidirectional: it influences in results concerning safety performance of car models but also in calculated accident and injury risks of driver populations.

If the proportion of "vulnerable" users of certain car model is large compared to the other car models, will the safety analyses give too negative results for observed cars. Moreover, if the vulnerable drivers use old and small cars, like it seems to be according to Figure 2, it is quite obvious that the drivers will get injuries in accidents. Respectively, if the drivers have higher probability of accidents, will the cars be involved in larger amount of accidents and the safety analyses will give too negative results again.

## 2.4 ACCIDENTS AND DRIVING BEHAVIOUR

Some differences can also be found by analysing driving behaviour and accident profiles of different driver populations. It is well known that young and old drivers have high accident risks. Injury risk of old drivers and female drivers in general, is high as well. For example, Evans (1991) found for females at age group 15–45 years that they are approximately 25% more likely to kill than males of same age in similar accidents. As mentioned before, those injury risks may be partly explained by car selection.

Evidence of clear difference on accident risks of young and old driving licence holders is provided in Figure 3. The accident risk of a driver older than 65 years is not remarkably high when the accident numbers are presented in proportion to the number inhabitants. When the exposure is the number of driving licence holders, which describes better the true number of drivers, the risk raises rapidly. Instead, the accident risk of young drivers is high in both cases. This is a consequence of remarkably higher share of driving licence holders among young people.

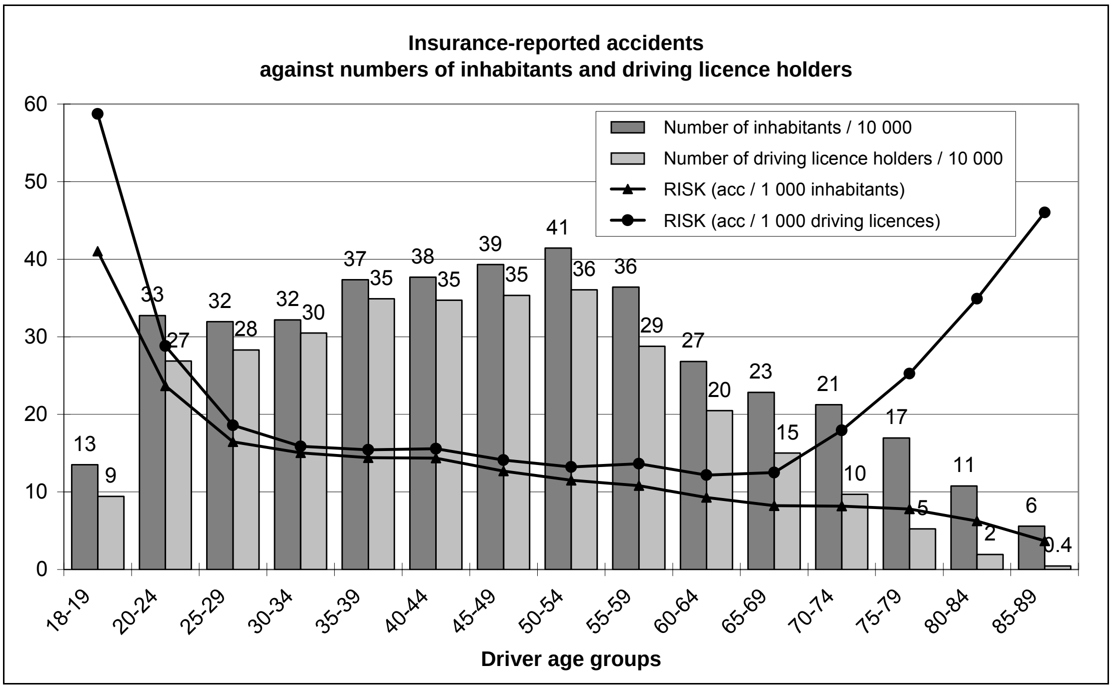


**Figure 3. Accident risks per inhabitants and driving license holders by age groups classified according to guilty car drivers. Source: Finnish insurance data from 2001 and 2002.**

Proportions of different accident types vary in relation to drivers' age. This is a consequence of changes in drivers' physical and mental performance and age-dependent changes in driving behaviour and routines as well. Proportions of different accident types for drivers of different ages based on Finnish accident data are presented in Table 4. Junction accidents are quite typical for old drivers due to their impairing ability to handle complex traffic situations. Many old drivers do therefore avoid driving during dark and rush hours. Small proportion of rear-end accidents supports the assumption of old drivers' tendency to avoid driving in rush city traffic.

Gender and age can also be found from backgrounds of attitude problems towards to safety equipments and traffic rules. For example, the use of safety belts is more popular among female drivers than male drivers. Also, male drivers are more often caught of speeding, drunken driving and other gross traffic offences than female drivers.

High speed run-off-road accidents are typical to young drivers for example due to unnecessary risk taking. In general, risk compensation by increased risk taking seems to be quite typical at least in some level to most male drivers. Young drivers' high proportion of run-off-road accidents is detectable also from Table 4.

**Table 4. Accident types by driver's age. Data: Personal injury accidents compensated by Finnish insurance companies 1997–2003. Drivers only. Curb weight of involved cars 1000–1700 kg.**

| Age | Proportion of accidents [%] | | | | | All |
|---|---|---|---|---|---|---|
| | Head-on | Junction | Run-off-road | Rear-End | Others | |
| 18-24 | 8.3 | 22.6 | 28.6 | 23.9 | 16.7 | 100 |
| 25-54 | 7.7 | 22.1 | 17.7 | 26.5 | 26.0 | 100 |
| 55- | 6.6 | 31.7 | 20.0 | 16.6 | 25.0 | 100 |

Traffic environment influences in severity of accidents and injuries. Car driver's injury risk per accident is much higher on highways than on city streets due to higher collision speeds. Therefore it is reasonable to find out if there are significant differences in typical driving environments between different driver groups.

In Figure 4 the possible differences in driving environments among different driver groups have been approached as a basis of location of accident site. Finnish accident database, based on insurance compensations, consist information whether the accident has taken its place on urban area indicated by certain traffic signs. According to a curve presented in Figure 4 about 85% of all accidents compensated by Finnish insurance companies have been urban area accidents. The proportion of urban area accidents does not differ significantly among driver populations.

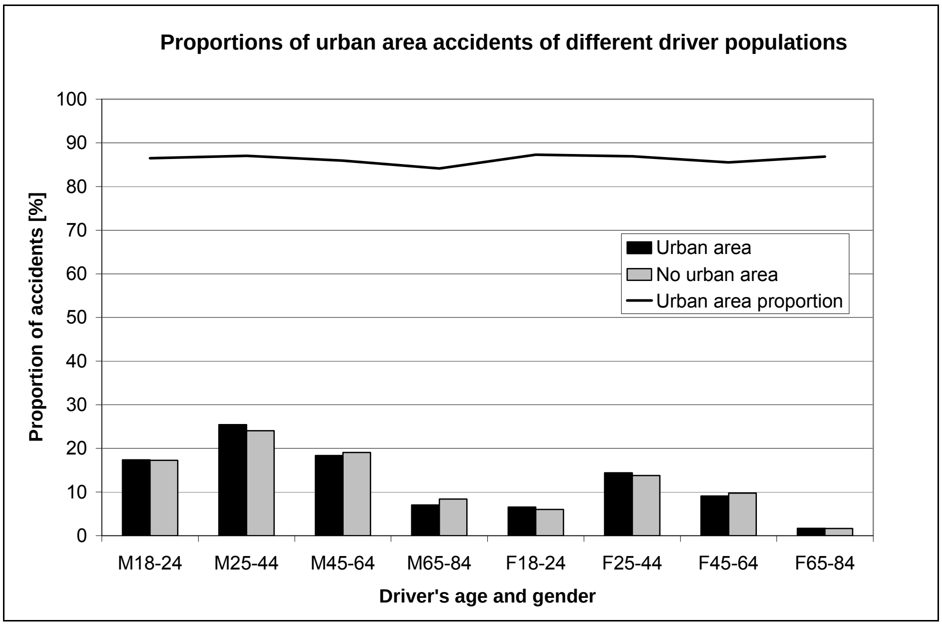

**Figure 4. Proportions of urban and rural accidents by different driver population. Guilty drivers only. Black bars illustrate the proportions of accidents in relation to all urban area accidents in data. Grey bars illustrate no-urban area accidents, respectively. For example, males 18-24 years have incurred some 18% of all urban area accidents. Black curve above the bars illustrates the proportion of urban area accidents in relation to all accidents of each driver profile. For example, 87% of all accidents incurred by males age 18-24 have taken their place at urban area. Data: passenger car accidents compensated by Finnish insurance companies 1999–2003.**

According to Figure 4 males and females from 25 to 44 years have incurred a little bit more urban area accidents than no-urban area accidents. Respectively, males from 45 to 84 years have incurred a little bit more no-urban area accidents, respectively. Noteworthy, drivers from 18 to 24 years have only some 10% of all driving licences but they have incurred some 25% of all accidents in urban areas and no-urban areas. In general, the distributions of urban area and no-urban area accidents of different driver populations are very similar.

As shown before, the owner and true driver populations differ widely by car models. The proportions of incurred accidents differ by car models and different driver populations. Injuries or fatalities in those accidents depend on driver and car populations as well. The use of the car models (for example rural/urban) influences also to the proportions of accidents and injuries. This variation can be reviewed with an example of selected car models in Table 5.

Table 5 illustrates the distributions of all guilty and injured non-guilty drivers of selected car models based on accidents compensated by Finnish insurance companies. A purpose of the table is to find hints of the possible influences of driver-car interaction.

**Table 5 Percentages of accident involvements of guilty drivers and percentages of all injured drivers (in parentheses). Dataset: Injury accidents compensated by Finnish insurance companies 2001-2003. Parking areas and private roads excluded.**

| | Male [%] | | | | Female [%] | | | | SUM | All |
|---|---|---|---|---|---|---|---|---|---|---|
| **Car model** | **M18_24** | **M25_44** | **M45_64** | **M65_84** | **F18_24** | **F25_44** | **F45_64** | **F65_84** | | **drivers** |
| Nissan Micra | 13 (8) | 9 (10) | 7 (5) | 12 (16) | 11 (11) | 14 (17) | 18 (15) | 8 (14) | 92 (96) | 100 (100) |
| Renault Clio | **19 (13)** | 19 (16) | 1 (6) | 10 (8) | **3 (16)** | 19 (19) | 17 (9) | 3 (6) | 91 (93) | 100 (100) |
| VW Golf | 15 (12) | 19 (21) | 13 (15) | 6 (10) | 8 (8) | 18 (15) | 10 (11) | 2 (3) | 91 (95) | 100 (100) |
| Toyota Corolla | 14 (12) | 16 (14) | 15 (15) | 16 (14) | 7 (11) | 12 (12) | 10 (15) | 4 (4) | 94 (97) | 100 (100) |
| Ford Mondeo | 8 (5) | 24 (28) | 26 (27) | 7 (9) | 4 (6) | 12 (14) | 10 (6) | 1 (1) | 92 (96) | 100 (100) |
| Opel Vectra | 13 (16) | 25 (24) | 20 (21) | 8 (9) | 4 (4) | 12 (12) | 9 (9) | 0 (0) | 91 (95) | 100 (100) |
| Volvo 850,70 | 5 (8) | **40 (29)** | 29 (30) | 2 (3) | 2 (2) | 12 (16) | 4 (6) | 0 (1) | 94 (95) | 100 (100) |
| MB E-series | 8 (6) | **37 (26)** | 34 (31) | 4 (8) | 3 (4) | **3 (11)** | 5 (6) | 0 (0) | 94 (92) | 100 (100) |
| SUM | 12 (11) | 23 (20) | 18 (19) | 9 (10) | 6 (8) | 13 (14) | 10 (11) | 3 (3) | 92 (96) | 100 (100) |

Unfortunately, the absolute numbers of observations for Table 5 are relatively low (see appendix 1 for the absolute numbers). However, the figures in Table 5 reflect large differences in driver populations between different car models. For example, females from 18 to 24 years have incurred 3% of all 'guilty' accidents of Renault Clio. Instead, 16% of all drivers injured in Renault Clio have also been females from 18 to 24 years. That is, young females have been more often the opposite party of accidents than guilty. For young males, the proportions are in reverse order. Consequently, these differences may reflect on the results of car safety ratings because the injury risks of guilty and opposite drivers are known to be different.

## 2.5 AGEING OF DRIVERS

In Europe car driver populations are generally getting older because younger age groups are typically smaller than the age groups of their parents. This can be roughly seen also from driving licence statistics. In Finland, for example, the trend of driving senior citizens is developing due to increased life expectancy. The average age of driving licence holders is increasing every year by 0.6–0.7 years. This kind of trend will be obvious in the whole EU.

In the cities students and working population live more often without a car due to increasing level of urbanization. This means that people in the cities are not obtaining the driving license, nor buying a car immediately after 18th birthday, but maybe just when they are building the family.

The large age groups, born after the World War II, are getting boundary of 60 years. This influences also on the increasing proportion of driving senior citizens. For the elderly people a car the easiest way to keep up the moving and the contacts to the surrounding world especially in the rural area. It is estimated that in 2013 15–20 percent of people having driving license are 65 years or older; while today in 2005 the amount is 11 percent. The Finnish trends of population and driving licence holders of different age groups are presented in Figure 5.

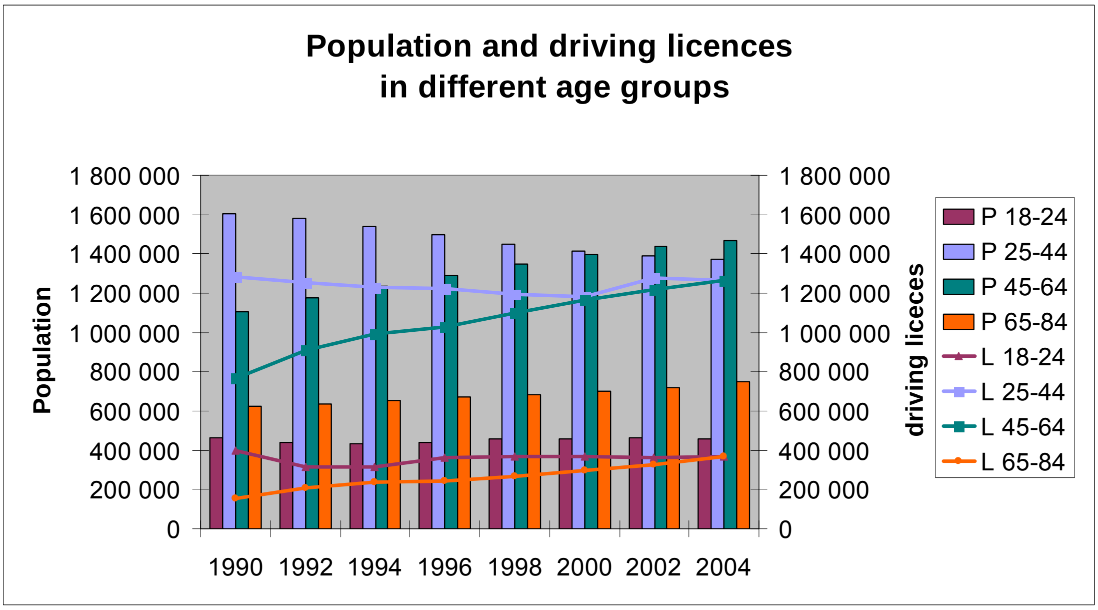


**Figure 5. Bars present the population of different age groups in Finland. Curves illustrate the numbers of driving license holders in different age groups. Source: Statistics Finland. P=Population, L=Licences**

The age trend of driving licence holders of Great Britain is quite similar with Finland (Table 1). The proportion of licence holders among middle-aged and female licence holders is growing quite fast in both countries. The proportion of young licence holders seems to be decreasing in Great Britain.

Ageing of the drivers can be seen as continuously increasing risk factor. Accident risk of drivers older than 65 years is remarkably higher than risk of drivers between 25 and 64 years. Consequences of car accidents are more severe for seniors than for younger people. A person 65 or older who is involved in a car accident is more likely to be seriously injured, more likely to require hospitalization, and more likely to die than younger person. In particular, fatal crash rates rise sharply after a driver has reached the age of 70.

The motor vehicle death rate per 100,000 people begins to increase among males at age 65. By age 80 and older, the rate among males is more than twice as high as it is at ages 40-74.

At all ages, males have much higher motor vehicle death rates per 100,000 people compared with females. By age 85 and older, the rate is more than 3 times as high among men as among women.

# 3 FLEET EFFECT - TRENDS OF CAR FLEETS FROM 1990 TO 2005

## 3.1 FLEET EFFECT IN GENERAL

This car fleet analysis is focused on the trends of physical dimensions and characteristics of cars. Some of the calculations are based on car fleet data and the other are based on the accident databases. The degree of the usage of the cars of different sizes is not very clear. We do not exactly know the time different car models spend in traffic, but the average mass of the cars in traffic can be estimated by analysing accident data and car registration data.

There are several factors affecting on the car fleet and its safety. In the safety ratings it is not possible to take all of them into consideration. These kind of factors are for example annual mileage, time spent in traffic, ageing of car and moving owner and driver characteristics.

When a car is ageing its annual mileage, its use environment and its drivers and owners normally change. Perhaps also more risky driving behaviour with the car increases. The risk to be involved in accidents changes as well. Different driver populations are more favour in certain car models, also from older ones, which causes differences between the risk levels of various model fleets. This phenomenon influences also on the whole fleet and its safety.

Of course the findings of improved vehicle safety based on more advanced car design and increased mass have impacts on the safety of the fleet and different way in different countries. A lack of similar recording statistics in different countries makes the identical comparisons difficult, but a deeper analysis even from one country may give a relevant hint from the progress from safety rating point of view.

The size of registered new vehicles tends to increase continuously. The changes in vehicle mass, wheelbase and engine power during recent years is described in the following chapters. Today especially new small and medium sized cars are getting heavier due to changes in kerb structures and increased numbers of safety equipments and comfort accessories.

## 3.2 MASS CHANGES IN THE CAR FLEET

Comparisons of car mass are problematic, because there are no identical mass statistics available in different countries. Even the definition of car mass seems to vary in statistics recorded by different authorities in different countries. Thought in the EU legislation there is a directive (92/21/ETY), which particularly defines the car mass. Unfortunately the old practices have remained in many registers. Looking at the development of car mass in time in a certain country, it is more important that the recording system has been the same during the investigation period.

It has been shown in several studies that vehicle mass has a dominant influence on the consequences of two-car crashes. When cars from the lightest and the heaviest categories crash with each other, the driver in the lighter car is about 17 times more likely to die than the driver in the heavier car (Evans 1991).

The average mass of cars involved in accidents in France and Finland is shown in Figure 6. The mass average is increasing quite continuously. The average mass of cars in accident data has increased more than 100 kg during the 10 years in both countries. The growth of the average mass in the French car fleet has been parallel with Finland. On average, the French car fleet seems to be some 100 kg lighter than Finnish fleet.

The growth of the average mass of the Finnish and Spanish car fleets is shown in Figure 7. From Spain is only 10 most popular car models in this calculation. During the last 5 years the average mass in Spain has increased over 100 kg. The growth of the average mass in whole fleet is not what is preferable. The heavier the cars are the bigger the fuel consumption will be. The safety and compatibility of the cars should be the main target.

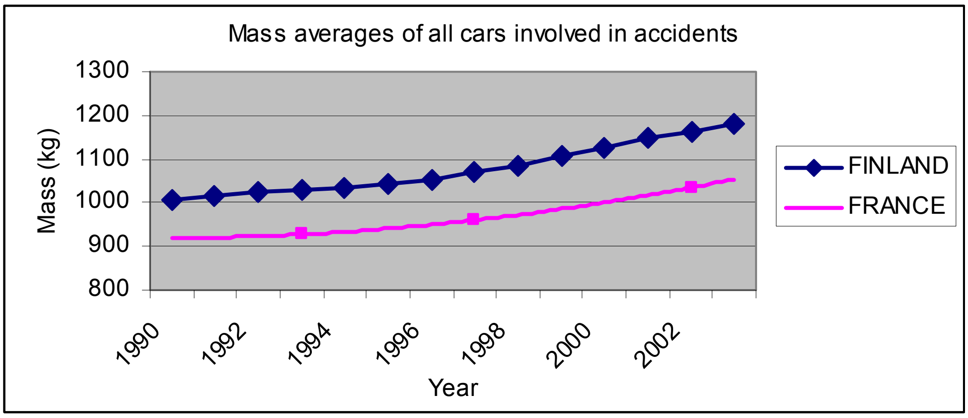


**Figure 6. Growth of the average mass of cars involved in accidents in France and Finland . Sources: Accidents compensated by insurance companies in Finland (VALT), French national database of road accidents**

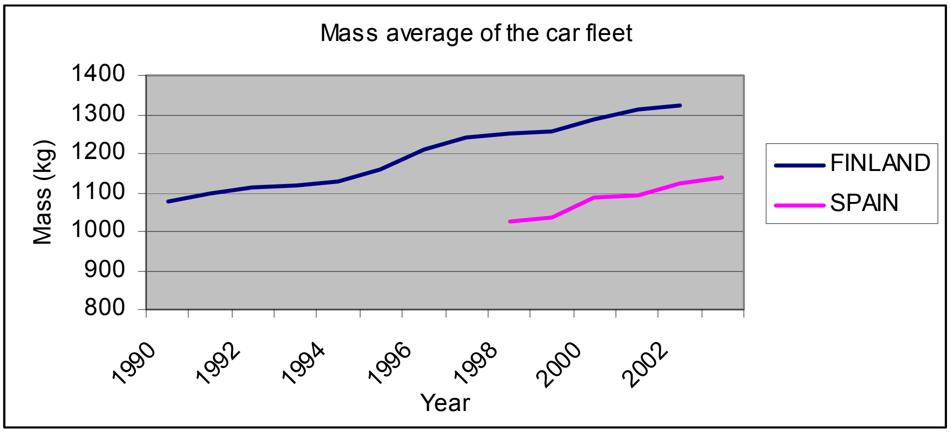

**Figure 7. Average mass of car fleet in Finland and 10 most popular car models in Spain Sources: Finnish Motor Vehicle Register, Olona 2005.**

An average mass of smaller cars has increased relatively more than the mass of larger car models. At the same time the relative gap of masses between smaller and bigger cars has become narrower. In Finnish accident data, for example, 10 years ago 74 per cent of the cars which involved in accidents belonged to mass group 700–1100 kg. Nowadays the proportion is less than 40 per cent.  All other mass groups have gained their proportions in the fleet (Figure 8). This reflects on the other hand an increasing popularity of larger cars but also increasing curb weights of newer car models. Furthermore, lighter cars will typically be replaced in traffic with heavier and larger cars.

In France (Figure 9) the profile of car size groups is similar with the Finnish one. The proportion of size group 700–1100 kg is, however, more popular in France than in Finland. In France the proportion of the mass group 700–1100 kg in the fleet still exceeds 60 per cents. The distribution between the other size groups is getting more balanced in France.

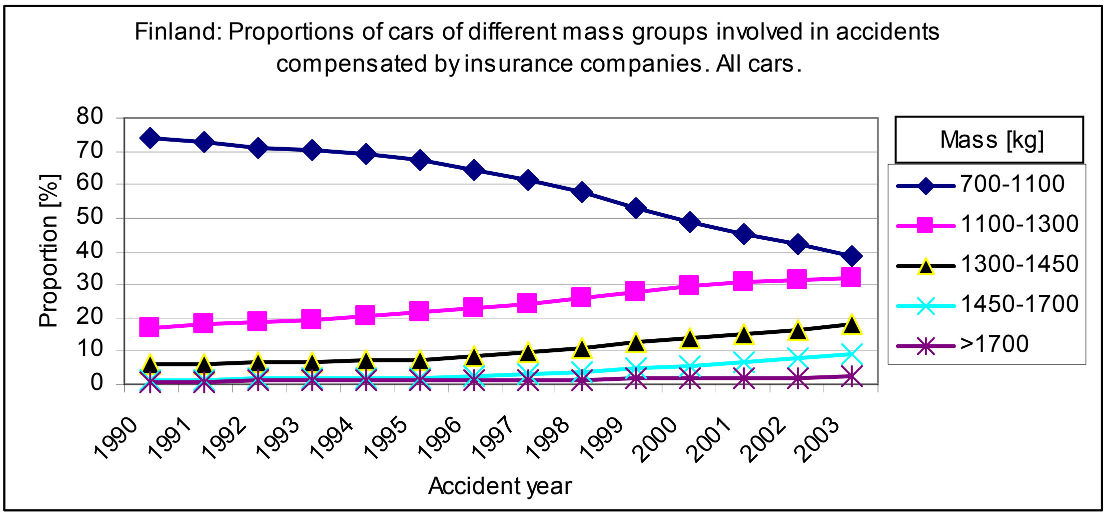


**Figure 8. Mass distribution of cars involved in accidents in Finland. Source: Statistics of accidents compensated by Finnish insurance companies 1990-2003**

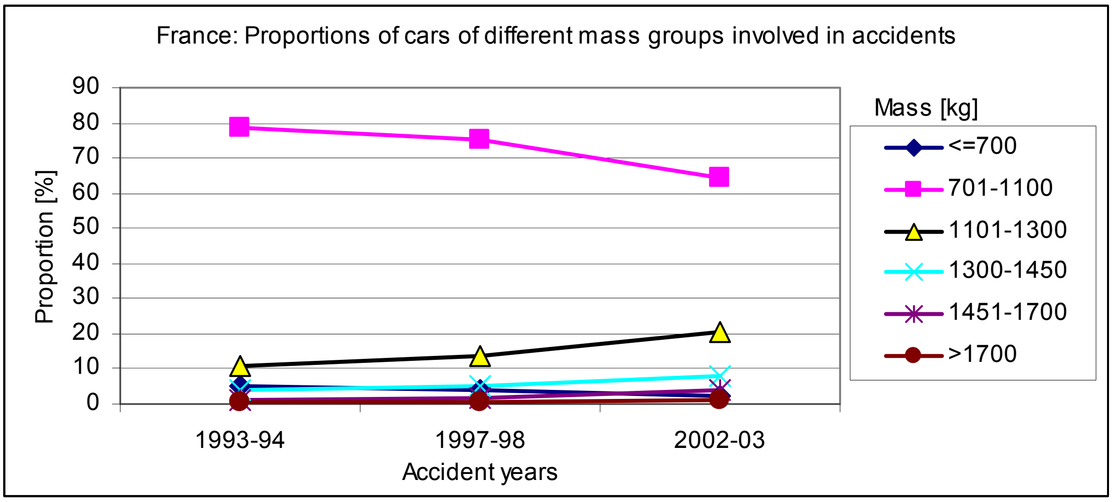


**Figure 9. Mass distribution of cars involved in accidents in France. Source: French national database of road accidents.**

## 3.3 CHANGES IN THE POPULARITY OF CAR SIZE CLASSES

In generally the size classes has been divided to classes by engine volume or purpose of use point of view.

In Spain (Figure 10) Centro Zaragoza has obtained a data set of most sold cars in Spain in 1994–2003. The data is classified according to the following variables; engine volume, maximum speed and masses of the most powerful and the weakest engine variant. When observing the Spanish cars from their engine volume point of view, there are no big changes in the amounts of cars with smallest and largest engine size classes. Instead, the new registrations in engine volume classes 1.2 to 16 litres and 1.6 to 1.9 litres have increased in total some 70% from the year 1994.

In UK (Figure 11) the fleet has been classified also according to the engine volume, but the limits of the four classes differ from the Spanish ones. The vehicle fleet consists of clearly larger cars compared to Spain. The engine volume class 1.2 to 1.8 litres is the most popular in UK and has increased its market share from 1994 as it has taken place also with the class of 1.9 to 2.5 litres. The popularity of high-end and low-end groups have remained roughly on the same levels during the last ten years (1993-2003).(DfT, 2003 a)

The car fleet in Australia is clustering to large and small cars. This trend has continued since 1980 (Figure 12 and Figure 13). This development is not good for the total compatibility of the fleet. Crashes between large car and small car product more severe injuries and fatalities compared to crashes between cars of relative same size. The remarkably quick reduction of the proportion of middle-size cars in Australia is astonishing ( Figure 13), because middle-size seem to grow their market share in Europe.

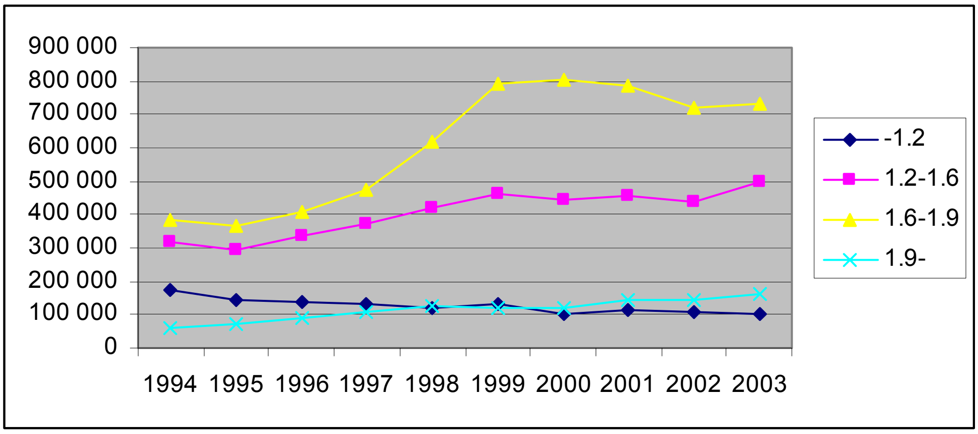


**Figure 10. The numbers of registration for ten most popular cars by engine volume in Spain. (Olona 2005)**

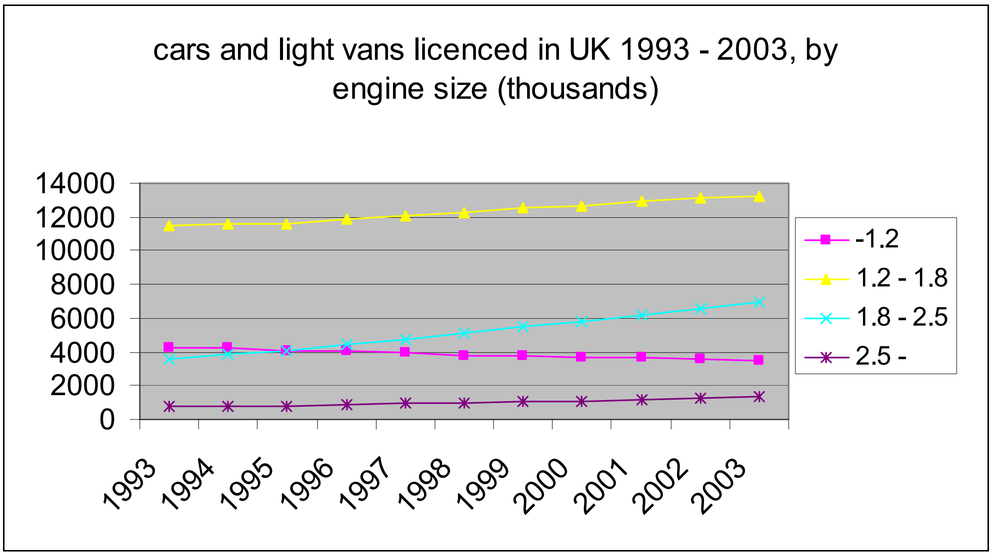


**Figure 11. Vehicle licensing numbers by engine volume in UK (Transport Statistics Bulletin**

**2003 a)**

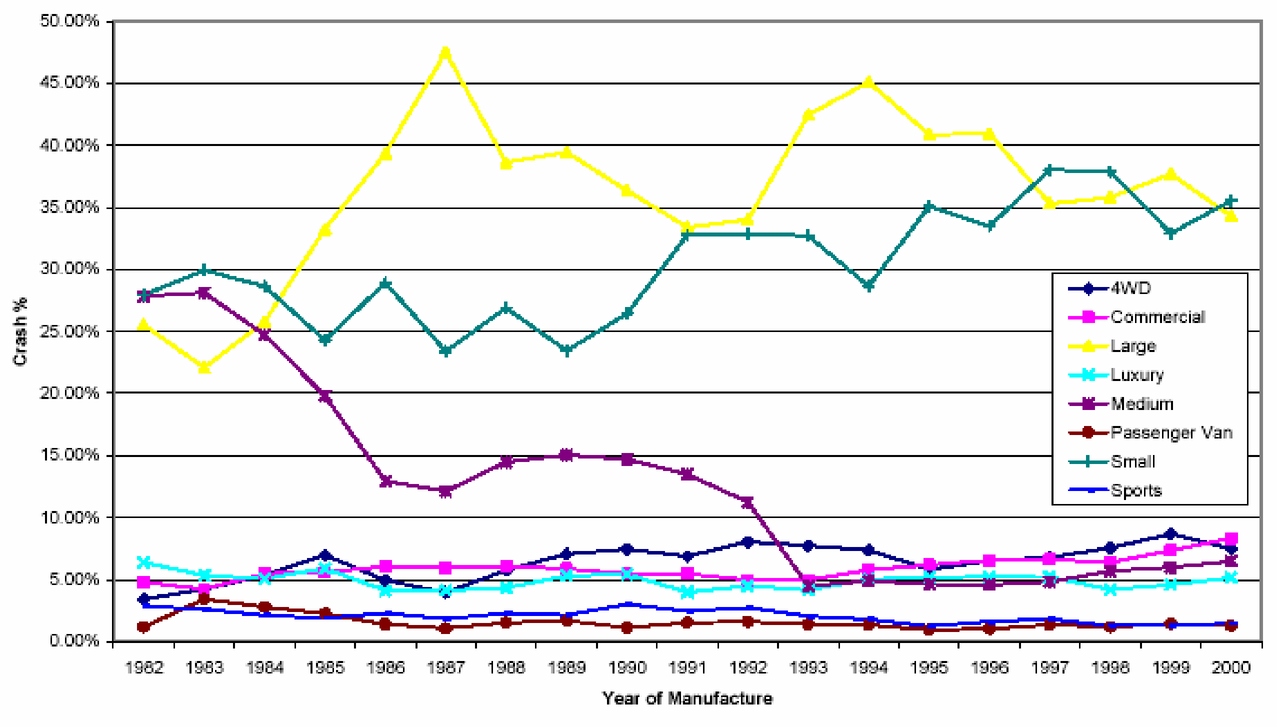


**Figure 12. Crash population composition by vehicle market group and year of manufacture. (Newstead et al. 2004 b).**

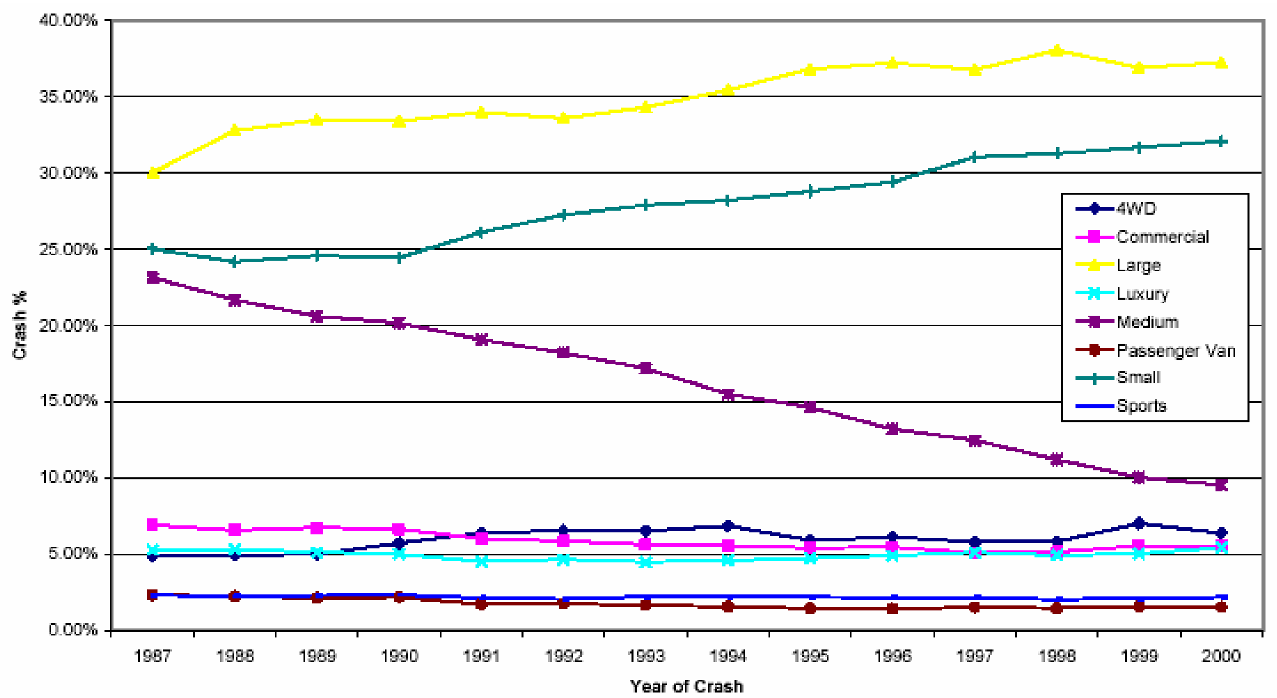


**Figure 13. Crash population composition by market group and year of crash. (Newstead et al 2004 b)**

## 3.4 OTHER FEATURES OF CAR FLEET

### 3.4.1 Wheelbase and body type

Cars with short wheelbase may be more susceptible to skidding and rollover accidents than those with longer wheelbase. Wheelbase is commonly used for grouping of car models. Cumulative distribution of wheel base of new cars (car age under 3 years) at three moments of examination based on Finnish car fleet data is presented in Figure 14. In Finland the average of wheel base of registered cars has grown from 2548 mm to 2590 mm during years 1996 to 2002. Contrary to mass averages of Finnish car fleet, the intersection between curves and x-axis has maintained its position all the time.

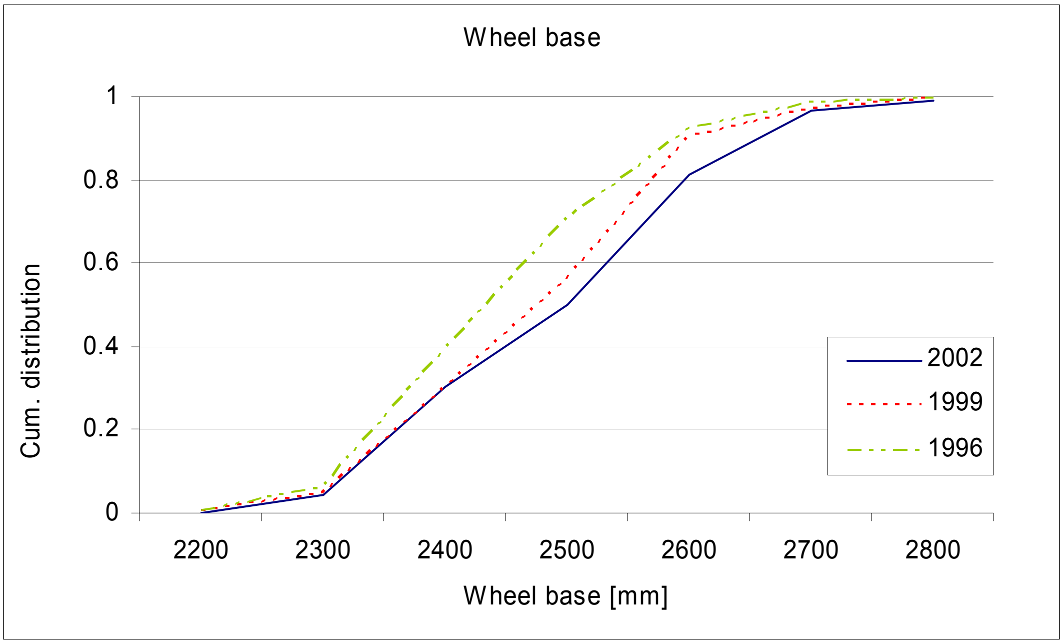


**Figure 14. Cumulative wheel base for new (under 3 years old) cars in the Finish fleet in 1996, 1999 and 2002.**

Comparison of cars registered in Finland in 1996, 1999, 2002 reveals a clear change in the popularity of different body types of new cars. The most remarkable change is increased popularity of station wagons (Figure 15). The role of station wagon has also changed towards to regular family car. The proportion of station wagons in relation to all registered cars has increased from 10% to some 17%. In this moment there is equal a mount of new registrations of sedans and station wagons. Popularity of hatchbacks and coupes has not changed remarkably. In 1996 Finnish car fleet consisted 1 047 398 sedans and 166 586 station wagons while in 2002 the fleet consisted 994 101 sedans and 354 074 station wagons.

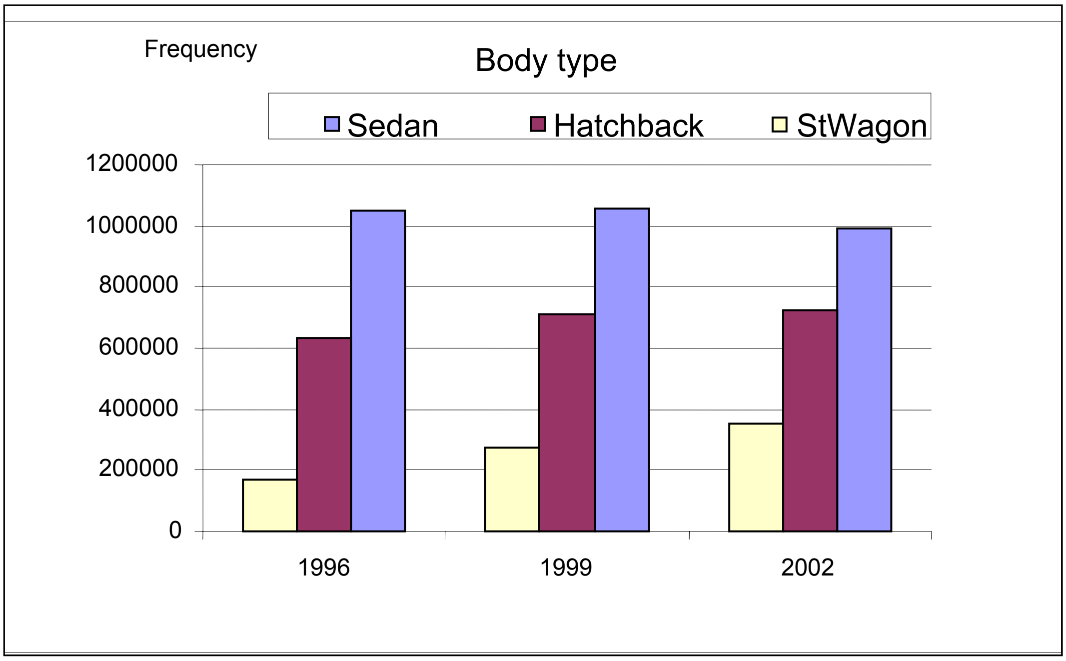


**Figure 15 Frequency of different body types in the Finnish fleet in 1996, 1999 and 2002.**

When comparing new cars (1-3 years old ones) from car fleets 1996 and 2002 (Figure 16) it can be seen that 56% of the fleet were sedans and 10% station wagons in 1996. In 2002 the proportions were 48% of sedans and 18% of station wagons, respectively.

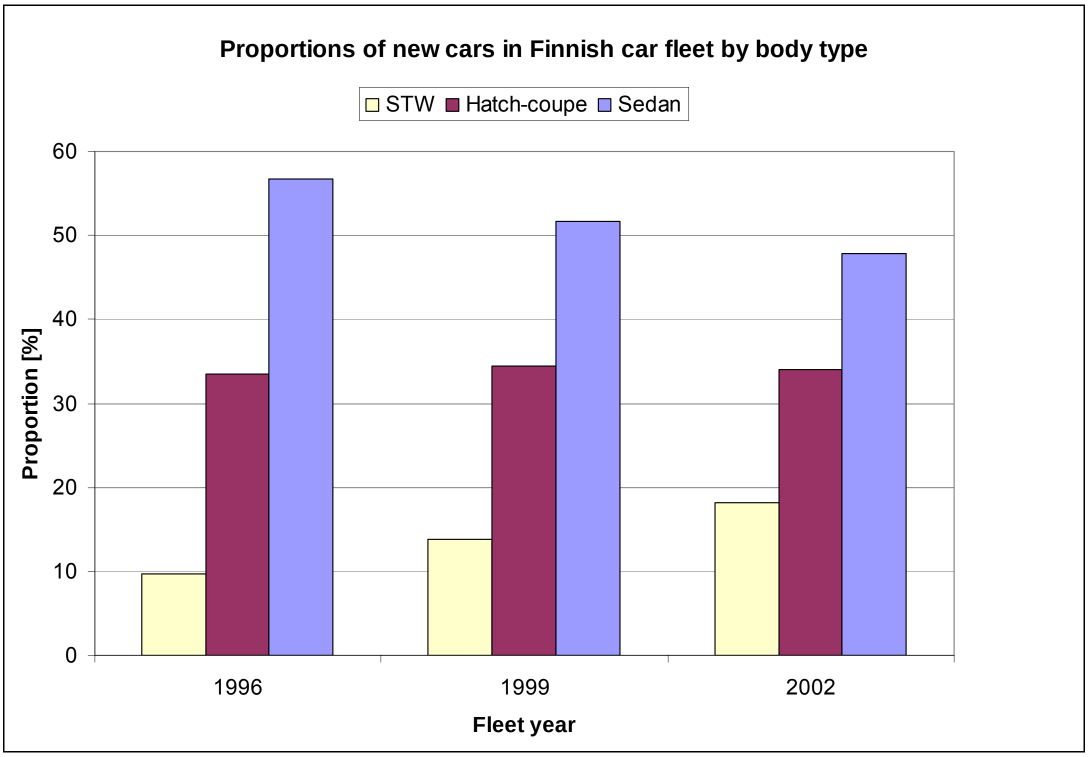


**Figure 16. Proportions of new cars (car age under 3 years) in Finnish car fleet at three moments of examination (1996, 1999 and 2002).**

Body type and wheelbase were listed as potential safety exposures already in SARAC 1-project. Unfortunately their influence on safety ratings is still open.

### 3.4.2. Engine power

Engine power distributions were available only from Finland for the trend estimation. Engine power seems to increase (Figure 17) all the time and the proportion of more powerful engines tends to grow quicker. Due to increasing price of fuel more people are selecting cars with lower fuel consumption and more friendly cars from environmental point of view. The engine technology has developed a lot during the past decade Instead of higher engine power, however, the emissions of the newer cars are lower and the fuel consumption equal compared to the older fleet. On the other hand an increasing popularity of diesel cars is decelerating the growth engine power. Therefore comparability of engine power trends from long time period is not easy.

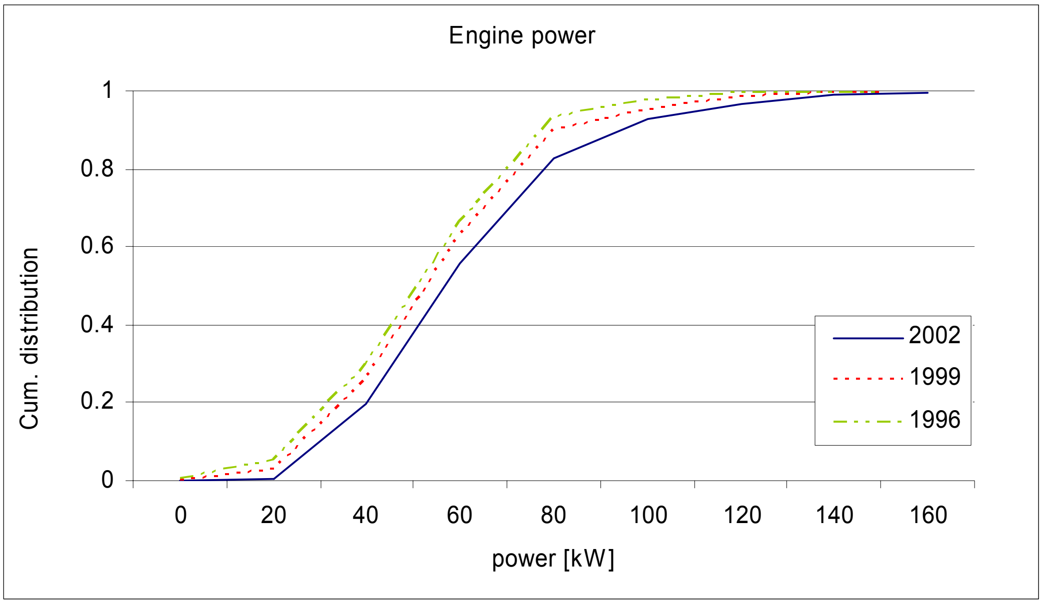


**Figure 17. Cumulative distribution of new cars (car age under 3 years) by engine power in Finnish car fleet in 1996, 1999 and 2002.**

## 3.5 OWNER PROFILES OF DIFFERENT CAR MODELS

The same eight car models from different size classes as in chapters 2.3 and 2.4 were chosen into the comparison. The car models were assumed to have different profiles of use. The study was made in three different cross sections based on car fleet years 1996, 1999 and 2002. The observed car samples consists only the cars registered in the years 1993–1995.

The owner profiles vary significantly between the car models. Females favour small cars and, in general, a proportion of females as car owner grow when the car gets older. On average, about 38% of cars are owned by females in Finland. However, there are large differences between car models, for example some 60% of Nissan Micra and Renault Clio owners are females. For especially Nissan Micra, old females are the largest owner group. Large cars are very rarely owned by old females and by females of all ages in general.

It has to be noted that the owner recorded in the car registration may not necessary be the actual user of the car. Rough comparison between Finnish car owner and accident data revealed some 60% match between the driver and the owner. However, compared to driven kilometres the true match is supposed to be higher.

Owner profiles for 8 selected car models are presented in Figure 18. The figure presents the numbers of registered cars per owner profiles. In the figure the time-dependent changes in owner profiles are showed by presenting three different fleet years. In fleet 1996 the observed cars have been used 1-3 years and in fleet 2002 the cars have been used 7–9 years. The smallest car models are presented at top of the figure and the largest models at the lowest part of the figure.

According to Figure 18 the proportion of female car owners decreases when car size increases. Similar to all car models, the proportion of young male owners and female owners of all ages increases when cars are getting older. Also, the higher is the price of the car, the higher is the proportion of middle-aged male owners.

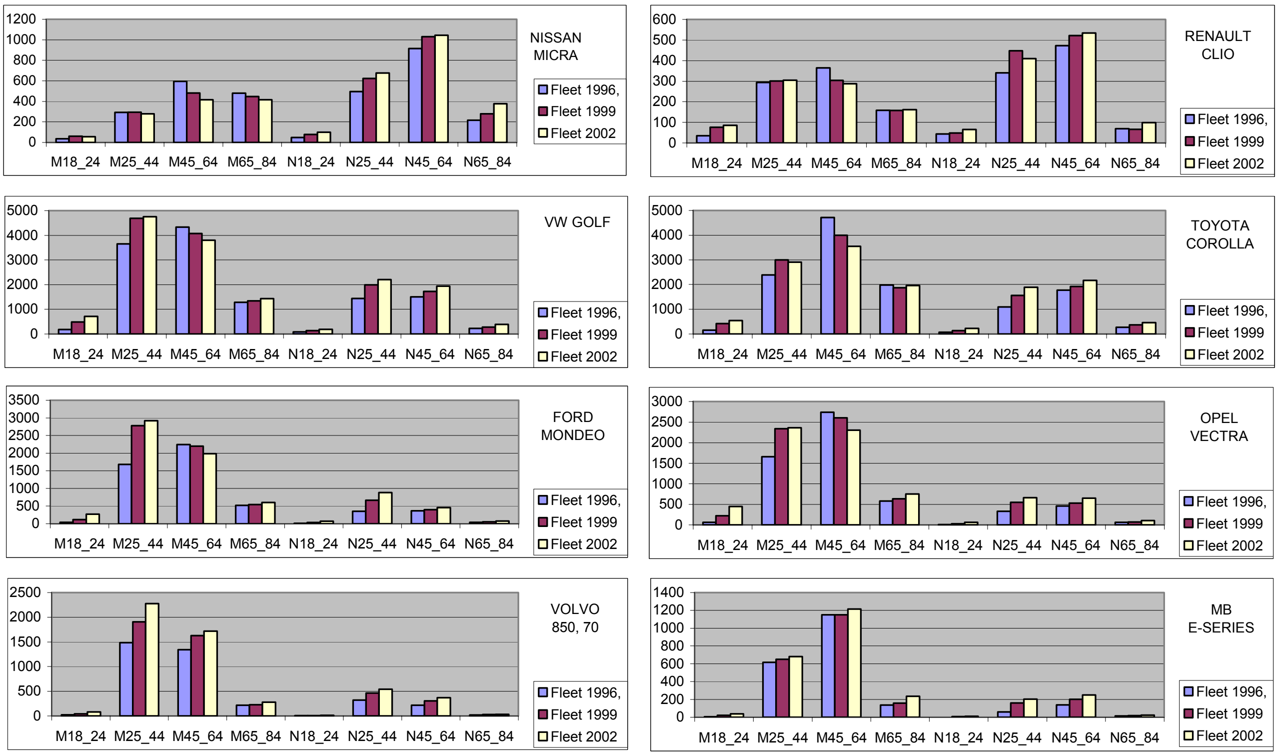


**Figure 18. Numbers of registered cars by owner profiles (first registration year 1993-1995) by owner of the car (male (M) and female (N) in three fleet cross-sections (Finnish vehicle fleet data 1996, 1999 and 2002).**

It can be suggested from Figure 18 that some car models have larger proportions of risky drivers than the others. For example, a majority of owners of small car are females who naturally have higher injury risk than males. Furthermore, increasing proportions of young owners increases the accident risk of old cars. Moreover, increasing proportions of female owners increase the computational injury risk of old cars. These changes in car owner profiles should have been taken into account when comparing the safety of cars of different age and size.

## 3.6 REGIONAL MOVEMENT AMONG THE CAR FLEET

There is certain time-depended regional movement among car fleet. New cars are often registered to large cities and regional centres from where they move slowly to smaller municipalities and rural areas. The regional movement of the selected 8 popular car models (the same samples used in chapter 3.5) according to population of the home municipality of cars is examined in Figure 19.

Similar to all car models examined in the Figure 19, the numbers of cars registered to small (A) and middle-sized municipalities (B) increase when the cars are ageing. Instead, the numbers of registration in the biggest municipalities (C) goes down. That is, the used cars move from big cities to smaller cities and villages. The proportional change is the most remarkable among middle-sized cars; even 1/3 of cars may have been moved out from the biggest cities when the cars have been used 10 years.

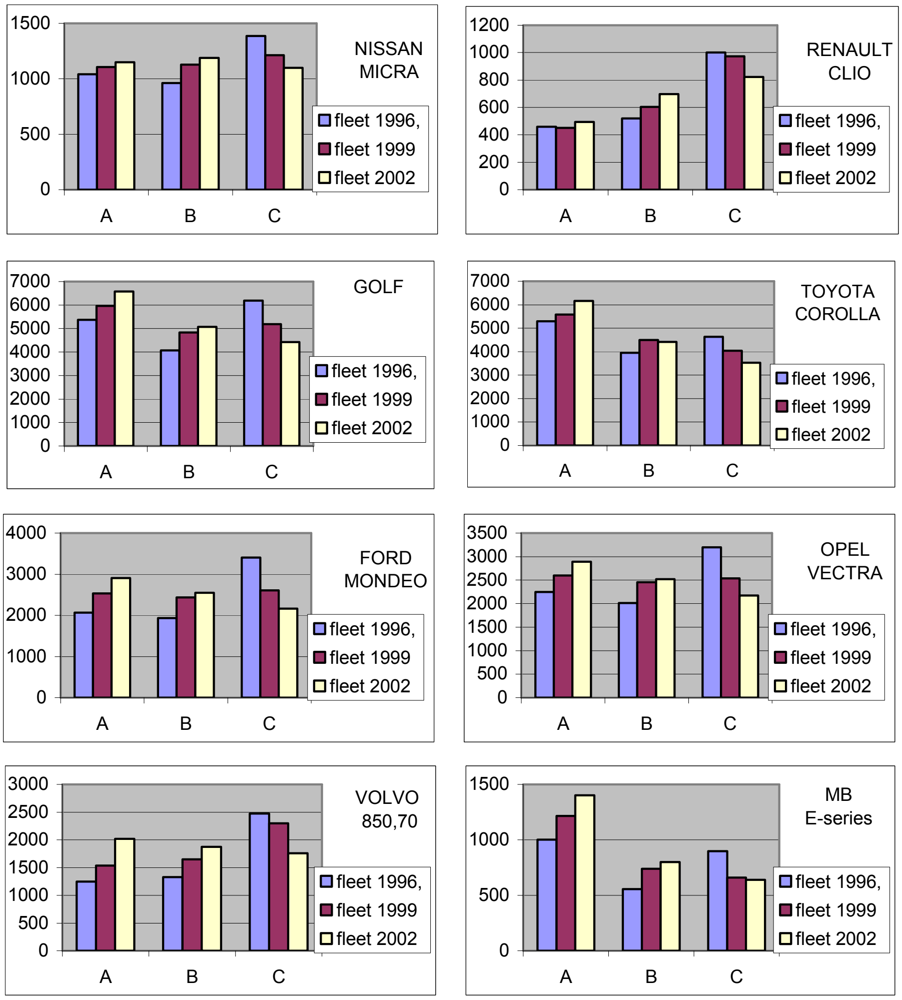


**Figure 19. Numbers of registered cars (first registration year 1993-1995) by size of home municipality. A: < 15 00 inhabitants, B: 15 000 – 70 000 inhabitants and C: > 70 000 inhabitants in Finnish car fleets 1996, 1999 and 2002 (Finnish car fleet data).**

The continuous geographical movement of the whole car fleet is examined in Figure 20. Table 6 presents the distributions numerically. The age distribution of the car fleet has been quite stabile during last 6 years. The distribution between Southern, Central and Northern car fleets has not changed remarkably. However, the Southern car fleet is the youngest at every moment of examination. This is problematic for the traffic safety because the major part of the mileages accumulated in the Central and Northern regions takes place on country side and rural roads. Older fleet, higher speed limits and older driver population is a very bad and unrewarding combination.

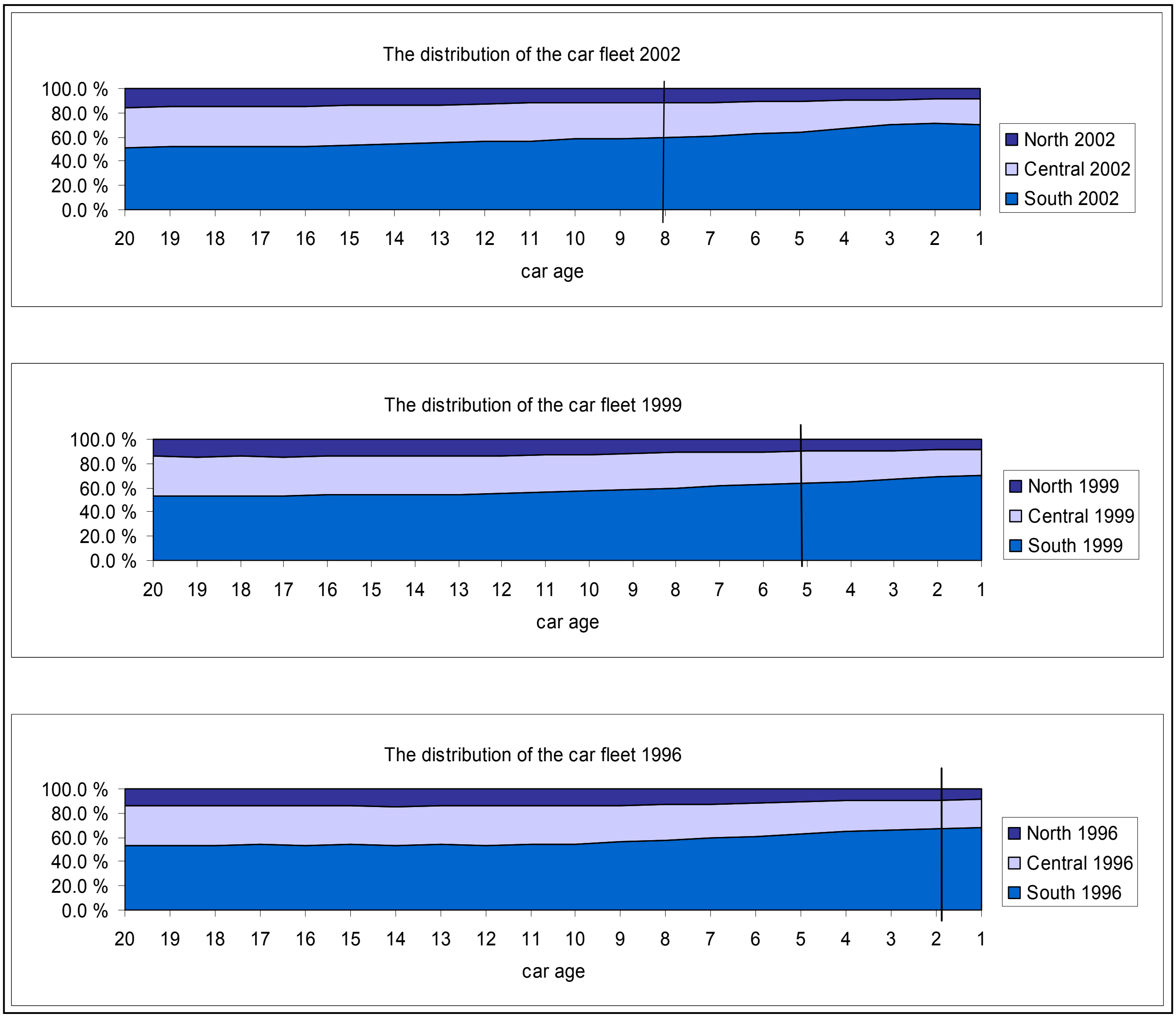


**Figure 20. Geographical distribution of Finnish car fleet on three different years. A vertical black lane in the charts illustrates the position of cars registered at the beginning of 1995.**

**Table 6. Geographical distribution of cars registered in 1995 at three moments of examination (1996, 1999, 2002).**

| *Area* | *1996* | *1999* | *2002* | *Inhabitants 2002* |
|---|---|---|---|---|
| South | 67.1 % | 63.8 % | 59.8 % | 3 110 385 |
| Central | 23.6 % | 26.2 % | 28.9 % | 1 415 652 |
| North | 9.2 % | 10.0 % | 11.4 % | 645 122 |

Unfortunately, any material about the purchase and movement for international comparisons is not available in other countries. In UK the average age of the car fleet in Birmingham region and in Manchester region is remarkably younger than average and in outlying counties like in Cornwall, Devon and Norfolk clearly higher. (DfT , 2003 b).

There is often asked, how the changes in the car fleet influence to results of the ratings. Making deduction is very difficult, because in different countries the internal structure of the fleet and the regional identity vary.

In generally the daily travels for a car are working trips, commercial trips and leisure trips at the maximum radius of 30-40 kilometres from home. In addition a couple of longer holiday travels per year are done as well. While counting the risks proportioning the risk figures to averages of the car fleet, leads an exceptional car model or exceptional use of a car model to different results.

## 3.7 ANNUAL MILEAGES

### 3.7.1 Annual mileage calculations

An important exposure when calculating the accident risk is the mileage driven annually. The average mileage for a car model could be the most accurate variable to describe the use of the car. Unfortunately, mileage data is not always very reliable. The mileage data for a certain car can be collected with reading the distance gauge at certain intervals or for a certain driver with different travel surveys, questionnaires or interviews.

In Finland and Sweden the mileage is collected in yearly technical vehicle inspections. The coverage in Finland is over 60% and in Sweden over 90% of all registered cars. The mileage data includes also inaccurate information that stems from misreading, decimal point fault, mileage gauge manipulation and gauge going around. These kinds of errors were filtered away before the calculations. In many countries the newest fleet is free from the inspection, for example in Finland the first inspection has to be made 3 years after the first registration. This practise causes some problems to calculate the mileages of the newest fleet exactly.

In Germany the annual mileage was calculated from a driver survey (Hautzinger et al. 2004). In this survey a sample of car owners was interviewed and their travels were calculated with a log book. The average number of kilometres travelled by cars in Germany in 2002 was approximately 13,400 km per car. Compared with the results of the travel survey in 1993 the decrease in the average annual kilometres travelled by privately owned cars in Germany has been until 2002 some 6.4 % (Hautzinger et al. 2004). This can be interpreted against three perspectives; car ownership in Germany has increased, driver population has become older and travelling needs and habits probably have changed. According to Table 7 the annual mileages in Germany, Sweden and Great Britain seem to be very similar, some 13500 kilometres per year, but the average mileage in Finland is approximately 17000 km per year.

The average annual mileage travelled by cars is depending on several influencing factors. Variables affecting on annual mileage are for example the age, the size class and the engine volume of the car, the driver distribution by car model and on countrywide also the level of urbanisation. The mileages of cars with diesel engines tend to have higher mileages compared to cars with petrol engines.

### 3.7.2 Annual mileage and car age

Average mileages in some European countries by age of the car are presented in Table 7. As mentioned before the average annual mileage in Sweden and Germany is about 15–20 per cent smaller than in Finland. During the first two or three years the mileage remains on higher level, but then the mileage after the third year, however, begins to decrease almost linearly up to 10 years in each inspected country. In Germany the mileage for new cars is about 18800 km per year, in Sweden some 20000 km and in Finland a lot of more. At the age of 10 years the average mileage in Germany is some 11000 km, in Sweden almost 14000 km and in Finland some 16000 km per year. Remarkable is that the age of the car is classified different ways in different countries.

The available estimation for annual mileages by age and ownership of British cars is old, from the period 1992–1994, but the main purpose of the figures is to present more the great difference between the mileages of private and company cars. The classification of cars according the national taxation regulation makes the interpretation of statistical data more difficult.

**Table 7. Average annual mileage [km] by age of the car in Finland (Kari et al. 2005), Sweden (Sika 2003), UK (Transport statistics 1994) and Germany (Hautzinger et al.2004).**

| FINLAND 2002 | | SWEDEN 2001 | | UK 1994 | | | GERMANY 2002 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Vehicle age* | *km* | *Model year* | *km* | *Vehicle age* | *Company* | *Private* | *Vehicle age* | *Total* | *Petrol* | *Diesel* | *Vehicle age* | *Private* | *Company* |
| *0-1* | | | | 0-1 | 35 400 | 16 400 | 0-1 | 18 837 | 13 722 | 27 114 | 0-6 | 14 401 | 23 679 |
| 1-2 | | 2000 | 19 170 | 1-2 | 37 000 | 16 000 | 1-2 | 17 895 | 13 790 | 25 810 | | | |
| 2-3 | 21 600 | 1999 | 19 680 | 2-3 | 33 800 | 15 900 | 2-3 | 17 208 | 14 089 | 25 360 | | | |
| 3-4 | | 1998 | 18 880 | 3 - | 27 400 | 13 000 | 3-4 | 15 847 | 13 907 | 24 368 | | | |
| 4-5 | 18 100 | 1997 | 17 150 | | | | 4-5 | 14 702 | 13 524 | 21 555 | | | |
| 5-6 | | 1996 | 16 120 | | | | 5-6 | 13 691 | 12 852 | 19 333 | | | |
| 6-7 | 17 300 | 1995 | 15 200 | | | | 6-8 | 13 540 | 12 720 | 19 204 | 6-12 | 11 884 | 14 919 |
| 7-8 | | 1994 | 14 710 | | | | | | | | | | |
| 8-9 | 16 600 | 1993 | 14 860 | | | | 8-11 | 11 500 | 11 055 | 15 315 | | | |
| 9-10 | | 1992 | 13 810 | | | | | | | | | | |
| 10-11 | 15 500 | 1991 | 13 170 | | | | | | | | | | |
| 11-12 | | 1990 | 12 440 | | | | 11-14 | 10 425 | 10 204 | 13 063 | | | |
| 12-13 | 14 300 | | | | | | | | | | 12 - | 9 305 | 10 511 |
| 13-14 | | | | | | | | | | | | | |
| 14-15 | 12 900 | | | | | | 14-20 | 8 708 | 8 118 | 11 410 | | | |
| 15-16 | | | | | | | | | | | | | |
| 16-17 | 11 600 | | | | | | | | | | | | |
| 17-18 | | | | | | | | | | | | | |
| 18-19 | | | | | | | | | | | | | |
| 19-20 | | | | | | | 20- | 6 569 | 6 423 | 7 982 | | | |
| Total | 17 000 | Total | 13 450 | Total | 33 500 | 13 800 | Total | 13 397 | 11 934 | 20 925 | | | |

### 3.7.3 Annual mileage and vehicle size

The size of the car is important variable when studying the accumulated annual mileage (Figure 21). The average mileage of the smallest size class of cars is typically 20-25 per cent lower than the average mileage in the whole fleet. Small family cars are the most common in Finland and their mileages seem to be very close of the average level. As seen before the proportion of large family cars is increasing and their annual mileage exceeds the average with some 10-15 per cent.

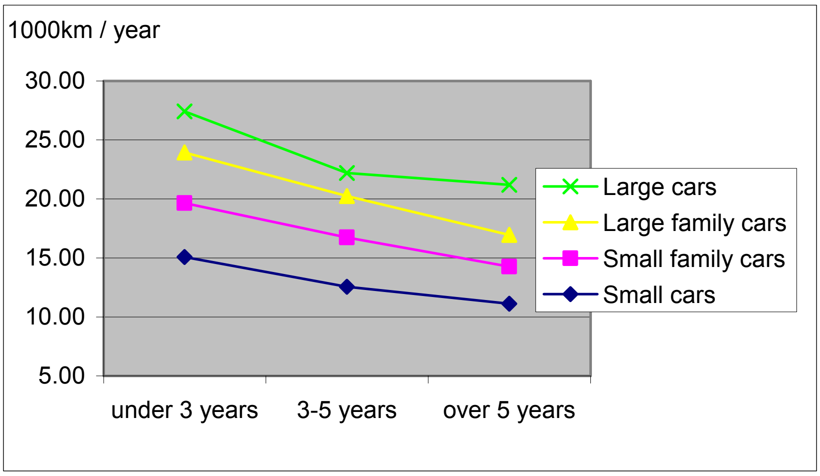


**Figure 21. Annual mileage by size and age of car in Finland. (Kari et al. 2005).**

There are mileage estimations from Sweden related to vehicle mass and from UK and Germany related to engine volumes. They were collected together and are presented in Table 8. According to the table the annual mileage is directly proportional with engine volume and vehicle mass. This might result from the role of bigger cars as “number one” car in the family. For example most holiday trips are made with these cars. The engine size influences the same way to the mileage of a car. The bigger the engine volume is the more kilometres per year are driven with the car. The highest mileage is driven by the owners of the diesel cars on every engine size class in Germany. The mileage of the diesel cars is mainly above 20 000 km per year (Hautzinger et al 2004).

**Table 8. Average mileage [km] by the size of the car in Sweden (Sika 2003), UK (Transport statistics 1994) and Germany (Hautzinger et al.2004).**

| SWEDEN 2001 | |
|---|---|
| *Weight [kg]* | *Mileage (km)* |
| - 899 | 8 000 |
| 900- 999 | 8 910 |
| 1000 -1099 | 10 410 |
| 1100 -1199 | 11 530 |
| 1200 -1299 | 12 250 |
| 1300 -1399 | 13 140 |
| 1400 -1499 | 15 030 |
| 1500 -1599 | 17 750 |
| 1600 -1699 | 18 310 |
| 1700 -1999 | 17 610 |
| 2000 -2499 | 17 650 |
| 2500 -2900 | 23 250 |
| 3000 - | 37 870 |
| **Total** | 13 450 |

| UK 1994 | | GERMANY 2002 | | | |
|---|---|---|---|---|---|
| *Engine volume (cc)* | *Mileage (km)* | *Engine volume (cc)* | *Total (km)* | *Petrol (km)* | *Diesel (km)* |
| - 1000 | 9 000 | -1000 | 9 746 | 9 708 | 14 061 |
| 1000 - 1300 | 12 200 | 1000 - 1200 | 10 082 | 10 040 | 20 350 |
| | | 1200 - 1400 | 10 989 | 10 945 | 21 028 |
| 1300 - 1400 | 15 300 | | | | |
| 1400 - 1800 | 17 700 | 1400 - 1600 | 12 077 | 11 996 | 13 450 |
| | | 1600 - 1800 | 13 431 | 12 698 | 20 077 |
| 1800 - 2000 | 20 600 | 1800 - 2000 | 16 494 | 12 734 | 22 065 |
| 2000 - | 19 500 | 2000 - 2500 | 16 909 | 13 770 | 20 900 |
| | | 2500 - | 16 183 | 14 732 | 21 599 |
| | 15 300 | | 13397 | 11934 | 20925 |

### 3.7.4 Annual mileage and driver

The large travel survey 2002 from Germany (Hautzinger et al, 2004) examines widely the connection between the mileage and different driver populations. There are once again difficulties in interpretation of the results because there are a lot of difficulties to identify the drivers of “company cars”. The proportion of women as private car owners and as drivers in traffic has increased clearly from 1993 to 2002. The tendency based on Finnish accident data is very parallel with those German results. Table 9 shows estimated annual average mileage travelled by one car in 1993 and 2002. The average mileage of male drivers has degreased almost with10 per cent to 13000 km per year, but the mileage estimate for females has decreased only less than 2 per cent to 11 200 km per year between the two surveys

**Table 9 Private car mileages in Germany in 2002 and 1993 (Hautzinger et al. 2004)**

| Survey year | 2002 | 1993 |
|---|---|---|
| | | |
| *Annual total mileage* | *496 milliard km* | *452.6 milliard km* |
| Male | 57 % | 60 % |
| Female | 43 % | 40 % |
| *Annual average mileage (km)* | *12443* | *13260* |
| Male | 13000 | 14400 |
| Female | 11200 | 11400 |
| *Car fleet* | *39.9 Mill* | *34.1 Mill* |
| Male | 68 % | 74 % |
| Female | 32 % | 26 % |

# 4 RISK EFFECT – IMPROVED SAFETY OF PASSENGER CARS

## 4.1 COMPARISONS OF RATINGS FROM DIFFERENT COUNTRIES

In different connections is noticed, that safety ratings from different countries or different time are not directly comparable. The most important international problems are national differences in the criteria for recording to database, different injury classifications and different variables used in the rating calculations. On national level the biggest problems is fleet effect; when the fleet moves towards to rural areas and new safer car models are introduced, accidents and their consequences will change.

Table 10 presents injury risk, injury severity risk and crashworthiness rates from UK, France and Germany as a short example for a selected group of car models. These figures are not internationally commensurable because of differences in original data materials. The calculations are based on logistic regression method and they have been produced by MUARC. is using. The datasets from UK and France are from 1993-2001 and from Germany 1998-2002.

**Table 10. Crashwothiness, injury risk and injury severity risks by some selected car models based on accident data sets from UK, France and Germany. . ( Newstead et al 2005)**

| *MODEL* | | *CWR %* | | | *INJURY RISK %* | | | *SEVERITY RISK %* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *UK* | *France* | *Germany* | *UK* | *France* | *Germany* | *UK* | *France* | *Germany* |
| Fiat Punto | 3/94-5/97 | 7,68 | 17,66 | 12,45 | 71,29 | 74,93 | 73,16 | 10,77 | 23,57 | 17,02 |
| Renault Clio | 7/96-4/98 | 8,29 | 21,27 | 13,73 | 70,40 | 75,31 | 67,99 | 11,78 | 28,84 | 20,19 |
| Nissan Micra | 8/95-2/98 | 10,22 | 21,29 | 17,41 | 71,69 | 78,40 | 76,56 | 14,26 | 27,98 | 22,74 |
| Opel Corsa | 9/95-9/00 | 7,37 | 19,51 | 13,13 | 65,98 | 73,23 | 72,59 | 11,16 | 26,64 | 18,09 |
| VW Polo | 10/94-12/99 | 7,42 | 19,95 | 11,95 | 67,96 | 72,26 | 69,26 | 10,92 | 27,61 | 17,26 |
| | | | | | | | | | | |
| Ford Escort 1,6 LX | 1/95-7/00 | 7,35 | 18,22 | 12,39 | 63,29 | 68,92 | 62,54 | 11,05 | 26,53 | 19,82 |
| Opel Astra 1.6i | 2/98-12/01 | 7,84 | 12,42 | 15,96 | 69,55 | 65,27 | 59,35 | 11,27 | 19,03 | 15,96 |
| Honda Civic 1,4i | 4/95-11/00 | 9,02 | 15,65 | 14,66 | 65,04 | 61,65 | 67,43 | 13,87 | 25,38 | 21,27 |
| Peugeot 306 1,6 GLX | 4/97-3/01 | 8,36 | 16,64 | 10,91 | 67,09 | 68,00 | 57,89 | 12,47 | 24,47 | 18,85 |
| Renault Megane 1.6 | 4/96-3/99 | 6,71 | 20,08 | 9,55 | 66,45 | 68,31 | 59,19 | 10,09 | 29,40 | 16,14 |
| | | | | | | | | | | |
| Opel Vectra | 10/95-2/99 | 7,08 | 12,19 | 8,64 | 59,89 | 57,87 | 58,26 | 11,82 | 21,06 | 14,83 |
| Peugeot 406 1,8LX | 1/96-2/99 | 5,72 | 12,81 | 10,66 | 54,07 | 55,68 | 49,92 | 10,57 | 23,01 | 21,38 |
| Citroen Xantia 1,8i | 7/94-12/97 | 5,62 | 15,10 | 10,77 | 55,58 | 59,25 | 57,57 | 10,11 | 25,47 | 18,71 |
| BMW 316i | 9/93-8/98 | 6,14 | 18,54 | 9,38 | 55,36 | 60,19 | 60,86 | 11,10 | 30,87 | 15,41 |
| | | | | | | | | | | |
| Audi A6 2,4 | 5/97-12/01 | 3,53 | | 6,32 | 54,09 | | 47,89 | 6,53 | | 13,21 |
| M-B E200 | 9/97-7/0-99 | 6,12 | | 5,92 | 52,83 | | 47,36 | 11,59 | | 12,51 |
| BMW 520i | 9/97-12/01 | 6,46 | | 6,53 | 50,32 | | 50,32 | 12,84 | | 13,51 |
| TOTAL | | 6,79 | 15,51 | 11,50 | 63,34 | 66,23 | 62,17 | 10,72 | 23,42 | 18,47 |

Car mass influences much on injury risk, which is clearly detectable in all ratings at Table 10. However, the influence of car mass on severity risk is not as obvious. That is, because of differences in typical use of small and large cars, for example. As mentioned before larger car size reflects increasingly on the annual mileage. Smaller cars are often used more in urban traffic with lower speeds. Both lower mileage and larger proposition reduce the risk to be injured. Larger cars need for their higher mileage also more kilometres on rural roads, where the accident risk is lower, but the injury risk and especially the injury severity risk much higher when an accident occurs. The clear variations in risk rates of the same car model in different countries depend most on the national differences in accident recording criteria. Also a lower average mass of the total fleet which is typical in southern Europe may have an influence on higher injury risk rates.

Especially the severity risk rates of UK are very equal between different car models and sizes, which reveal the high share of urban traffic and furthermore low speed of accidents. However, the figures are averages and they depend on the size distribution of the fleets and the size of the crash samples. The statistical confidence intervals vary widely between countries. Table 11 shows the essential variables used for the calculation of the figures presented in Table 10.

The variables reflect clearly problems and differences in accident data recording systems in different countries. It seems, however, that driver's age and gender are dominant variables in each country when calculating injury and injury severity risks from various accident data sets by car model. Naturally the accident type itself is important as well. The criteria to record accident types vary a lot in different countries. Also the descriptions of accident site and driving circumstances vary from accident data to another. Such exposures like driven mileage, driving experience or used time in traffic are not available at all.

From Table 11 we can see that the year of crash is one important variable especially in injury severity ratings. This tends to reflect the influence of changing fleet and occupant population on car safety ratings.

**Table 11. The most important variables for injury and injury severity risk calculations in British, French and German accident data. (Newstead et al 2001 b, Newstead et al 2005)**

| UK | France | Germany |
|---|---|---|
| *Injury risk* | | |
| Driver age | Driver age | Driver age |
| Driver sex | Driver sex | Driver sex |
| Junction type | Intersection | Intersection |
| Point of impact | Urbanisation | Location of crash |
| Speed limit | | Cost of crash |
| | | Year of crash |
| *Injury severity risk* | | |
| Driver age | Driver age | Driver age |
| Driver sex | Driver sex | Driver sex |
| Junction type | Number of vehicles | Number of vehicles |
| Number of vehicles | Intersection | Location of crash |
| Point of impact | Urbanisation | Cost of crash |
| Speed limit | Year of crash | Year of crash |

## 4.2 CRASHWORTHINESS TRENDS IN AUSTRALIAN CAR FLEET

There are significant differences in the trends of crashworthiness rates by the year of manufacture between small, medium, large and 4WD market groups of Australian vehicles. Analysis has identified trends to poorer crashworthiness in the small car class from 1993 to 1998 in contrast to consistent or slightly improving crashworthiness in the large and 4WD vehicle classes. Trends in crashworthiness in the medium car class are similar to those in the small vehicle class from 1993 onwards. (Newstead and Cameron, 2001). It seems that Australian small vehicle buyers are shifting their purchase preferences towards cheaper vehicles with poor safety performance. This can explain the trend towards poorer crashworthiness in the small car group. It seems that tightening of vehicle safety standards through legislation ensures all vehicles on the Australian market, including those at the cheapest end of the market, to improve their safety performance in the future.

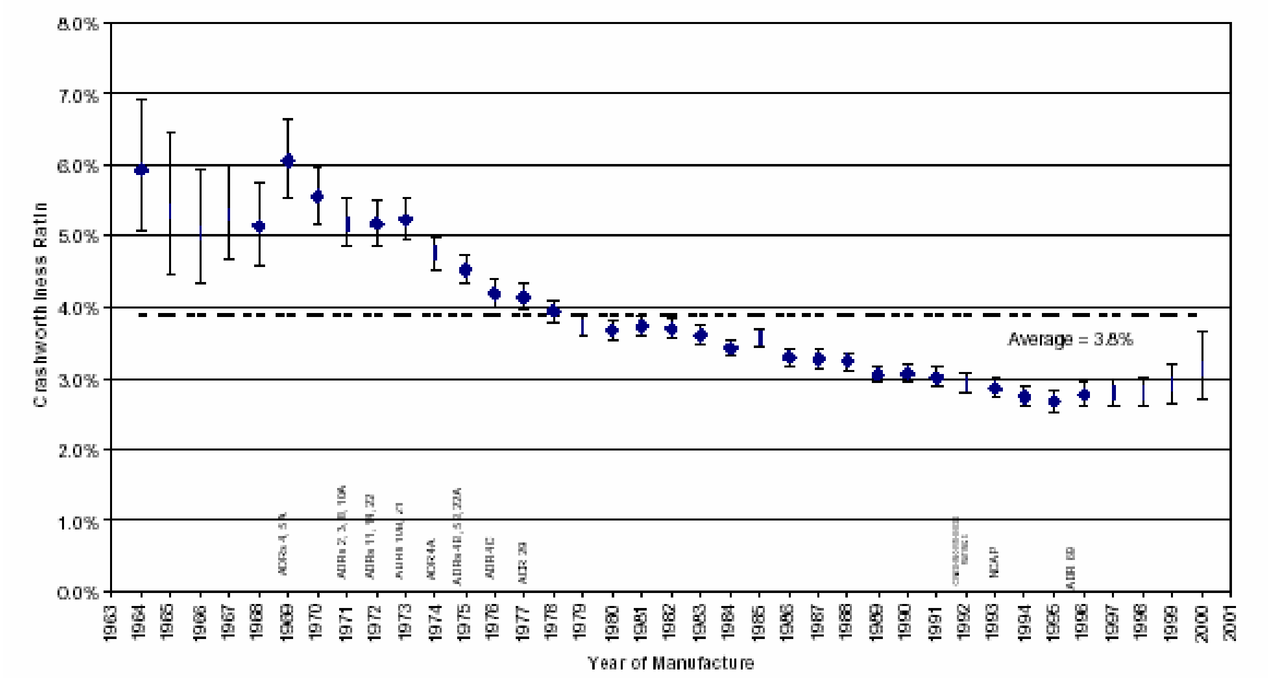


**Figure 22. Crashworthiness trends in Australian car fleet by year of manufacture (with 95% confidence limits). Data: Victoria and NSW crashes during 1987-2000, Queensland and Western Australia crashes during 1991-2000. (Newstead et. al 2004 a)**

When comparing those rates in Figure 22 we can roughly see that cars manufactured in the middle 90´s have some 15–20% lower crashworthiness rate compared to those of early 80´s and some 40% lower compared to model fleets from early 70´s.

## 4.3 STUDIES FROM SWEDISH CAR FLEET AND ACCIDENT DATA

Swedish Insurance Company Folksam has investigated vehicle safety and injury mechanism issues based on Swedish accident data for decades. They have also published several car safety ratings since 1991.

Folksam (2003) calculated an average injury risk rate for the Swedish fleet based on Police reported accident data set 1994–2002. The data consisted of two-car injury accident in which at least one occupant were injured. The injury severity was taken into the consideration as it was reported by the police, minor, severe, killed. Compared the average injury risk to the level of 1994 (R=1.00) the average injury risk of the fleet has decreased continuously (*Figure 23*) and was only about 0.82 in 2002 accident data. This means that the fleet in 2002 were 18 per cent safer than the fleet in 1994.

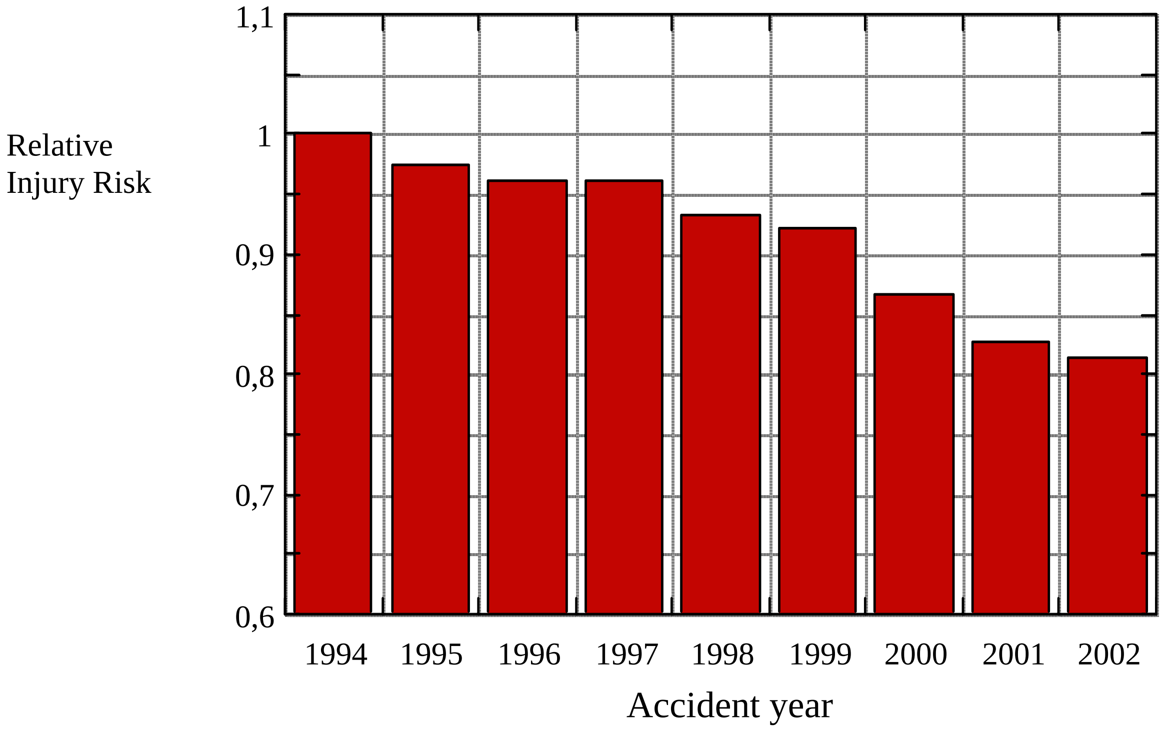


**Figure 23. The safety progress of car fleet in Sweden.(Folksam 2003)**

Kullgren (2002) has used a data set of 17 228 injury accidents from 1994–2002 and investigated injury outcomes by body regions and AIS-levels among different age groups of cars in Sweden. The age groups were 1980–84, 1985–89, 1990–94 and 1995–99. Comparing especially the car models introduced 1980–84 with models introduced 1995–99 it was found that the newest population was remarkable safer and the proportion of severe injuries (AIS3+) was decreased by 80%. Furthermore, the relative risk of permanent disability and fatality decreased by 29%. The disability risk of AIS2+ injuries decreased also by 76%, but minor injuries (AIS 1) had an increase of 18%. In this special data also the detailed injury outcomes by body regions were available. Reduction between70% and 90% were found for injuries of all inspected body regions, except for neck injuries, which had an increase of 14% (Table 12 and Table 13).

**Table 12. Relative disability and fatality risks at different AIS levels. (Kullgren,2002)**

| *AIS level* | *Relative disability and fatality risk* 1980-84 | 1985-89 | 1990-94 | 1995-99 | *Difference 1980 to 1995* (%) |
|---|---|---|---|---|---|
| AIS1 | 204,5 | 244,1 | 255,5 | 240,7 | +18 |
| AIS2 | 57,3 | 40,4 | 30,4 | 16,1 | -72 |
| AIS3 | 73,7 | 60,1 | 35,7 | 18,5 | -75 |
| AIS4 | 12,6 | 6,5 | 3,5 | 1,0 | -92 |
| AIS5 | 33,9 | 22,9 | 19,5 | 9,2 | -73 |
| AIS6 | 25,8 | 21,5 | 6,8 | 3,5 | -86 |
| AIS2+ | 203,4 | 151,3 | 96 | 48,3 | -76 |
| Total | 407,9 | 395,4 | 351,5 | 289,0 | -29 |

**Table 13. Relative disability and fatality risks for injuries to different body regions. (Kullgren, 2002)**

| *Body region* | *Relative disability and fatality risk* 1980-84 | 1985-89 | 1990-94 | 1995-99 | *Difference 1980 to 1995 (%)* |
|---|---|---|---|---|---|
| Head | 61,2 | 44,9 | 29,2 | 17,4 | -72 |
| Neck | 203,6 | 241,6 | 250,9 | 231,7 | +14 |
| Face | 5,4 | 5,6 | 1,9 | 0,8 | -85 |
| Upper extremities | 26,2 | 21,7 | 18,0 | 8,9 | -66 |
| Lower extremities | 63,6 | 45,2 | 24,9 | 14,0 | -78 |
| Thorax | 8,7 | 3,2 | 2,2 | 1,5 | -83 |
| Pelvis/abdomen | 1,7 | 1,0 | 0,9 | 0,005 | -100 |
| Lumbar and thoracic spine | 35,4 | 31,9 | 22,9 | 14,5 | -59 |
| External | 2,1 | 0,2 | 0,5 | 0,2 | -90 |
| **Total** | **407,9** | **395,4** | **351,5** | **289,0** | **-29** |

Kullgren (2002) estimated also the average injury risk for those four car age groups mentioned before. The results are shown in Table 14. The average injury risk of the total sample is 1,000. Older models have higher risk and more recent models have lower risk than the average value. Car models introduced 1980-84 was found to have 19% higher relative injury risk than models introduced 1995-99.

**Table 14. Change of the relative injury risk (Kullgren 2002).**

| *Year of introduction* | *1980-84* | *1985-89* | *1990-94* | *1995-99* |
|---|---|---|---|---|
| Average relative injury risk | 1,077 | 1,029 | 0,988 | 0,906 |

Folksam (2003) has compared also the average injury risks by car model generations. The Police reported accident data from 1994-2002 was grouped to four 5 years long sub-groups according to the introduction year of each car models. The groups were 1983-87, 1988-92, 1993-97 and 1998-2002. Also the size class of cars was taken into account. Injury severity in the data set was classified only by the Police to minor, severe or killed.

Large improvements in the average injury risks were found between different size and age groups of the fleet as it can be seen in ***Figure 24***. The models introduced in 1998-2002 are systematically much safer than their predecessors. Their safety influence seems to be some 35% in the smallest group, 10% among small family cars, 30% for family cars and 25% for large cars compared to models introduced in 1983-87. An interesting observation is also that the largest model group introduced in 1983-87 is less safe than the average level of the whole Swedish fleet in the investigated data set. The same is situation when comparing the large car population of 1983-87 with the smallest size group introduced in 1998-2002.

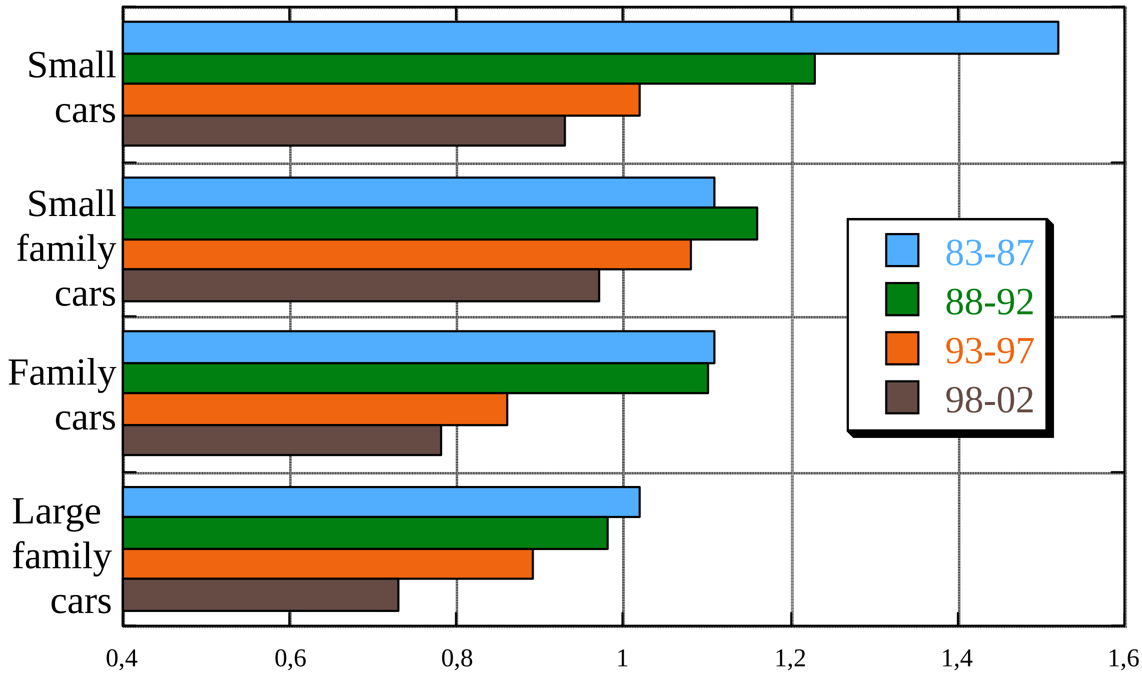


**Figure 24. Development of average injury risks by car size and introduction period in Swedish car fleet (Folksam 2003).**

The average injury risk of the total fleet changes all the time. When using the paired comparison method with an accident sample including accidents that occurred several years back in time, the results will be influenced by this increase, particularly for older car models. Hägg (1992) has investigated relative injury risk of some common car models launched in Sweden in the beginning of the 80's. He presented the injury risk rate for that special model sample from the accident data of each year from 1985 to 1998. The models he studied were Volvo 200, 300 and 700 series and Saab 900, which can be regarded safe models as we can see from the first figures on Figure 25 (R=0.7 in 1985). There were not significant changes in these car models during this time period so there were not significant changes in their safety level, either. A linear relationship between accident year and relative injury risk was found.

Figure 25 shows the increase of average injury risk rate by different years for the 3 Volvo models and the Saab model. The relative injury risk compared to the level of the average car increased by on average 1.5% per year.

During those 13 years the injury risk related to the total fleet was increased with 19%. If we assume that the same progress would have continued, those “very safe” models in 1985 were in 2005 less safe than an average car model in the Swedish fleet.

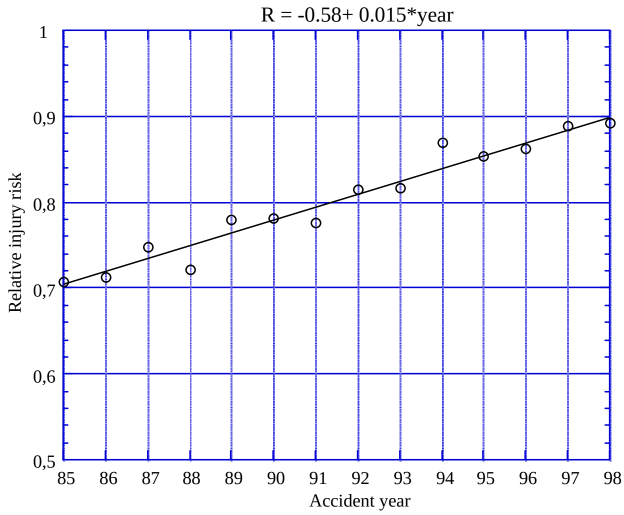


**Figure 25. Average relative injury risk for Volvo 200-, 300- and 700- series and Saab 900 for accident years 1985 to 1998 (Hägg et al 2001).**

## 4.4 IN-DEPTH ACCIDENT INVESTIGATIONS OF THE MERCEDES-BENZ ACCIDENT RESEARCH TEAM

Figure 26 shows the injury risk for drivers during the last three decades. The basis for the figure is the accident data for a specific car population of a specific car manufacturer. The data was collected under comparable conditions, e.g. only accidents during the time when the specific car population was manufactured and sold, that means no bias due to elder vehicles and its relationship to driver characteristics. The data are the result of in-depth accident investigations of the Mercedes-Benz accident research team in a certain area of Germany.

In order to demonstrate the efficiency of safety measures which were introduced during the last 30 years and tested and optimized in frontal crash tests between 48 and 60 km/h EES (Energy Equivalent Speed), only accidents of a comparable impact configuration and impact severity level (EES 41 to 60 km/h) were selected. The influence of the driver can be neglected because it was always the same kind of vehicles, e.g. predecessor and successor. That means that the characteristics of the drivers should be nearly the same in all groups, e.g. no bias due to different age, gender or body weight.

The comparison of the different injury probabilities shows the efficiency of different safety measures. In detail:

1. The influence of the belt usage in an identical vehicle population

2. The influence of a new developed car structure taking especially into account the frequent offset collisions including optimization of the restraint systems such as emergency tensioning retractors, but without an front airbag which was at that time an optional extra

3. The influence of the front airbag for the identical car population as in (2) but with the additional protection potential of an activated airbag

4. The influence of the latest protection devices tested in the EuroNCAP program and the USNCAP program such as a further optimized front end structure, belt force limiter, partially a two step airbag and other detail improvements

The technical conclusion is that these results collected over three decades significantly demonstrate the progress in passive safety within this time period. The strategic conclusion of this comparison might be the demand for the customers to buy and drive new vehicles only.

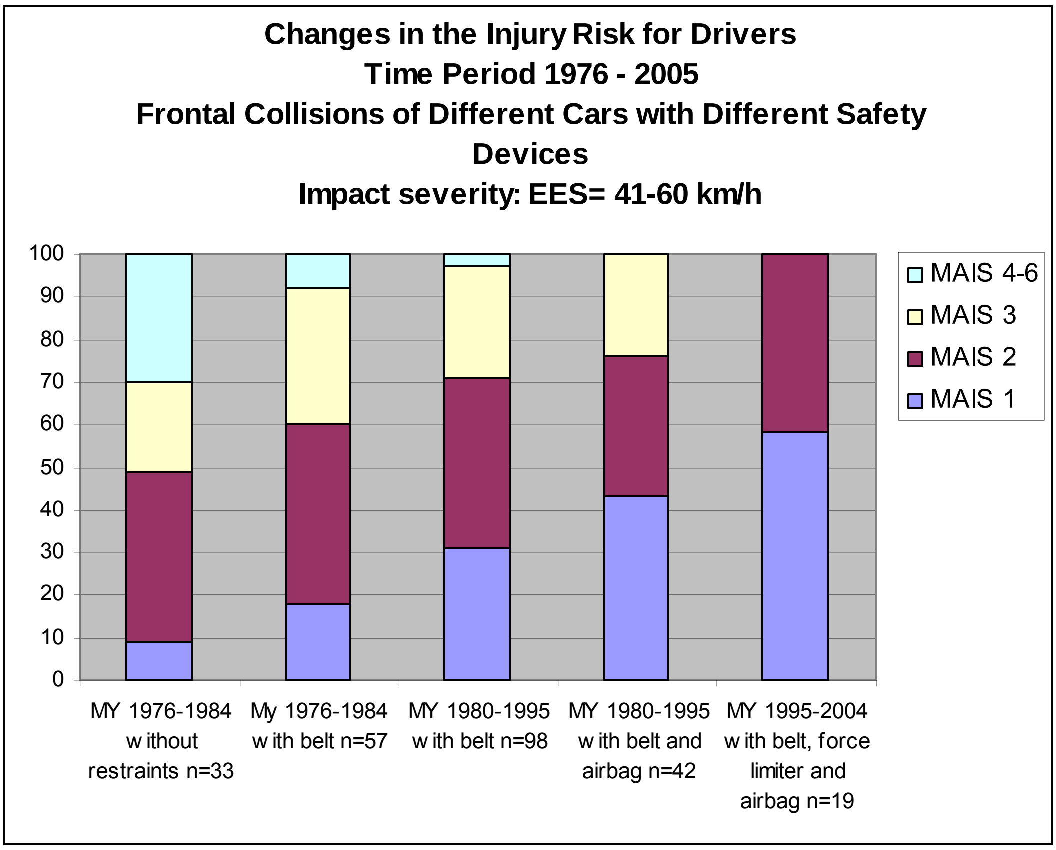


**Figure 26. Changes in the injury risk for drivers based on in-depth accident investigations of the Mercedes-Benz accident research team (Zeidler 2005).**

## 4.5 VEHICLE SAFETY PERFORMANCE BY MODEL SERIES IN GERMANY

It is expected that the introduction of a new vehicle model generation would result in an improvement in the safety performance of that vehicle model. MUARC has studied the police reported crash data from Germany (Delaney et al. 2005) with a logistic regression model and the results show for the majority of vehicles and models considered that there is strong evidence of an improvement in estimated crashworthiness over successive model generation. In large number of cases these results are statistically significant. In Figure 27 and Figure 28 there are presented as examples the calculated crashworthiness rates of Toyota Corolla and Volkswagen Golf and their 4 latest generations. Both car makes are popular in Germany and the samples of their model generations in the German accident data large enough, which can also be interpreted based on very narrow confidential limits. According the results of the study the safety performance of newer model generations is much better compared to their predecessors and the trend is continuous. In these two examples the improvement is 40-60 per cent. Quite similar results are available also from other countries.

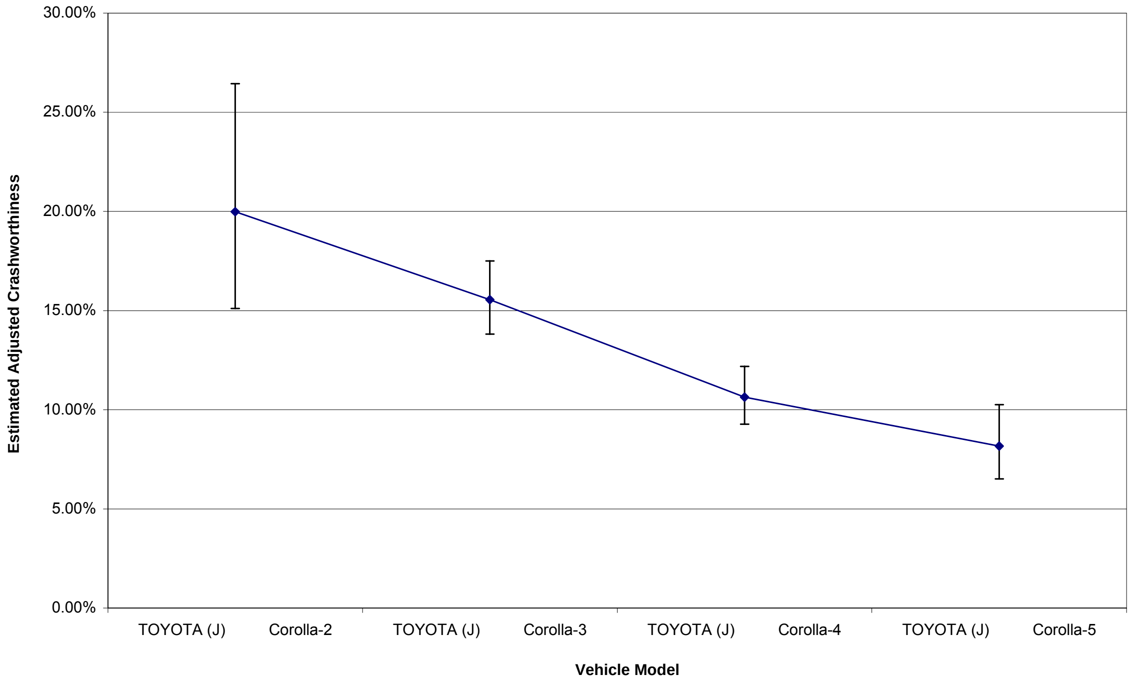


**Figure 27. Estimated crashworthiness rates of the Toyota Corolla over four model generations with 95% confidential limits (Delaney et al. 2005).**

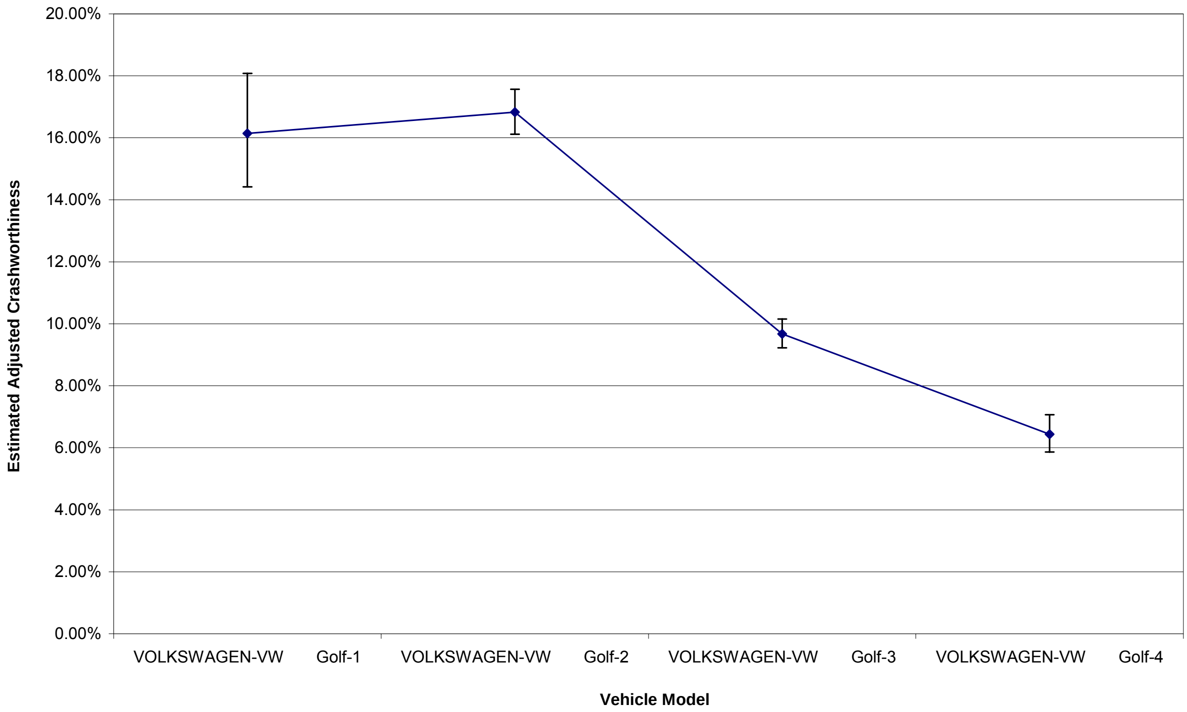


**Figure 28. Estimated crashworthiness rates of the VW Golf over four model generations with 95% confidential limits (Delaney et al. 2005).**

These results support the original hypothesis that new generation vehicle model would have better safety performance than the previous generation of the same vehicle model. These German results are based on the still unpublished report (Delaney, Newstead and Cameron;, “An investigation of historical improvement in vehicle safety performance by model series using German crash data”, MUARC, 2005 ). The study has been done as a part of SARAC2 project and the full study is integrated to this report as appendix 2.

## 4.6 DRIVER INJURY RISK BY MAKE AND MODEL IN GREAT BRITAIN 1994-2000

In Great Britain the severity of two-car accidents has reduced during the 1990´s. The decrease can be seen in the proportions of severe injuries and fatalities. The proportion of injuries has generally remained on the level of 63% in the Police recorded annual accident data. (DfT, 2003 a). Table 15 and Table 16 is present the trends of injury and injury severity rates in Great Britain between 1994 and 2000 by different fleet, driver and accident characteristics.

**Table 15. Proportions of fatalities, severe injuries and injuries by car size and driver according to British accident data (two-car crashes) in 1994 and 2000. (DTRL 1995, DfT 2003 a)**

| Car size | Fatalities [%] | | Severe injuries [%] | | Injuries [%] | |
|---|---|---|---|---|---|---|
| | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 |
| small | 0.5 | 0.5 | 9 | 6 | 72 | 71 |
| small family | 0.4 | 0.3 | 7 | 5 | 63 | 64 |
| medium | 0.3 | 0.2 | 6 | 5 | 56 | 58 |
| large | 0.2 | 0.1 | 5 | 4 | 46 | 50 |
| Average | 0.4 | 0.3 | 7 | 5 | 63 | 63 |

| Driver age [years] | Fatalities [%] | | Severe injuries [%] | | Injuries [%] | | Accidents [%] | |
|---|---|---|---|---|---|---|---|---|
| | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 |
| 17-24 | 0.3 | 0.3 | 7 | 5 | 63 | 63 | 29 | 23 |
| 25-34 | 0.3 | 0.2 | 6 | 5 | 62 | 63 | 28 | 29 |
| 35-54 | 0.4 | 0.3 | 7 | 5 | 62 | 63 | 31 | 33 |
| 55- | 0.9 | 0.7 | 10 | 7 | 67 | 64 | 13 | 14 |
| Average | 0.4 | 0.3 | 7 | 5 | 63 | 63 | | |

The distribution of injury accidents by driver age in Great Britain has been quite stable during 1990´s. No major changes in injury risk rates have not taken place during 1994–2000, except a lower injury risk of drivers older than 55. The risk of severe injury has reduced remarkable among all size classes and all driver groups as well. The largest decrease has taken place in the smallest vehicle group and among the eldest driver group. The rate of fatality risk in Great Britain is one of the lowest in the world, and in two-car crashes only 0.3%.

It is very obvious that relatively high new car registration numbers have also improved the safety of the total car fleet and influenced especially on lower injury severity.

**Table 16. Proportion of fatalities, severe injuries and injuries by accident type and speed limit area based on British accident data (two-car crashes) in 1994 and 2000. (DTRL 1995, DfT 2003 a)**

| Accident type | Fatalities [%] | | Severe injuries [%] | | Injuries [%] | |
|---|---|---|---|---|---|---|
| | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 |
| Front | 0.4 | 0.4 | 8 | 6 | 53 | 51 |
| Back | 0.1 | 0.1 | 3 | 2 | 84 | 86 |
| Offside | 0.7 | 0.7 | 9 | 7 | 70 | 68 |
| Nearside | 0.8 | 0.8 | 8 | 6 | 64 | 65 |

| Speed limit [mph] | Fatalities [%] | | Severe injuries [%] | | Injuries [%] | | Accidents [%] | |
|---|---|---|---|---|---|---|---|---|
| | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 | 1994 | 2000 |
| 20 or 30 | 0.1 | 0.1 | 5 | 4 | 60 | 61 | 61 | 61 |
| 40 or 50 | 0.6 | 0.6 | 8 | 6 | 61 | 62 | 11 | 12 |
| 60 | 1.9 | 1.8 | 15 | 12 | 71 | 72 | 23 | 21 |
| 70- | 1.9 | 1.2 | 11 | 6 | 60 | 58 | 5 | 6 |
| Average | 0.4 | 0.3 | 7 | 5 | 63 | 63 | | |

The distributions of two-car crashes occurred in different speed zones have also been very similar both in 1994 and 2000. There are no practical differences between the accident types. The injury risks have been stable, but the decreasing in the risks of severe injuries is great in all speed zones and in all accident types. Positive influence can be seen especially on high speed roads, where also the proportion of fatalities has gone strongly down. Also based on these results it is obvious that newer cars are safer and give better protection to their occupants, but any absolute estimates of better protection cannot be presented with these tables.

## 4.7 AGE EFFECTS OF THE FINNISH CAR FLEET

The latest car safety rating based on Finnish insurance data was published in 2005 (Kari et al. 2005). According to the rating the newest models proved much safer than the older ones. The result is in line with the ratings done in Sweden, UK and Australia. Figure 29 describes the internal injury risk in inspected car fleet by first year of use of the car. Safety has clearly increased since the late 1980's. Because the analysis was based on accident data bases from the years 1997-2003, the cars from early 80's in ***Figure 29*** are almost 20 years old and only a part of the largest and safest cars of that time are still left and in active use. Therefore the curve bends slowly down in the beginning. Those car models which were registered in the middle of the 1980´s tend to have some 50% higher injury risk compared to the newest year models.

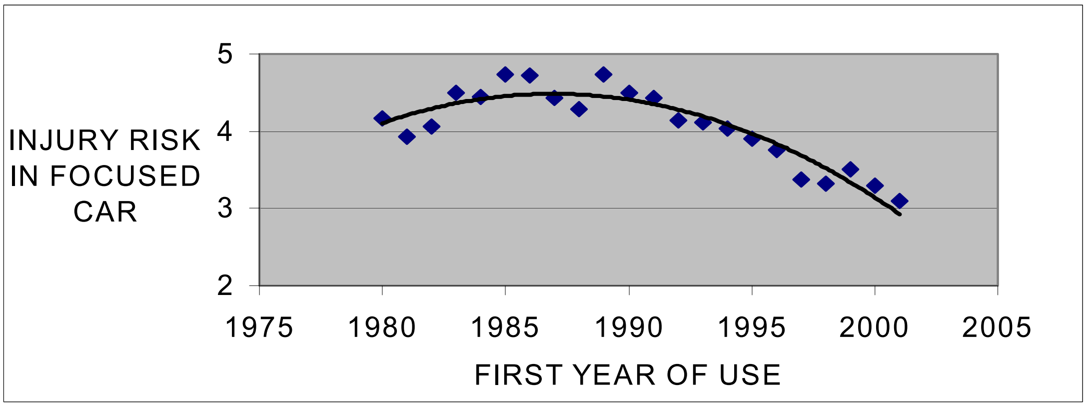


**Figure 29. The connection between first year of registration and internal injury risk in focused car. Two car crash data from Finland 1997-2003 [injuries/100 accidents]. (Kari et al. 2005)**

According to ***Figure 30*** newer cars seem to be also less aggressive. Better kerb and front structures of the newest car models may explain the positive development of aggressivity. Lower aggressivity of newer cars is quite understandable, because the modern structures of new vehicles are able to absorb better the releasing energy of a crash.

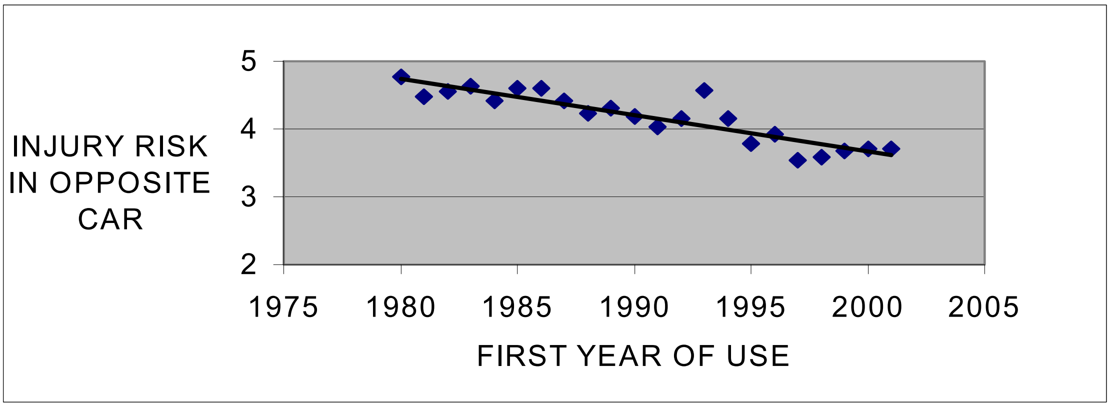


**Figure 30. The connection between first year of registration and aggressivity. Two car crash data from Finland 1997-2003 [injuries/100 accidents]. (Kari et al. 2005)**

Total risk is a combination of internal risk and aggressivity of the inspected car. Based on previous findings it is natural that also the total injury risk in both cars has clearly decreased during the 90's (***Figure 31***).

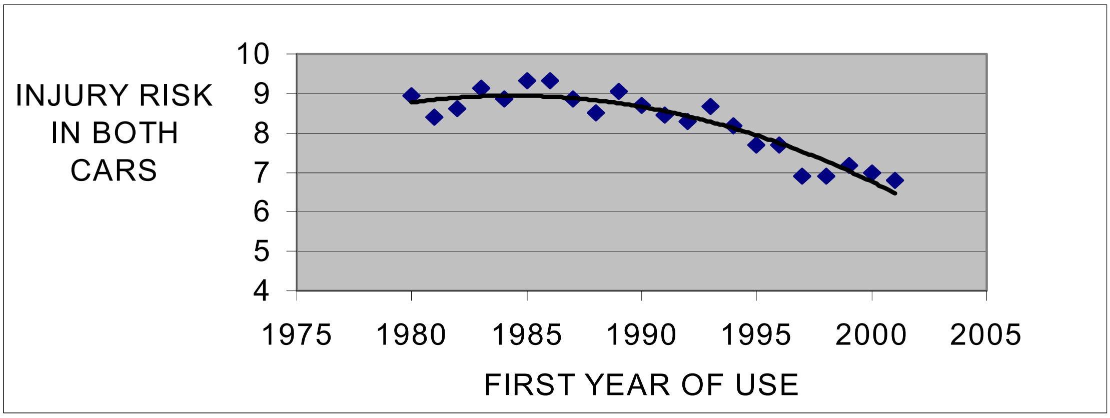


**Figure 31. The connection between first year of registration and total injury risk in both cars. Two car crash data from Finland 1997-2003 [injuries/100 accidents]. (Kari et al. 2005)**

Table 17 describes the numbers and their proportions by accident type in the Finnish two-car crash data of 232 020 accidents. Even though head-on accidents cover only 5% of the accidents, the proportion of injured drivers in head-on accidents is 12.3 % and the injury risk is about 2.5 times higher than the average injury risk in the data.

**Table 17. Driver injury risk by accident type. Two car crash data from Finland 1997-2003. (Kari et al. 2005)**

| ACCIDENT TYPE | ACCIDENTS | | INJURED DRIVERS | | INJURED DRIVERS / 100 ACCIDENTS |
|---|---|---|---|---|---|
| | PCS | % | PCS | % | |
| HEAD-ON | 10 922 | 4,7 | 2 394 | 12,3 | 21,92 |
| REAR-END | 69 733 | 30,1 | 5 828 | 29,9 | 8,36 |
| JUNCTION | 78 226 | 33,7 | 8 600 | 44,2 | 10,99 |
| OTHER | 73 139 | 31,5 | 2 649 | 13,6 | 3,62 |

| | | | | | |
|---|---|---|---|---|---|
| SUM | 232 020 | 100,0 | 19 471 | 100,0 | 8,39 |

Table 18 shows some selected examples of common car model generations and their average mileage per year and their observed accident and injury risks based on the average annual mileage. The values were calculated in two different 3 years period 1997-99 and 2000-02 and they describe absolute risk rates, which make them comparable. Clear positive in the risk rates can be seen both in vertical and horizontal direction.

**Table 18. Average annual mileages, accident and injury risks per driven mileage by some selected makes and model generations in two time periods 1997-1999 and 2000-2002 according the Finnish insurance data 1997-2002.**

| *Car model* | *Generation* | *Average mileage per car (1000 km)* | | *Acc per $10^6$ km* | | *Injuries per $10^6$ km* | |
|---|---|---|---|---|---|---|---|
| | | *97-99* | *00-02* | *97-99* | *00-02* | *97-99* | *00-02* |
| Nissan Micra 1 | 1983-1992 | 10.51 | 9.35 | 2.22 | 2.46 | 0.43 | 0.36 |
| Nissan Micra 2 | 1992-1998 | 13.72 | 11.73 | 1.60 | 1.85 | 0.44 | 0.49 |
| Nissan Micra 3 | 1998-2002 | | 13.83 | | 1.15 | | 0.26 |
| Volkswagen Golf 2 | 1983-1991 | 15.61 | 13.55 | 1.84 | 2.12 | 0.35 | 0.35 |
| Volkswagen Golf 3 | 1991-1997 | 20.29 | 18.13 | 1.15 | 1.36 | 0.18 | 0.23 |
| Volkswagen Golf 4 | 1997-2004 | | 21.47 | | 0.67 | | 0.12 |
| Toyota Corolla 5 | 1987-1992 | 15.70 | 14.29 | 1.79 | 2.00 | 0.33 | 0.40 |
| Toyota Corolla 6 | 1992-1997 | 17.52 | 15.85 | 1.35 | 1.47 | 0.28 | 0.31 |
| Toyota Corolla 7 | 1997-2001 | | 17.32 | | 1.14 | | 0.21 |
| Ford Sierra | 1987-1993 | 16.17 | 14.30 | 1.68 | 2.06 | 0.37 | 0.40 |
| Ford Mondeo 1 | 1993-1996 | 24.33 | 17.78 | 1.27 | 1.64 | 0.19 | 0.22 |
| Ford Mondeo 2 | 1996-2000 | 35.69 | 25.45 | 0.45 | 1.07 | 0.05 | 0.15 |
| Opel Ascona | 1984-1989 | 15.08 | 12.93 | 2.11 | 2.79 | 0.37 | 0.41 |
| Opel Vectra 1 | 1988-1993 | 18.87 | 17.20 | 1.53 | 1.86 | 0.25 | 0.31 |
| Opel Vectra 2 | 1993-1995 | 23.25 | 17.68 | 1.03 | 1.55 | 0.23 | 0.36 |
| Opel Vectra 3 | 1995-2002 | 23.06 | 22.55 | 0.75 | 0.98 | 0.11 | 0.13 |

When a certain car model generation gets older its annual mileage decreases, but both its accident risk and injury risk per mileage increases (horizontal values). For example, when the fleet of Golf 3 was 3 year older in the latter period, its mileage in Finland was decreased by 19 % and accident risk was increased by 19 %, respectively. The injury risk of Volkswagen 3-drivers increased, however, during the same time period with some 25 % (from 0.18 to 0.23 injuries/mill. km)).

Comparisons between different generations of any listed make show almost systematically the newer generation much safer than its processor (vertical values). Both accidents and injuries per mileage are decreasing continuously. When a car model generation is getting older it will be more often involved in accidents and does have more injuries per mileage. This might relate to the owner population of new cars. As mentioned before, it seems based on the German and the Finnish fleet data that new cars are purchased mostly by males of 50-60 years. Their risk to be involved in an accident is the lowest. The older becomes the fleet the higher is the proportion of young drivers with remarkably higher accident risk. It has also assessed that new technologies of active safety in newer vehicles might reduce the number of accidents. Unfortunately, the cases which didn't ever lead to an accident are extremely difficult to prove or to model.

According to Table 18 new model generations are safer than the old ones in both 3 years periods 1997–99 and 2000–2002. Older cars proved also to be less safe than the same cars few years earlier. In most car models the injury risk rate has decreased roughly 40-50% or even more from the oldest to the youngest generation. The results are in line with the results calculated from the German accident data.

In injury risk calculations it is also possible to use the number of insurance years during a certain time interval as an exposure. These kinds of investigations give also a clear result from the continuous improved safety of newer model generations as the Table in appendix 1 presents.

# 5 CHARACTERISTICS OF RATINGS

## 5.1 RATINGS

### 5.1.1 Absolute risk rates

Absolute risk rates are defined based on the real recorded numbers of accident, injuries or fatalities related to some suitable exposure. Commonly used exposures are for example number of population, car fleet, recorded accidents, time, mileage driven or the length of road network. The risk rates by car models describe and compare those models related to the total or to some sub-group of the exposure group. Some examples of possible units could be killed/$10^6$inh., injuries/100 acc., or accidents/$10^6$ km.

The time series of absolute risk rates reflect generally quite well the progress from traffic safety point of view, but they do not explain the reasons which have influenced on the changes.

### 5.1.2 Relative risk ratings based on two-car collisions

Two-car crashes give quite good possibilities to evaluate the risk ratings by car models. In this kind of comparisons it is typically assumed that in a two car crash one or both of the drivers were injured. In the fact each car performs in the analysis twice, once as a case car (inspected car) and once as an opponent one. If:

$X_1$ = number of two car crashes, in which the driver of the inspected car model was injured

$X_2$ = number of two car crashes, in which the drivers of both cars were injured

$X_3$ = number of two car crashes, in which the driver of the opponent car was injured

$X_0$ = number of two car crashes occurred to the inspected car model without driver injuries

A rating method (called also Folksam-method) introduced by the Swedish Insurance Company, Folksam compares the relative risk $R_F$ basely as follows:

$$R_F = \frac{X_1 + X_2}{X_2 + X_3}$$

The formula gives an average value of $R_F$ =1.00 for the total fleet, because each crash “exists twice in the statistics”. The first case the inspected model (in numerator) collides with another car (in denominator), and the second case, when whatever car model (in numerator) collides with the inspected car model (in denominator). It is remarkable that in each rating (from different accident sample or from time period) the average value for the whole fleet is 1.00, if no other corrections or definitions are done. This is because the crashes in different rating periods have occurred to different cars and driver populations in different places and circumstances.

In Great Britain TRL introduced in 1990 a rating method (later called and known also as DETR-method), which compares the number of crashes in which the drivers of inspected car model were injured to all those crashes in which the inspected car model was involved and at least one driver was injured.

$$R_{TRL} = \frac{X_1 + X_2}{X_1 + X_2 + X_3}$$

The average value of $R_{DTR}$ depends on the proportion of $X_2$ crashes. Both the car fleet and the distribution of accident types are changing quite slowly. So the average value of $R_{DETR}$ in Great Britain has remained on the level 0.63–0.64 in all passenger car ratings done during the 1990´s.

The Road and Transport Laboratory of University of Oulu, in Finland, has used since early 1990´s in their risk ratings (OULU-method) the following formula:

$$R_{OULU} = \frac{X_1 + X_2}{X_1 + 2X_2 + X_3}$$

The formula of $R_{OULU}$ looks quite similar with the British one, but instead of comparing the numbers of crashes, the OULU-method compares the numbers of injured drivers in the inspected car models to all driver injuries in crashes the inspected car model were involved.

For the total fleet the expected average value of $R_{OULU}$ is 0.50.

The Accident Research Centre of Monash University (MUARC), in Australia, has used also two-car crashes without driver injuries in their injury risk calculations (MUARC-method) as follows:

$$R_{MUARC} = \frac{X_1 + X_2}{X_1 + X_2 + X_3 + X_0}$$

The number of $X_0$ (crashes without driver injuries) is highly dependent on the accident recording system. In accident databases recorded by insurance companies the proportion of very slight crashes is dominant (even 80-90 %) and therefore the influence of $X_0$ on $R_{MUARC}$

rate as well. When using the police databases the influence of $X_0$ is much smaller. In the fact the MUARC-method can be regarded rather as an absolute risk method than a relative one, because the denominator is the total number of chosen accidents.

As it already was mentioned within Folksam-method, the results of the ratings produced from different accident databases and in different time periods regardless the used method are not directly comparative.

Basely each method works without any correction of car, driver or accident type characteristics. Different kind of corrections for example based on car mass, driver's sex and age etc. are, of course, possible to do.

All methods are suitable also for aggressivity ratings. Then we are looking at those driver injuries that the inspected car model has caused to its opponent party in the crashes. The formulas for aggressivity can be created by replacing $X_1$ with $X_3$ and $X_3$ with $X_1$ in the previous formulas.

### 1.1.1 Crashworthiness ratings

Thought relative risk methods are suitable also for the comparisons of severe injury accidents, the low number of severe cases by car model restricts the possibilities to use only them in the analysis.

The crashworthiness ratings take both the injury risk and the severity of those injury accidents into the consideration at the same time as follows:

C = R * S

where C = crashworthiness risk (by car model)
R = injury risk (by car model)
S = severity rate (proportion of severe injuries from all injury crashes by car model)

Because the method is based on injury risk and severity rate calculated from a certain accident data, it is not possible to compare crashworthiness risks by car model directly between different rating periods or different accident materials. Folksam has introduced an advanced method for severity definition already in the beginning of 1990´s.

MUARC calculates both C and R one by one and uses logistic regression techniques in their analyses. The method is described briefly in 5.1.5.

Crashworthiness rates have been calculated by MUARC with all methods mentioned before from different accident databases. Because of different car fleets and accident type distributions in different accident data sets are not compatible; the international safety ratings are not directly comparable.

### 1.1.2 Actual vs. expected injuries -method

University of Oulu and Helsinki University of Technology have used in Finland a method which compares the actual number of injuries to an expected number of injuries in inspected car models.

For expected values the method uses as a starting value the average injury risk of the total fleet for each model. Different classified variables like driver age and sex, annual mileage, accident type, speed limit and urbanisation level of crash site, injury severity and position of the crash (guilty/non-guilty) vary widely from one car model to another. The correction terms of each variable are calculated for each inspected car model and the final number of expected injuries is the starting value multiplied by each correction terms.

Both the population (total number of insurance years) and the total mileage of each model fleet were used for the calculations of the starting values.

Also in this method ratings done from different accident databases vary remarkable, because both the starting values and the correction terms utilize the average risks of the inspected database.

### 1.1.3 Regression models

Injuries and fatalities depend typically on several different variables or let us say their unexpected combinations. Accidents and injuries are, however, very rare occasions and the real reasons affected on the accident often are and stay unknown. If the number of suitable cases is large enough and the information of potential variables affecting typically on accidents of such type is available, different kind of statistical procedures like regression models can be used. On car model level it is possible to define injury risks both with linear and logistic regression models.

Linear regression models need typically larger samples for the calculation of regression coefficients of the explanatory variables. University of Oulu and HUT have used in their accident risk calculations a linear regression model, for example, as follows:

$N = a + b_1x_1 + b_2x_2 + b_3x_3 + c$

where N = dependent variable (expected number of accidents of a certain car model )
$a$ = constant
$x_{1,}$ = total annual mileage the car model
$x_{2,}$ =risk of drivers´ age and sex group
$x_{3,}$ =risk of different using circumstances
$b_1, b_2, b_3$ = regression coefficients
$c$ = error

Logistic models are more complex, but they generally give opportunities to operate with lower number of cases and with interactions of several variables. MUARC for example has used a logistic regression and calculated risk rates by car models successfully using relatively general variables and their combinations in quite small samples. Their injury risk was calculated as follows:

$$R_i = \frac{e^{(x_i+L)}}{1+e^{(x_i+L)}}$$

where $R_i$ = injury risk for car model i
$x_i$ = estimate for car model i based on logistic regression
L = logit-value for the whole sample

$$L = \ln\left(\frac{R_{tot}}{1-R_{tot}}\right)$$

where $R_{tot}$= injury risk for the whole acceptable sample.

MUARC has used in their crashworthiness calculations a stepwise logistic regression method (Newstead, ). In the beginning the model searches the main effects affecting significantly on the injury risk of each accident data set and then the first, second and higher order interactions of those main effects. The injury risks and their confidential limits are then possible to calculate to each inspected car model. Of course it is possible to use similar method for the calculations of injury severity risk rate $S_i$ or crashworthiness rate $C_i$ for each car model or any other sufficient sub-group of the data. Looking at any sub-group, for example severe injuries, different crash types, etc, we must keep in mind that the main effects vary and they have different interactions.

The regression analysis itself is based on some certain accident data and the results describe the situation only in that particular accident material. Comparisons between ratings from different time periods, from different data sets or in different countries are not comparable.

## 5.2 FLEET EFFECT RELATED TO DIFFERENT RISK RATINGS

As mentioned before, it is not possible to compare directly the results of different ratings done based on different data sets or different time periods.. In all ratings, however, a general conclusion has been that for the driver the newer models are safer than their previous model generations. Also an increasing number of points and collected number of stars in the EuroNCAP test seem to influence positively on injury risks and crashworthiness rates (Newstead et al 2005).

This chapter analyses what kind of observations or expectations of improved safety can be done based on vehicle safety ratings generally.

Table 19 gives a fictitious description how "a safer fleet" does influence on rating results, if the old fleet would totally be replaced by a newer and safer one in 15 years period, lets say from 1990 to 2005. The example in Table 19 has been calculated with the basic Folksam method without any mass or design corrections. The size distribution of the fleet in the example is close to the Swedish one and the safety improvements are fictitious. Due to the method the average injury risk for the total fleet both in 1990 and in 2005 are, of course, equally 1.00. Looking only at the calculated risk rates of the size groups it seems that only the smallest models would be much safer and small family cars a little bit safer nowadays, but medium and large models were less safe than 15 years ago. However, due to the original hypothesis the improved safety varied from 20 per cent to 35 per cent according to different size class. The new fleet must therefore be at least 25 per cent "safer" than the old one. This example shows clearly, that ratings done in different time periods are not comparable.

**Table 19 An example from the influence of "fleet effect" on injury risk ratings bu car size group. The values in the table are fictitious and the method used is the basic Folksam method.**

| Car size | Proportion in the fleet [%] | Improved safety [%] | Average injury risk 1990 | 2005 |
|---|---|---|---|---|
| small | 10 | 35 | 1.70 | 1.43 |
| small family | 20 | 30 | 1.20 | 1.15 |
| medium | 30 | 25 | 0.90 | 0.92 |
| large | 40 | 20 | 0.80 | 0.88 |
| Average | | | 1.00 | 1.00 |

The results tell, however, that all relative risks between the size groups have changed and the smallest group has changed (improved) most ,but the values do not explain, how much safer is the new fleet compared to the old one. Using more variables in the analysis like injury or crash severity or more detailed occupant and vehicle data it would be possible to calculate and evaluate risks better.

Table 20 presents as an example the numbers of crashes with different injury outcomes, $X_{0,}$ $X_{1,}$ $X_2$ or $X_3$, when each of them in turn are reduced with 20%. Column A describes a base situation, in column B only $X_1$ (=injury only in inspected car model) is reduced by 20% (from 5 % to 4 %), in column C only $X_2$ (=injuries in both cars) is reduced by 20% (from 4% to 3.2 %), in column D only $X_3$ (=injury only in the opponent car) is reduced by 20% (from 7 % to 5.4 %) and in column E the number of all injury crashes ($X_1$+$X_2$+$X_3$) are reduced by 20% (from 16 % to 12.6 %). $X_0$ means the number of crashes without injury. In the basic situation the total number of crashes is 10000 and in each new situation 11000.

**Table 20. The numbers of different injury crash types in two-car crashes, when each crash type $X_0$, $X_1$, $X_2$ or $X_3$ is reduced in turn with fictitious 20%**

| | A | B | C | D | E |
|---|---|---|---|---|---|
| | ACTUAL | **$X_1$** (-20%) | **$X_2$** (-20%) | **$X_3$** (-20%) | **$X_1$,$X_2$,$X_3$** (-20%) |
| **$X_1$** | 500 (5%) | **440** (4%) | 550 (5%) | 550 (5%) | **440** (4,0%) |
| **$X_2$** | 400 (4%) | 440 (4%) | **352** (3,2%) | 440 (4%) | **352** (3,2%) |
| **$X_3$** | 700 (7%) | 770 (7%) | 770 (7%) | **616** (5,4%) | **616** (5,4%) |
| **$X_0$** | 8400 | 9350 | 9328 | 9394 | 9592 |
| **Tot** | 10000 | 11000 | 11000 | 11000 | 11000 |

**Table 21. Injury risks calculated with four diffrent relative risk methods with the values of columns A-E in Table 22**

| | $R_{FOLKSAM}$ | $R_{DETR}$ | $R_{OULU}$ | $R_{MUARC}$ | Injury crashes % | Injured drivers % |
|---|---|---|---|---|---|---|
| A | 0,819 | 0,562 | 0,450 | 0,090 | 16,0 | 10,0 |
| B | 0,727 | 0,533 | 0,421 | 0,080 | 15,0 | 9,5 |
| C | 0,804 | 0,539 | 0,445 | 0,082 | 15,2 | 9,2 |
| D | 0,938 | 0,616 | 0,484 | 0,090 | 14,6 | 9,3 |
| E | 0,819 | 0,562 | 0,450 | 0,072 | 12,8 | 8,0 |

From Table 20 and Table 21 we can see that in each case (B-E) the proportions of injury crashes and injured drivers are lower than in the basic situation (A). This leads to a conclusion that the safety of the fleet has generally improved, because the new proportion injury crashes in all alternatives B–E is less than former 16 % in case A and the proportion of injured driver less than 10 %, respectively.

In case A and E the values are equal thought both $X_1$, $X_2$ and $X_3$ are 20% lower. This is the problem of all relative risk methods, because both the numerator and the denominator are decreasing (in this case both with 20%), when the fleet is becoming safer. Only the MUARC-method, which in the fact is an absolute risk method, shows a clear improvement, because it takes also the non-injury cases $X_0$ into the consideration.

The fictitious car model which is shown in the Table 21 is safer than an average car model because it gets good rating according to all methods already in the basic situation (A).

From Table 22 we can see very similar result we got already in the example of Table 19. The average injury risk for the **total fleet** in Great Britain has in the 1990´s remained on 63%. This is quite understandable because both traffic environment and traffic behaviour are changing very slowly and so does also the accident type distribution.

**Table 22. Injury risks (%) by selected car size groups and age generations in four British ratings 1991–2000.**

| | SMALL | | | | SMALL FAMILY | | | |
|---|---|---|---|---|---|---|---|---|
| Generations | 1991 | 1994 | 1997 | 2000 | 1991 | 1994 | 1997 | 2000 |
| 85-89 | 71 | 71 | 72 | 72 | 61 | 63 | 64 | 65 |
| 90-95 | | 68 | 69 | 70 | | 59 | 60 | 63 |
| 94-98 | | | 68 | 69 | | | 59 | 62 |
| TOTAL | 71 | 71 | 71 | 71 | 62 | 62 | 63 | 64 |

| | MEDIUM | | | | LARGE | | | |
|---|---|---|---|---|---|---|---|---|
| Generations | 1991 | 1994 | 1997 | 2000 | 1991 | 1994 | 1997 | 2000 |
| 85-89 | 53 | 55 | 57 | 59 | 45 | 46 | 48 | 50 |
| 90-95 | | 50 | 53 | 56 | | | 45 | 51 |
| 94-98 | | | 48 | 53 | | | | 46 |
| TOTAL | 56 | 57 | 57 | 58 | 45 | 46 | 48 | 50 |

| | TOTAL FLEET | | | |
|---|---|---|---|---|
| Generations | 1991 | 1994 | 1997 | 2000 |
| Average | 63 | 63 | 63 | 63 |

The newer generations of each **size classes** (in the same columns) are systematically much safer than their predecessors. When we are looking at the risk rates by car generations in each size classes from older to newer rating (in the same lines), we can see a negative tendency. The injury risks seem to increase the newer is the rating. This result is quite understandable. Because newer car generations are safer, it means that older generations are relatively weakening compared to the total fleet. When considering only, how have the injury risks of size classes totally developed, we can easily get a faulty conclusion. Larger cars are not worsening, actually they are also much safer compared to their predecessors. The average safety level of the whole fleet is all the time increasing from rating to another. It means that the fleet is homogenising from safety point of view. Inside the fleet the differences in the protection between newer small and large cars are narrowing but between older and newer models the differences are increasing.

# 6 CONCLUDING REMARKS

## 6.1 OCCUPANT EFFECT

The age of car driver influences both on accident, injury and injury severity risks. In the accident data we normally have the information of drivers involved in accidents and from the vehicle registration data we can clarify the owner or the official holder of the collided vehicle.

Driver and owner do not match very well, because for example in Finland some 40% of those drivers involved in accidents are not the owners or the official holders of the vehicles. Typically young drivers use cars of their friends or relatives and cars used by females are registered to somebody else in their family. This means that the total annual mileage of a single car is often accumulated by several drivers. According to Figure 32 the mileage correlates strongly with the age of the car and the age of the owner or driver. The newest cars are typically owned by males from 50 to 60 years and the mileages of those cars are also the highest.

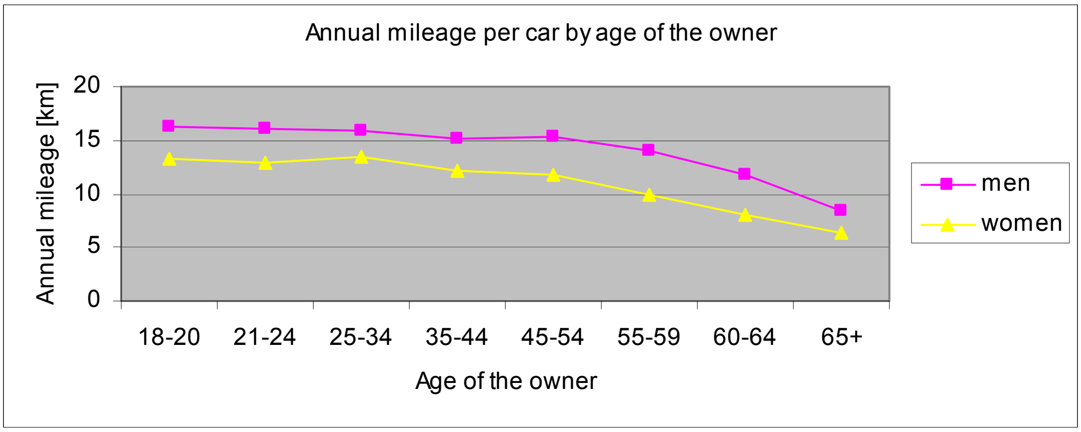


**Figure 32. Annual mileage of cars in relation to owner age based on German mileage data. (Hautzinger et al.2004)**

Among young persons the car ownership rate is much lower compared to older age groups. Those young drivers, who own a car, tend to have much higher mileage compared to those driving licence holders, who do not have a car of their own. The situation is similar also among elderly drivers.

Females tend to own cars, which are some 100kg lighter compared to cars owned by males of same age (Figure 33). The smallest cars are typically owned by young and old females. Unfortunately they together with young males have also the oldest cars.

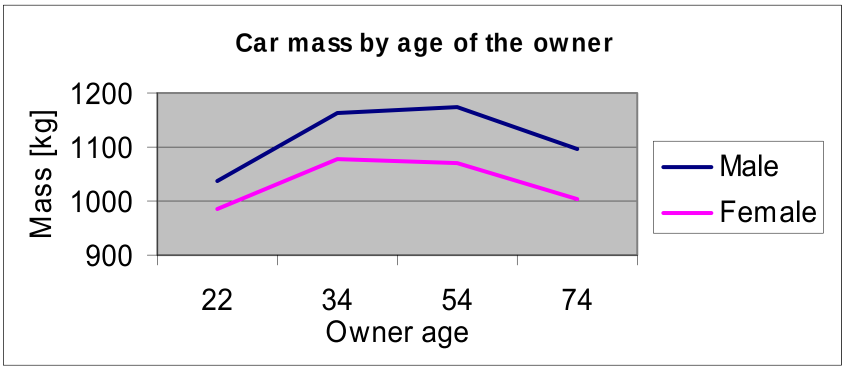


**Figure 33. Car mass in relation to the age of car owner. ( Finnish car registration data).**

Accident risk is high in urban areas where the traffic volumes are high and the traffic environment is complicated especially to less experienced young and old drivers. Most of the “accidents” are rather incidents which happen without intentional risk taking or traffic violence. Because of lower speed limit and driving speed the most part of urban accidents are typically property only accidents. Injury outcomes in urban areas are typically quite light. A significant proportion of injuries in urban areas could be prevented if the using rate of safety restraints (safety belt, child seats etc.) were higher.

An accident itself is always a sudden occasion and the parties of the crash don’t have much time to react and operate for avoiding the crash. The situation is especially embarrassing for the non-guilty party who cannot expect a mistake of another road user. This increases the injury risk of non-guilty party in two-car crashes.

Except of the youngest drivers, injury risk increases in line with the driver’s age. Figure 34 presents the injury risk rates (injuries / 100 accidents) by the age of car owner and car driver. The figure supports strongly the fact that driver and owner populations in traffic differ remarkable which makes the injury risk calculations more complicated.

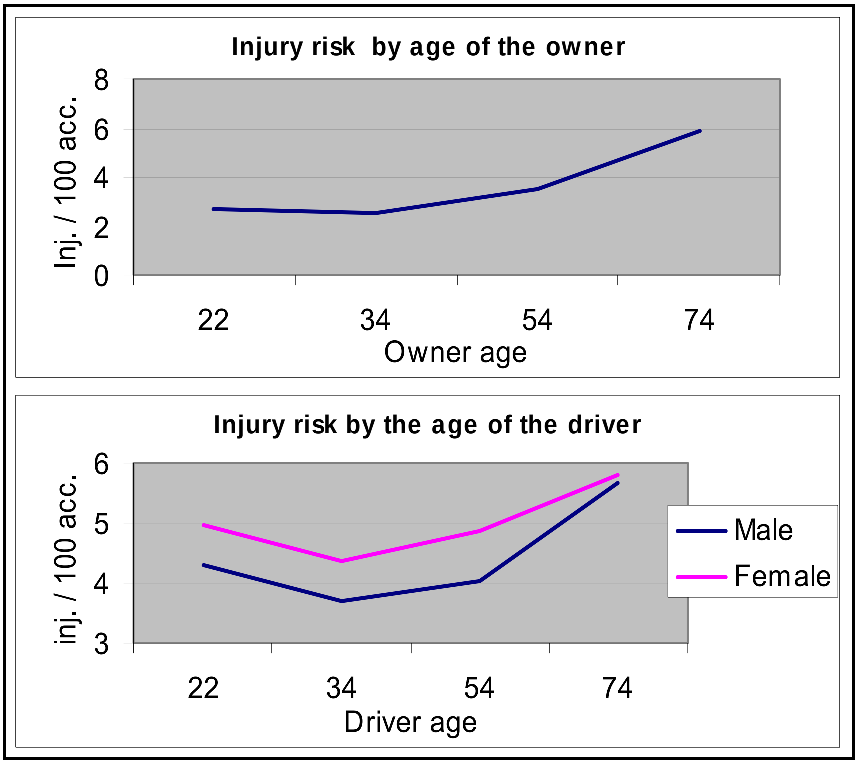


**Figure 34. Injury risk in relation to age of the car owner and age of the driver. ( Finnish accident data)**

Young people own relatively low amount of cars, which does not represent a high proportion of all injury accidents of whole fleet. When However, the role of young drivers is remarkable in the accident data, and their injury risk is higher than risk of middle-aged drivers (Figure 34).

The aggressivity rates of cars owned by young people are the highest and clearly higher than their own injury risks are. (Figure 35). This may reflect among the young car owners more risky driving habits and difficulties to control the car in challenging driving environment.

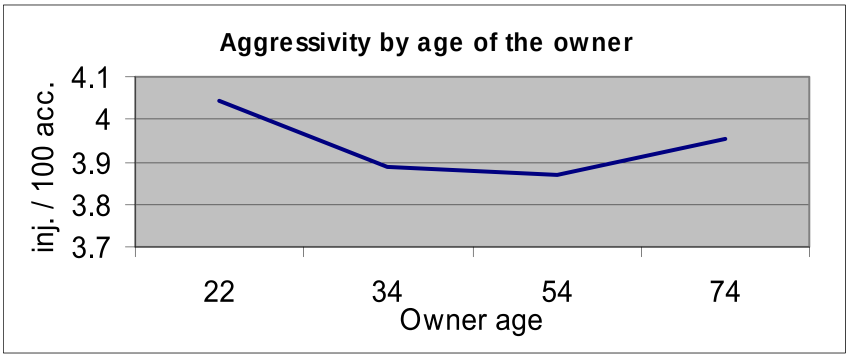


**Figure 35. Aggressivity of cars in relation to age of car owner. ( Finnish accident data)**

## 6.2 FLEET EFFECT

As mentioned before the annual mileages are higher for newer cars and the mileages decrease steadily the older the cars become (Figure 36)., This means that the risks related to driven kilometres are still lower for new cars compared to the whole fleet. Unfortunately the existing mileage data of individual cars is still poor for the purposes of car safety ratings, because the information where the mileage is accumulated misses.

In spite of the differences of average annual mileages in different countries at the age of ten years the mileage per car is typically some 35 per cent lower than the mileages of new passenger cars. These kinds of findings are available both from Germany, Finland and Sweden.

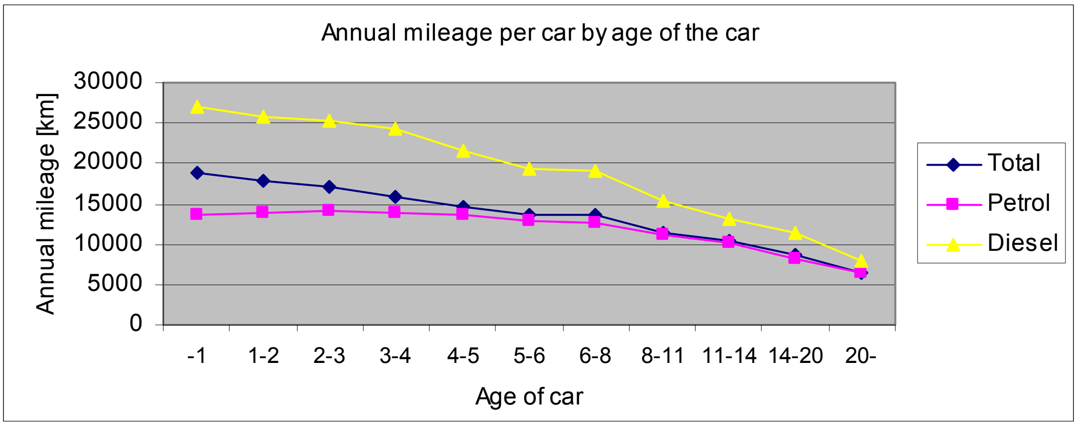


**Figure 36. Annual mileage per car in relation to age of the car based on German car mileage data. (Hautzinger et al. 2004)**

In spite of the differences in the average annual mileages of the fleets in different countries at the age of ten years the mileage of a car is typically some 35 per cent lower than the mileage of new passenger cars. These kinds of findings are available both from Germany, Finland and Sweden.

Numerous analyses done with several methods from different data bases show without controversy that new car models are much safer compared to their predecessors. The improvement of passive safety has been in German data even more than 50 per cent better within some individual model generations during the past 15 to 20 years, when no mass or vehicle design corrections were done. (Delaney et al, 2005). According to Swedish investigations (Folksam 2003) the Swedish fleet in 2002 was 18 % safer than the fleet was in 1994. Furthermore the models introduced in 1998-2002 are in Sweden systematically much safer than their predecessors. The safety improvement of year models 1998-2002 seems to be some 35% in the smallest group, 10% among small family cars, 30% for family cars and 25% for large cars compared to models introduced in 1983-87. According to the Finnish accident data new cars have roughly 30% lower injury risks than their 10 year old correspondent models have. As an example in Sweden the models introduced in the mid 80´s are independently of their size and mass class today less safe than the total fleet on an average.

Injury severity risks seem to have improved more than injury risks do. For example the relative disability and fatality risks by body regions are much lower when comparing the car models of the late 90´s with those of the early 80´s. The risk reductions within all other body regions except neck are at least 60 per cent.

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Thought the new car models are almost 150kg heavier compared to their 10-12 years old predecessors, the aggressivity of new cars has decreased more than 10 per cent. (Figure 37).

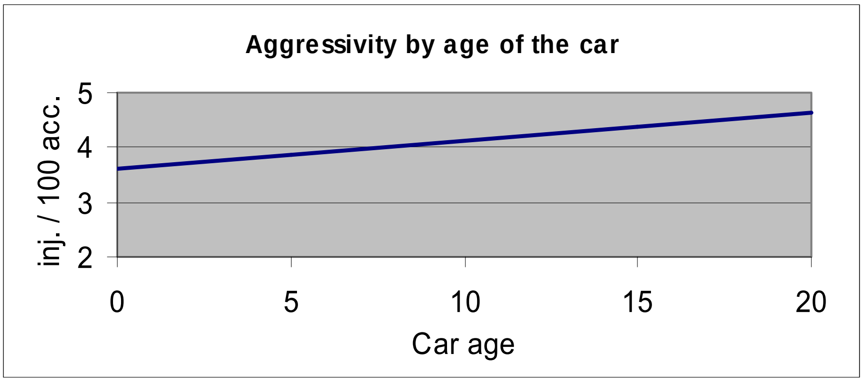


**Figure 37. Aggressivity of cars in relation to car age based on Finnish accident data.**

## 6.3 TRAFFIC SAFETY RESEARCH

The European car fleets are still increasing in the near future. In the countries of high motorization the driver populations will get older and therefore the outcomes of similar accidents will be more severe. Therefore, we must be able to compensate the increasing susceptibility to injuries with safer car structures and safer traffic environment. In the countries where the car ownership is still growing, like in many countries in Eastern Europe) the driver population will obviously be younger than today. In both cases the accident risk increases. More edifying and administrative activities are needed to maintain the safety of the traffic system.

Numerous safety ratings have showed the new cars safer than their predecessors. The tendency is clear but the real degree of improvement in not clear because the absolute safety impacts are not possible to measure or define based only on safety ratings. The results of safety ratings vary because of different fleet effects in different countries.

The car safety ratings are everywhere based on relative risk methods, which generally use average values as basic levels for the explanatory variables. Every different accident data from different time period or from different car fleet leads to a different comparison level even in the same country. This phenomenon can be remarked when comparing the figures of small and large cars in consecutive ratings. Small cars have much lower risk rates while large cars may have even worse ratings regardless of clearly decreased numbers of injuries and especially severe injuries. In fact, the whole fleet, however, is safer in the latest investigations and especially the newest part of the fleet much more. Furthermore, the narrowed dispersion of mass in the car fleet has also helped to reach the safety targets. However, there are already some signals from USA and Australia of less harmonious fleet. In those countries the proportions of pick-up vans and large off-road vehicle have increased largely.

The regeneration towards to safer fleets will continue a while. Unfortunately, there seems to be evidence of new threads. On some day the path of protecting the occupants by improving the safety structures of cars will end. Therefore we should pay more attention to find new safety solutions from the field of primary safety for maintaining the positive trend of traffic safety.

# 7 RECOMMENDATIONS

## Protection of car occupants

Driver populations in most EU-countries are ageing quickly and the proportions of female drivers in traffic are increasing. Both of them influence on increasing injury and injury severity risk. During the past 15 years newer car models have become all the time safer than their predecessors because of their more advanced structures and passive safety devices. It seems, however, there is less probable to improve vehicle safety any more as much as in the last decade by design and structural means. Therefore we should pay more attention to accident preventive technologies and try to quicken the regeneration the fleets with vehicles equipped with new primary safety systems like ESP, ACC, BAS, etc. Better information about the benefits of those technologies should be given to the consumers; the technologies should be widely available also in the smaller and cheaper car models and the taxation systems in member states should not be restrictive for safety systems.

Naturally all efforts to create less complex and also still softer traffic environments must be continued to decrease the numbers of victims in European traffic.

## Harmonization of car fleets

In Europe relative size differences of the car fleets are getting smaller, which has influences positively on occupant safety in both vehicles in two-car crashes. This positive trend of car compatibility should be continued. Therefore we should try in Europe to avoid the re-polarization of the fleet. In the U.S. and in Australia there already are observations about increasing proportions of large SUV, MPV and pick-ups but also smaller city cars in the fleet.

## Developing of vehicle and accident data

Urbanisation, centralisation of commercial activities and leisure time are increasing in the EU. All these are influencing on car use, car choice and travel behaviour. In different countries the changes in traffic circumstances vary but also the data bases describing the characteristics of drivers, car owners, vehicles, accidents, trip purposes, mileages or road and street classifications have been recorded based on different criteria. In spite of good intentions congruent statistics even to identify car models and their dimensions internationally do not exist. For risk analyses one major problem is the lack of relevant mileage information by individual cars. This information can be recorded in connection to yearly car inspections as done in some member states. The information of when or where or in what kind of use the mileages are accumulated is important, but there are, for example, no comparable travel surveys available for these purposes. Therefore the methods of recording vehicle and accident data should be harmonised in the EU.

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**APPENDIX 1. Injury risks in Finland by car model in three years interval 1996, 1999 and 2002 per mileage and per insurance years.**

| Model | Model years | Inj Acc per mileage (* 1000) | | Inj Acc per insurance year (*100) | | |
|---|---|---|---|---|---|---|
| | | R99 | R02 | R96 | R99 | R02 |
| Ford Fiesta | 1986-1989 | 0.58 | 0.57 | 0.39 | 0.60 | 0.51 |
| Ford Fiesta | 1989-1995 | 0.39 | 0.38 | 0.37 | 0.46 | 0.40 |
| Ford Fiesta | 1995-2002 | 0.15 | 0.29 | 0.00 | 0.32 | 0.42 |
| Nissan Micra | 1983-1992 | 0.43 | 0.36 | 0.32 | 0.47 | 0.33 |
| Nissan Micra | 1992-1998 | 0.44 | 0.49 | 0.27 | 0.69 | 0.59 |
| Nissan Micra | 1998-2002 | | 0.26 | | 0.53 | 0.51 |
| Opel Corsa | 1983-1993 | 0.43 | 0.56 | 0.37 | 0.50 | 0.55 |
| Opel Corsa | 1993-2000 | 0.21 | 0.34 | 0.22 | 0.49 | 0.55 |
| Peugeot 205 | 1983-1993 | 0.42 | 0.57 | 0.49 | 0.56 | 0.63 |
| Peugeot 206 | 1998- | | 0.23 | | 0.22 | 0.65 |
| Toyota Starlet | 1978-1987 | 0.67 | 0.82 | 0.61 | 0.65 | 0.67 |
| Toyota Starlet | 1984-1993 | 0.53 | 0.51 | 0.75 | 0.57 | 0.50 |
| Toyota Starlet | 1995-1999 | 0.30 | 0.32 | 0.00 | 0.68 | 0.48 |
| Volkswagen Polo | 1976-1980 | 0.45 | 1.80 | 0.41 | 0.31 | 0.75 |
| Volkswagen Polo | 1981-1989 | 0.47 | 0.50 | 0.32 | 0.53 | 0.46 |
| Volkswagen Polo | 1990-1994 | 0.36 | 0.37 | 0.29 | 0.48 | 0.43 |
| Volkswagen Polo | 1994-2001 | 0.17 | 0.20 | 0.03 | 0.52 | 0.41 |
| Ford Escort | 1980-1990 | 0.53 | 0.64 | 0.48 | 0.66 | 0.65 |
| Ford Escort | 1990-2000 | 0.27 | 0.30 | 0.31 | 0.54 | 0.48 |
| Ford Focus | 1998- | | 0.12 | | 0.26 | 0.38 |
| Nissan Sunny | 1990-1996 | 0.26 | 0.33 | 0.34 | 0.44 | 0.52 |
| Nissan Almera | 1995-2000 | 0.18 | 0.27 | 0.00 | 0.58 | 0.51 |
| Opel Kadett E | 1984-1991 | 0.38 | 0.42 | 0.40 | 0.57 | 0.54 |
| Opel Astra | 1991-1997 | 0.21 | 0.27 | 0.30 | 0.47 | 0.49 |
| Opel Astra | 1997- | 0.01 | 0.12 | 0.00 | 0.18 | 0.36 |
| Peugeot 306 | 1993-1997 | 0.28 | 0.30 | 0.29 | 0.59 | 0.50 |
| Peugeot 306 | 1997- | | 0.23 | | 0.57 | 0.61 |
| Peugeot 309 | 1986-1993 | 0.34 | 0.46 | 0.44 | 0.51 | 0.58 |
| Toyota Corolla | 1987-1992 | 0.33 | 0.40 | 0.38 | 0.53 | 0.59 |
| Toyota Corolla | 1992-1997 | 0.28 | 0.31 | 0.37 | 0.53 | 0.51 |
| Toyota Corolla | 1997-2001 | 0.06 | 0.21 | | 0.40 | 0.41 |
| Volkswagen Golf | 1983-1988 | 0.35 | 0.35 | 0.34 | 0.56 | 0.48 |
| Volkswagen Golf | 1988-1991 | 0.53 | 0.09 | 0.44 | 1.60 | 0.22 |
| Volkswagen Golf | 1991-1997 | 0.18 | 0.23 | 0.29 | 0.45 | 0.43 |
| Volkswagen Golf | 1997-2004 | 0.11 | 0.12 | | 0.24 | 0.41 |
| Ford Sierra | 1982-1987 | 0.52 | 0.54 | 0.53 | 0.76 | 0.61 |
| Ford Sierra | 1987-1993 | 0.37 | 0.40 | 0.52 | 0.63 | 0.59 |
| Ford Mondeo | 1993-1996 | 0.19 | 0.22 | 0.27 | 0.49 | 0.42 |
| Ford Mondeo | 1996-2000 | 0.05 | 0.15 | 0.00 | 0.38 | 0.43 |
| Nissan Bluebird | 1986-1991 | 0.32 | 0.34 | 0.36 | 0.58 | 0.54 |
| Nissan Primera | 1990-1996 | 0.25 | 0.32 | 0.40 | 0.52 | 0.60 |
| Nissan Primera | 1996-2001 | 0.08 | 0.16 | 0.00 | 0.39 | 0.40 |
| Opel Ascona | 1984-1989 | 0.37 | 0.41 | 0.38 | 0.58 | 0.52 |
| Opel Vectra | 1988-1993 | 0.25 | 0.31 | 0.42 | 0.50 | 0.56 |
| Opel Vectra | 1993-1995 | 0.23 | 0.36 | 0.26 | 0.56 | 0.66 |
| Opel Vectra | 1995-2002 | 0.11 | 0.13 | 0.00 | 0.47 | 0.38 |
| Peugeot 405 | 1987-1992 | 0.27 | 0.32 | 0.45 | 0.52 | 0.52 |
| Peugeot 405 | 1992-1997 | 0.20 | 0.25 | 0.34 | 0.51 | 0.46 |
| Peugeot 406 | 1995- | 0.11 | 0.14 | 0.00 | 0.61 | 0.51 |
| Toyota Carina E | 1992-1997 | 0.23 | 0.19 | 0.43 | 0.54 | 0.38 |
| Toyota Carina E | 1993-1997 | 0.17 | 0.17 | 0.13 | 0.56 | 0.36 |
| Toyota Avensis | 1997-2003 | 0.03 | 0.13 | | 0.37 | 0.46 |
| Volkswagen Passat | 1988-1993 | 0.25 | 0.27 | 0.38 | 0.55 | 0.53 |
| Volkswagen Passat | 1993-1996 | 0.18 | 0.15 | 0.45 | 0.75 | 0.40 |
| Volkswagen Passat | 1996-2000 | 0.04 | 0.12 | 0.00 | 0.48 | 0.43 |

**APPENDIX 2. An Investigation of Historical Improvement in Vehicle Safety Performance by Model Series Using German Crash Data**

# SARAC II

## Quality Criteria for the Safety Assessment of Cars based on Real-World Crashes

| | |
|---|---|
| Working Group: | 3 |
| Sub-Task: | 3.3 |
| Pilot: | HUT |
| NR of Report: | S2-225 |

# An Investigation of Historical Improvement in Vehicle Safety Performance by Model Series Using German Crash Data

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# 1 INTRODUCTION

This report describes analysis undertaken as part of SARAC II sub-task 3.3 aimed at assessing changes in the safety performance of individual vehicle types of the same make and model over a number of model generations. It might be expected that the introduction of a new vehicle model generation would result in an improvement in the safety performance of that vehicle model. That is, a new generation vehicle model would be expected to have better safety performance than the previous generation of the same vehicle model. This study aims to assess this premise by estimating measures of vehicle crashworthiness for a number of vehicle makes and models over time using real world crash data.

# 2 DATA SOURCES

Police reported crash data from Germany for the years 1998 to 2002 was used for this analysis. In Germany, every road accident attended by the police must be reported and is recorded in a database held at the German Federal Statistical Office. All crashes reported to police, including those involving only material damage or slight personal injuries, are included in the database. The sub-set of the data used here is identical to that used in SARAC II sub-tasks 2.1 and 2.2 and a full description of the data set used is available in Newstead et al., 2005 (SR-196). Given the volume of data available it has been possible to examine changes in the safety performance of a range of vehicle makes and models.

## 2.1 Identification of Vehicle Models

The German data used in this analysis did not contain information on the VIN of each crash involved vehicle. Therefore, selection of vehicle models from the crash data for inclusion in the analysis was conducted using the manufacturer name and vehicle model name variables ("mancnam" and "modcnam" respectively) provided in the data. The vehicle model name variable included a numerical indicator of the model generation of the subject vehicle. This numerical indicator was used to distinguish between vehicle models of the same type but of different generations with more recent models having higher generation number.

# 3 METHOD

Estimates of vehicle crashworthiness were calculated using the logistic regression procedure described in detail in Newstead et al., 2005 (SR-196). Estimation of the injury risk component of the crashworthiness rating was conducted using the DETR method using crash data for crashes involving two passenger vehicles only. The severity component of the crashworthiness rating was estimated using the MUARC method and used crash data from both single vehicle and vehicle-to-vehicle crashes. In order to obtain estimates of injury risk and injury severity unbiased by factors other than vehicle make and model a number of factors thought to influence the risk and severity of injury to drivers were included in the logistic regression model. Those factors considered were the same as those used in sub-tasks 2.1 and 2.2 for the German data. Of particular importance was the inclusion of year of crash as an adjustment factor in the logistic regression models. By adjusting for year of crash effects, the resulting estimates of vehicle crashworthiness within a particular model series will be unbiased for general improvements in German road safety over the years of crash data available. **Fehler! Verweisquelle konnte nicht gefunden werden.** details the main effects and interactions that were judged to be significant predictors of injury risk and injury severity through the stepwise logistic modelling approach.

**Table 1. Significant factors in the logistic regression models of injury risk and injury severity derived from German data using the DETR method.**

| Significant Model Factors | All Crash Types (Injury risk) | All Crash Types (Injury Severity) |
|---|---|---|
| Main Effects | driver age (age),<br>driver sex (sex),<br>intersection (int),<br>location of crash (loc)<br>cost of crash (cost)<br>year of crash (year) | driver age (age),<br>driver sex (sex),<br>number of vehicles (nbv),<br>location of crash (loc),<br>cost of crash (cost)<br>year of crash (year) |
| First Order Interactions | sex*age, age*int, age*loc, int*loc, age*cost, sex*cost, int*cost, loc*cost | age*sex, age*nbv, sex*nbv, age*int, sex*int, veh*int, veh*loc, int*loc, age*cost, sex*cost, nbv*cost, int*cost, loc*cost, int*year, loc*year, cost*year |
| Second Order Interactions | int*loc*cost | age*sex*nbv, nbv*int*loc, age*int*cost, nbv*int*cost, nbv*loc*cost, int*loc*cost, int*cost*year |

Models were selected for inclusion in the analysis on the basis of a minimum of 100 crash involved drivers and 20 injured drivers in each vehicle make and model generation. Further, those models included were restricted to those where more than one generation of the vehicle make and model met the above criteria and was thus available in sufficient quantities to allow comparison over time. Table 2 shows that there were 78 vehicles with sufficient real crash data to be included in the analysis including 27 individual vehicle makes and models.

**Table 2. Number of injured and involved drivers of crashed vehicles in the German data from 1998 to 2002.**

| Vehicle Identification Index | Vehicle Make/Model | Involved Drivers | Injured Drivers |
|---|---|---|---|
| A1 | AUDI AG A4-1 | 4217 | 2266 |
| A2 | AUDI AG A4-2 | 315 | 152 |
| B1 | BMW 3er-1 | 102 | 71 |
| B2 | BMW 3er-2 | 4713 | 2715 |
| B3 | BMW 3er-3 | 7416 | 4348 |
| B4 | BMW 3er-4 | 1987 | 1012 |
| C2 | BMW 5er-2 | 402 | 231 |
| C3 | BMW 5er-3 | 3524 | 1773 |
| C4 | BMW 5er-4 | 2239 | 951 |
| D1 | CHRYSLER (USA) Voyager-1 | 110 | 49 |
| D2 | CHRYSLER (USA) Voyager-2 | 297 | 121 |
| E2 | FIAT (I) Punto-2 | 480 | 339 |
| E1 | FIAT (I) Punto | 3175 | 2420 |
| F3 | FORD/EUROPA Escort-3 | 2857 | 1823 |
| F4 | FORD/EUROPA Escort-4 | 8390 | 5172 |
| G1 | FORD/EUROPA Fiesta-1 | 161 | 114 |
| G2 | FORD/EUROPA Fiesta-2 | 1720 | 1232 |
| G3 | FORD/EUROPA Fiesta-3 | 9213 | 6923 |

| | | | |
|---|---|---|---|
| G4 | FORD/EUROPA Fiesta-4 | 3003 | 2069 |
| H2 | FORD/EUROPA Mondeo-2 | 185 | 83 |
| H1 | FORD/EUROPA Mondeo | 3787 | 2042 |
| I1 | FUJI HEAVY (J) Legacy-1 | 211 | 109 |
| I2 | FUJI HEAVY (J) Legacy-2 | 145 | 77 |
| J2 | HONDA MOTOR (J) Accord-2 | 227 | 131 |
| J3 | HONDA MOTOR (J) Accord-3 | 383 | 189 |
| J4 | HONDA MOTOR (J) Accord-4 | 444 | 229 |
| J5 | HONDA MOTOR (J) Accord-5 | 101 | 51 |
| K2 | HONDA MOTOR (J) Civic-2 | 270 | 178 |
| K3 | HONDA MOTOR (J) Civic-3 | 1305 | 864 |
| K4 | HONDA MOTOR (J) Civic-4 | 1544 | 1042 |
| K5 | HONDA MOTOR (J) Civic-5 | 708 | 494 |
| K6 | HONDA MOTOR (J) Civic-6 | 488 | 298 |
| J1 | MERCEDES BENZ AG C-1 | 5024 | 2594 |
| J2 | MERCEDES BENZ AG C-2 | 572 | 270 |
| K3 | MERCEDES BENZ AG E-3-T | 210 | 83 |
| L3 | MERCEDES BENZ AG E-3 | 1035 | 467 |
| K4 | MERCEDES BENZ AG E-4-T | 1310 | 661 |
| L4 | MERCEDES BENZ AG E-4 | 6086 | 3260 |
| K5 | MERCEDES BENZ AG E-5-T | 639 | 255 |
| L5 | MERCEDES BENZ AG E-5 | 3344 | 1648 |
| M3 | MITSUBISHI (J) Colt-3 | 455 | 311 |
| M4 | MITSUBISHI (J) Colt-4 | 916 | 601 |
| M5 | MITSUBISHI (J) Colt-5 | 702 | 470 |
| M6 | MITSUBISHI (J) Colt-6 | 611 | 409 |
| N1 | MITSUBISHI (J) Space Runner-1 | 140 | 83 |
| N2 | MITSUBISHI (J) Space Runner-2 | 303 | 168 |
| O2 | NISSAN (J) Almera-2 | 109 | 66 |
| O1 | NISSAN (J) Almera | 780 | 470 |
| P1 | NISSAN (J) Micra-1 | 1519 | 1170 |
| P2 | NISSAN (J) Micra-2 | 1765 | 1395 |
| Q1 | NISSAN (J) Primera-1 | 1334 | 744 |
| Q2 | NISSAN (J) Primera-2 | 593 | 340 |
| R1 | OPEL Astra-1 | 12835 | 7873 |
| R2 | OPEL Astra-2 | 3192 | 1865 |
| S1 | OPEL Corsa-1 | 4983 | 3805 |
| S2 | OPEL Corsa-2 | 9178 | 6828 |
| S3 | OPEL Corsa-3 | 364 | 248 |
| T1 | OPEL Omega-1 | 2853 | 1543 |
| T2 | OPEL Omega-2 | 2159 | 1053 |
| U1 | OPEL Vectra-1 | 7275 | 4183 |
| U2 | OPEL Vectra-2 | 3538 | 1920 |
| V1 | RENAULT (F) Clio-1 | 3763 | 2661 |
| V2 | RENAULT (F) Clio-2 | 655 | 473 |
| W1 | SEAT (E) Ibiza-1 | 1249 | 832 |
| W2 | SEAT (E) Ibiza-2 | 2082 | 1434 |
| X2 | TOYOTA (J) Corolla-2 | 226 | 150 |
| X3 | TOYOTA (J) Corolla-3 | 1514 | 936 |
| X4 | TOYOTA (J) Corolla-4 | 1375 | 892 |
| X5 | TOYOTA (J) Corolla-5 | 631 | 400 |

| | | | |
|---|---|---|---|
| Y1 | VOLKSWAGEN-VW Golf-1 | 1844 | 1206 |
| Y2 | VOLKSWAGEN-VW Golf-2 | 19624 | 13200 |
| Y3 | VOLKSWAGEN-VW Golf-3 | 20401 | 12514 |
| Y4 | VOLKSWAGEN-VW Golf-4 | 5829 | 3543 |
| Z2 | VOLKSWAGEN-VW Passat-2 | 2203 | 1226 |
| Z3 | VOLKSWAGEN-VW Passat-3 | 9045 | 5115 |
| Z4 | VOLKSWAGEN-VW Passat-4 | 3846 | 1921 |
| AA2 | VOLKSWAGEN-VW Polo-2 | 8882 | 6665 |
| AA3 | VOLKSWAGEN-VW Polo-3 | 5986 | 4289 |

# 4. RESULTS

Injury risk, injury severity and crashworthiness ratings for each of the vehicle models considered are presented in Table 3 below. Upper and lower confidence limits and confidence limit width for each estimated crashworthiness rating are also provided. The coefficient of variation shown is the ratio of the width of the confidence limit to the magnitude of the point estimate and is useful as a scaled measure of rating accuracy.

**Table 3. Vehicle safety ratings estimated from German crash data 1998-2002.**

| | | | | | CWR 95% CL | | | |
|---|---|---|---|---|---|---|---|---|
| **Vehicle Index** | **Vehicle Make/Model** | **CWR** | **Risk** | **Severity** | **Lower** | **Upper** | **95% CL Width** | **CoV** |
| A1 | AUDI AG A4-1 | 7.00% | 53.39% | 13.12% | 6.34% | 7.74% | 1.40% | 0.20 |
| A2 | AUDI AG A4-2 | 4.66% | 46.83% | 9.94% | 2.92% | 7.42% | 4.50% | 0.97 |
| AA2 | VOLKSWAGEN-VW Polo-2 | 19.45% | 78.65% | 24.72% | 18.45% | 20.50% | 2.05% | 0.11 |
| AA3 | VOLKSWAGEN-VW Polo-3 | 9.77% | 67.36% | 14.50% | 9.07% | 10.52% | 1.44% | 0.15 |
| B1 | BMW 3er-1 | 14.25% | 76.60% | 18.60% | 8.99% | 22.59% | 13.60% | 0.95 |
| B2 | BMW 3er-2 | 13.42% | 64.47% | 20.82% | 12.49% | 14.43% | 1.94% | 0.14 |
| B3 | BMW 3er-3 | 7.84% | 57.64% | 13.60% | 7.33% | 8.38% | 1.05% | 0.13 |
| B4 | BMW 3er-4 | 5.05% | 48.21% | 10.46% | 4.33% | 5.88% | 1.56% | 0.31 |
| C2 | BMW 5er-2 | 13.00% | 66.52% | 19.54% | 9.90% | 17.07% | 7.16% | 0.55 |
| C3 | BMW 5er-3 | 7.22% | 53.10% | 13.60% | 6.50% | 8.02% | 1.52% | 0.21 |
| C4 | BMW 5er-4 | 3.98% | 40.70% | 9.77% | 3.38% | 4.68% | 1.29% | 0.33 |
| D1 | CHRYSLER (USA) Voyager-1 | 6.17% | 44.39% | 13.90% | 3.05% | 12.51% | 9.46% | 1.53 |
| D2 | CHRYSLER (USA) Voyager-2 | 4.30% | 36.45% | 11.79% | 2.73% | 6.77% | 4.05% | 0.94 |
| E1 | FIAT (I) Punto | 10.91% | 73.33% | 14.88% | 9.88% | 12.05% | 2.17% | 0.20 |
| E2 | FIAT (I) Punto-2 | 7.60% | 65.84% | 11.55% | 5.78% | 9.99% | 4.21% | 0.55 |
| F3 | FORD/EUROPA Escort-3 | 17.24% | 71.33% | 24.17% | 15.85% | 18.75% | 2.90% | 0.17 |
| F4 | FORD/EUROPA Escort-4 | 12.22% | 64.06% | 19.08% | 11.50% | 12.99% | 1.50% | 0.12 |
| G1 | FORD/EUROPA Fiesta-1 | 20.25% | 76.16% | 26.59% | 14.30% | 28.68% | 14.37% | 0.71 |
| G2 | FORD/EUROPA Fiesta-2 | 21.46% | 77.87% | 27.56% | 19.26% | 23.91% | 4.65% | 0.22 |
| G3 | FORD/EUROPA Fiesta-3 | 15.88% | 75.84% | 20.94% | 15.02% | 16.79% | 1.77% | 0.11 |
| G4 | FORD/EUROPA Fiesta-4 | 10.90% | 65.85% | 16.55% | 9.88% | 12.02% | 2.14% | 0.20 |
| H1 | FORD/EUROPA | 7.75% | 55.11% | 14.07% | 6.98% | 8.61% | 1.63% | 0.21 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mondeo | | | | | | | |
| H2 | FORD/EUROPA Mondeo-2 | 4.36% | 43.42% | 10.04% | 2.50% | 7.60% | 5.10% | 1.17 |
| I1 | FUJI HEAVY (J) Legacy-1 | 11.11% | 54.08% | 20.53% | 7.95% | 15.52% | 7.57% | 0.68 |
| I2 | FUJI HEAVY (J) Legacy-2 | 6.94% | 48.85% | 14.21% | 4.35% | 11.08% | 6.73% | 0.97 |
| J1 | MERCEDES BENZ AG C-1 | 5.42% | 50.58% | 10.72% | 4.91% | 6.00% | 1.09% | 0.20 |
| J2 | HONDA MOTOR (J) Accord-2 | 6.91% | 50.96% | 13.56% | 5.39% | 8.85% | 3.46% | 0.50 |
| J3 | HONDA MOTOR (J) Accord-3 | 8.81% | 54.20% | 16.26% | 6.51% | 11.93% | 5.42% | 0.61 |
| J4 | HONDA MOTOR (J) Accord-4 | 11.15% | 52.93% | 21.06% | 8.75% | 14.20% | 5.45% | 0.49 |
| J5 | HONDA MOTOR (J) Accord-5 | 5.81% | 50.57% | 11.49% | 3.07% | 10.99% | 7.91% | 1.36 |
| K2 | HONDA MOTOR (J) Civic-2 | 15.95% | 72.74% | 21.93% | 11.70% | 21.76% | 10.06% | 0.63 |
| K3 | HONDA MOTOR (J) Civic-3 | 15.92% | 67.61% | 23.54% | 14.24% | 17.79% | 3.54% | 0.22 |
| K4 | HONDA MOTOR (J) Civic-4 | 11.75% | 60.60% | 19.40% | 10.69% | 12.92% | 2.22% | 0.19 |
| K5 | HONDA MOTOR (J) Civic-5 | 8.58% | 53.10% | 16.17% | 7.38% | 9.99% | 2.61% | 0.30 |
| K6 | HONDA MOTOR (J) Civic-6 | 8.84% | 60.14% | 14.69% | 6.91% | 11.30% | 4.38% | 0.50 |
| L3 | MERCEDES BENZ AG E-3 | 10.66% | 55.89% | 19.08% | 8.73% | 13.02% | 4.29% | 0.40 |
| L4 | MERCEDES BENZ AG E-4 | 8.00% | 58.28% | 13.72% | 7.31% | 8.75% | 1.44% | 0.18 |
| L5 | MERCEDES BENZ AG E-5 | 5.09% | 49.86% | 10.20% | 4.46% | 5.81% | 1.35% | 0.27 |
| M3 | MITSUBISHI (J) Colt-3 | 20.03% | 74.62% | 26.85% | 16.47% | 24.37% | 7.90% | 0.39 |
| M4 | MITSUBISHI (J) Colt-4 | 14.53% | 69.47% | 20.91% | 12.45% | 16.95% | 4.50% | 0.31 |
| M5 | MITSUBISHI (J) Colt-5 | 12.82% | 66.25% | 19.35% | 10.74% | 15.30% | 4.56% | 0.36 |
| M6 | MITSUBISHI (J) Colt-6 | 9.95% | 63.25% | 15.73% | 7.99% | 12.38% | 4.40% | 0.44 |
| N1 | MITSUBISHI (J) Space Runner-1 | 4.48% | 65.14% | 6.88% | 1.90% | 10.58% | 8.69% | 1.94 |
| N2 | MITSUBISHI (J) Space Runner-2 | 8.16% | 54.49% | 14.98% | 5.80% | 11.49% | 5.69% | 0.70 |
| O1 | NISSAN (J) Almera | 9.18% | 58.71% | 15.64% | 7.57% | 11.13% | 3.56% | 0.39 |
| O2 | NISSAN (J) Almera-2 | 10.31% | 54.94% | 18.76% | 6.42% | 16.54% | 10.11% | 0.98 |
| P1 | NISSAN (J) Micra-1 | 21.16% | 79.10% | 26.76% | 18.91% | 23.69% | 4.77% | 0.23 |
| P2 | NISSAN (J) Micra-2 | 15.38% | 75.82% | 20.28% | 13.74% | 17.22% | 3.48% | 0.23 |
| Q1 | NISSAN (J) Primera-1 | 10.67% | 58.87% | 18.12% | 9.21% | 12.35% | 3.14% | 0.29 |
| Q2 | NISSAN (J) Primera-2 | 6.78% | 56.62% | 11.98% | 5.30% | 8.68% | 3.37% | 0.50 |
| R1 | OPEL Astra-1 | 10.43% | 62.81% | 16.61% | 9.85% | 11.05% | 1.20% | 0.12 |
| R2 | OPEL Astra-2 | 6.69% | 56.62% | 11.82% | 5.98% | 7.50% | 1.52% | 0.23 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| S1 | OPEL Corsa-1 | 18.62% | 79.62% | 23.39% | 17.42% | 19.90% | 2.48% | 0.13 |
| S2 | OPEL Corsa-2 | 11.62% | 71.21% | 16.32% | 10.95% | 12.34% | 1.40% | 0.12 |
| S3 | OPEL Corsa-3 | 7.73% | 61.89% | 12.49% | 5.78% | 10.35% | 4.57% | 0.59 |
| T1 | OPEL Omega-1 | 10.73% | 59.11% | 18.15% | 9.67% | 11.90% | 2.23% | 0.21 |
| T2 | OPEL Omega-2 | 5.11% | 49.23% | 10.39% | 4.37% | 5.99% | 1.62% | 0.32 |
| U1 | OPEL Vectra-1 | 12.00% | 63.58% | 18.87% | 11.22% | 12.83% | 1.61% | 0.13 |
| U2 | OPEL Vectra-2 | 7.20% | 54.67% | 13.17% | 6.48% | 8.00% | 1.52% | 0.21 |
| V1 | RENAULT (F) Clio-1 | 14.94% | 69.56% | 21.47% | 13.87% | 16.09% | 2.22% | 0.15 |
| V2 | RENAULT (F) Clio-2 | 10.99% | 67.80% | 16.21% | 9.14% | 13.21% | 4.07% | 0.37 |
| W1 | SEAT (E) Ibiza-1 | 15.87% | 70.90% | 22.39% | 13.95% | 18.06% | 4.12% | 0.26 |
| W2 | SEAT (E) Ibiza-2 | 10.69% | 66.11% | 16.18% | 9.57% | 11.94% | 2.37% | 0.22 |
| X2 | TOYOTA (J) Corolla-2 | 19.99% | 73.37% | 27.24% | 15.11% | 26.44% | 11.33% | 0.57 |
| X3 | TOYOTA (J) Corolla-3 | 15.55% | 66.67% | 23.32% | 13.82% | 17.50% | 3.68% | 0.24 |
| X4 | TOYOTA (J) Corolla-4 | 10.63% | 64.75% | 16.42% | 9.27% | 12.19% | 2.92% | 0.27 |
| X5 | TOYOTA (J) Corolla-5 | 8.17% | 61.53% | 13.28% | 6.51% | 10.25% | 3.74% | 0.46 |
| Y1 | VOLKSWAGEN-VW Golf-1 | 16.15% | 71.15% | 22.69% | 14.42% | 18.08% | 3.65% | 0.23 |
| Y2 | VOLKSWAGEN-VW Golf-2 | 16.83% | 72.96% | 23.06% | 16.12% | 17.56% | 1.45% | 0.09 |
| Y3 | VOLKSWAGEN-VW Golf-3 | 9.68% | 61.13% | 15.83% | 9.22% | 10.15% | 0.93% | 0.10 |
| Y4 | VOLKSWAGEN-VW Golf-4 | 6.44% | 59.48% | 10.82% | 5.86% | 7.07% | 1.21% | 0.19 |
| Z2 | VOLKSWAGEN-VW Passat-2 | 14.22% | 66.07% | 21.53% | 12.62% | 16.03% | 3.40% | 0.24 |
| Z3 | VOLKSWAGEN-VW Passat-3 | 9.86% | 58.63% | 16.82% | 9.23% | 10.55% | 1.32% | 0.13 |
| Z4 | VOLKSWAGEN-VW Passat-4 | 5.18% | 51.43% | 10.08% | 4.55% | 5.91% | 1.36% | 0.26 |

Those vehicle models with crashworthiness estimates available for three or more model generations have been selected fromTable 3. Individual charts have been created for these vehicle models that show the estimated crashworthiness and associated confidence limits for each model generation. Overlapping confidence limits between two or more model generations indicates that no statistically significant difference can be detected between the crashworthiness of those model generations. However, where the confidence limits associated with individual crashworthiness estimates do not overlap, as is the case for the majority of the vehicle makes and models, it can be concluded with 95% confidence that the true crashworthiness of the vehicle model differs across the relevant generations.

**Figure 1. Estimated crashworthiness of the BMW 3-series over 4 model generations.**

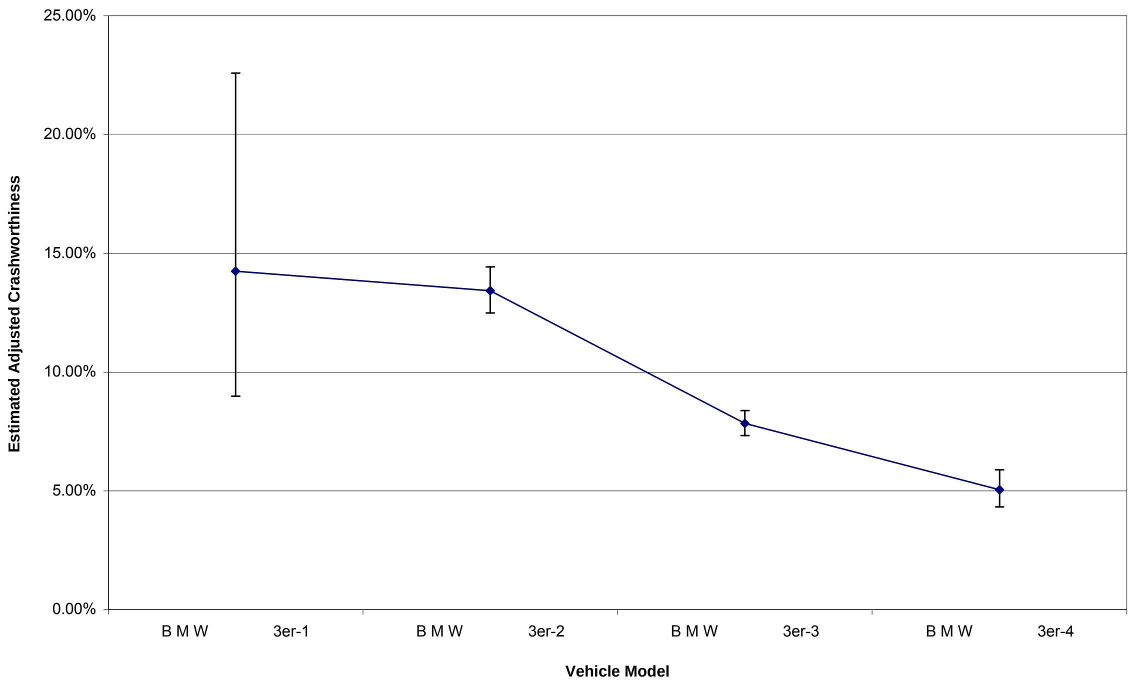

25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Estimated Adjusted Crashworthiness
B M W 3er-1
B M W 3er-2
B M W 3er-3
B M W 3er-4
Vehicle Model

**Figure 2. Estimated crashworthiness of the Ford Fiesta over 4 model generations.**

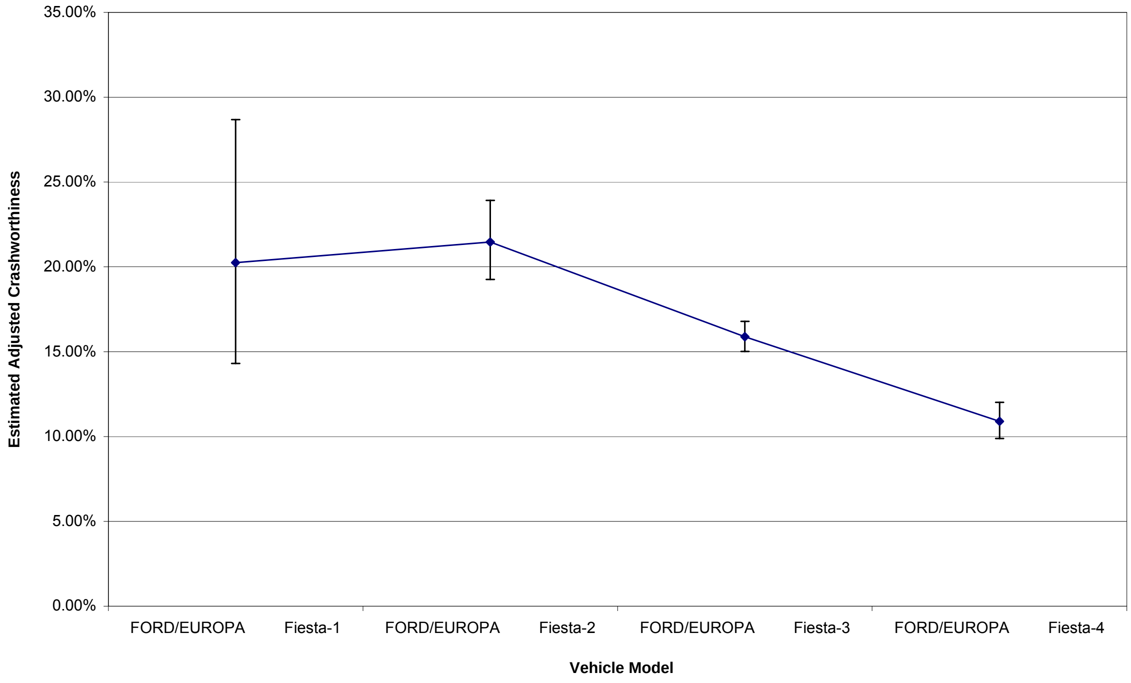



**Figure 3. Estimated crashworthiness of the Honda Accord over 4 model generations.**

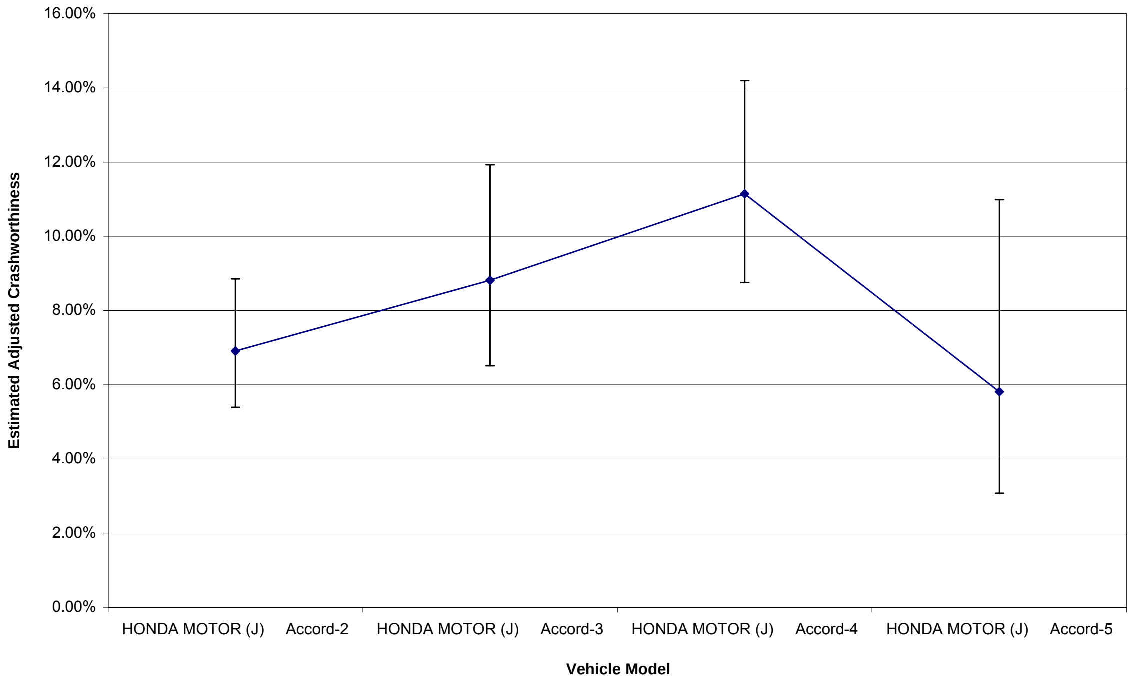


**Figure 4. Estimated crashworthiness of the Honda Civic over 5 model generations.**

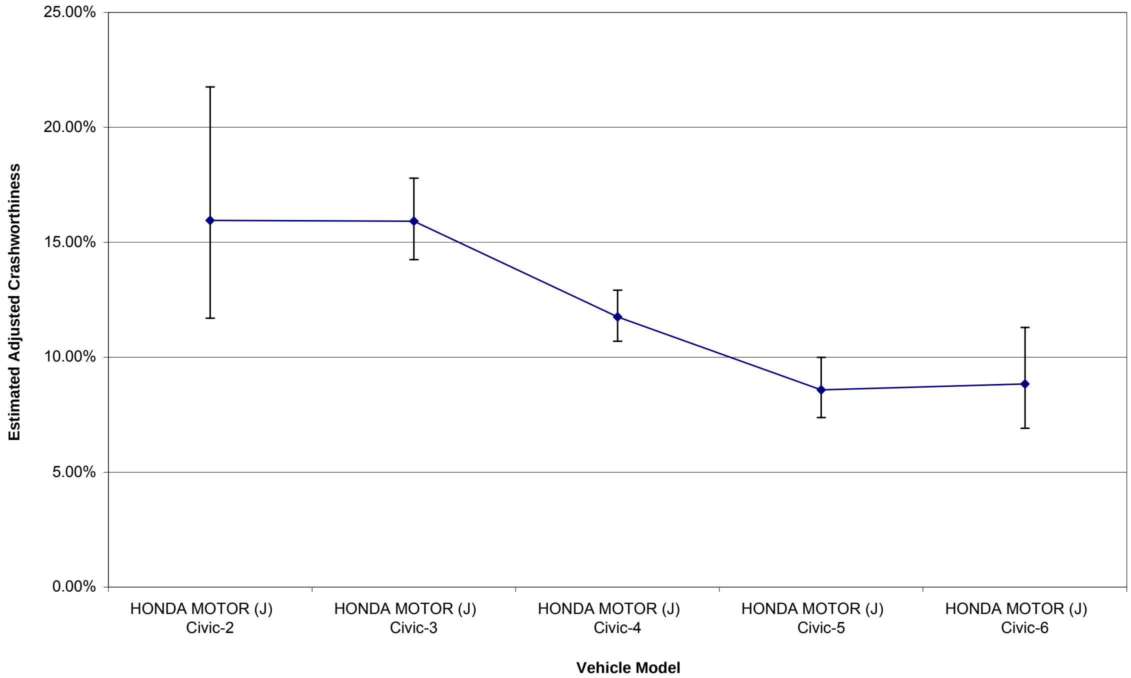



**Figure 5. Estimated crashworthiness of the Mercedes E Class over 3 model generations.**

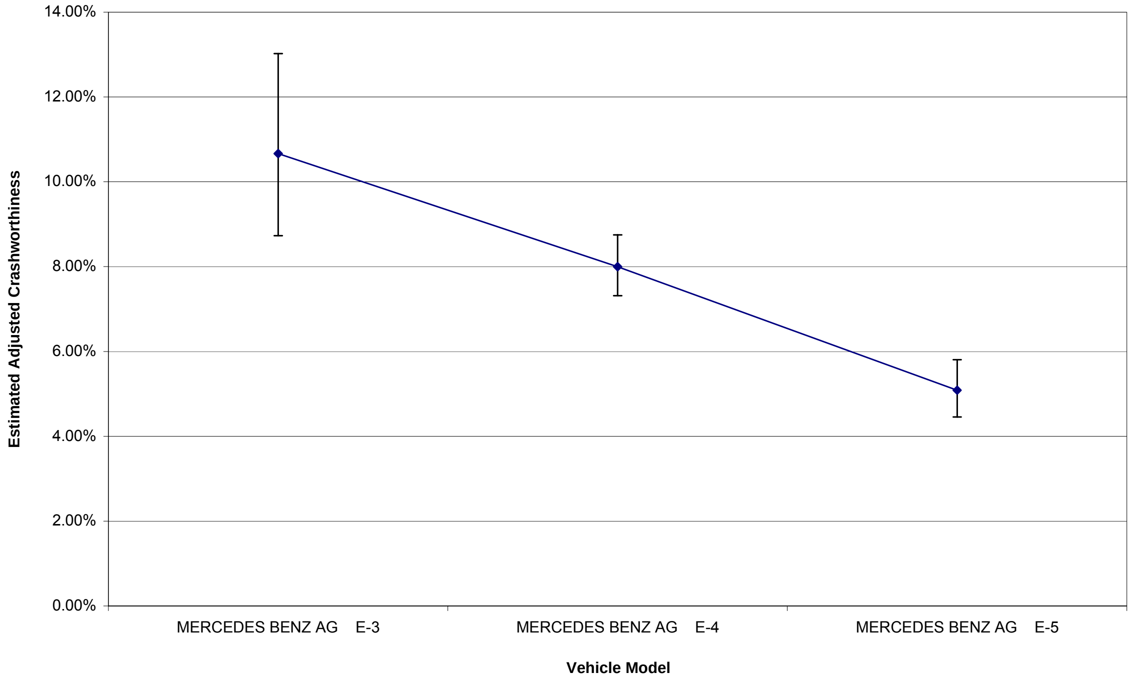


**Figure 6. Estimated crashworthiness of the Mitsubishi Colt over 4 model generations.**

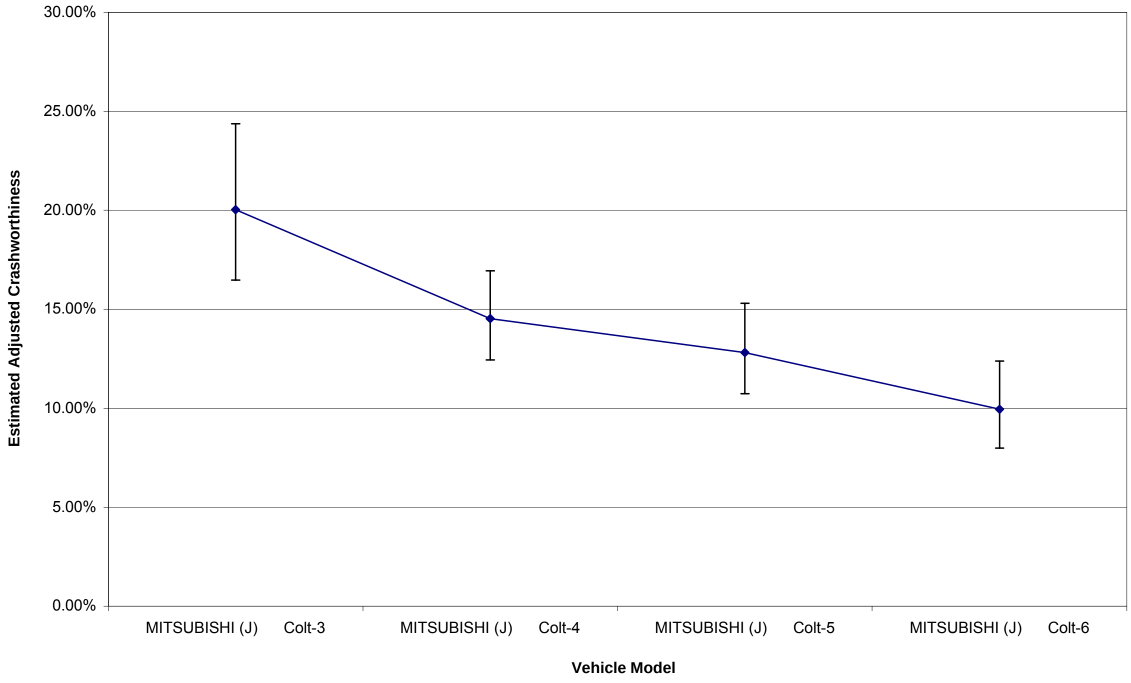



**Figure 7. Estimated crashworthiness of the Opel Corsa over 3 model generations.**

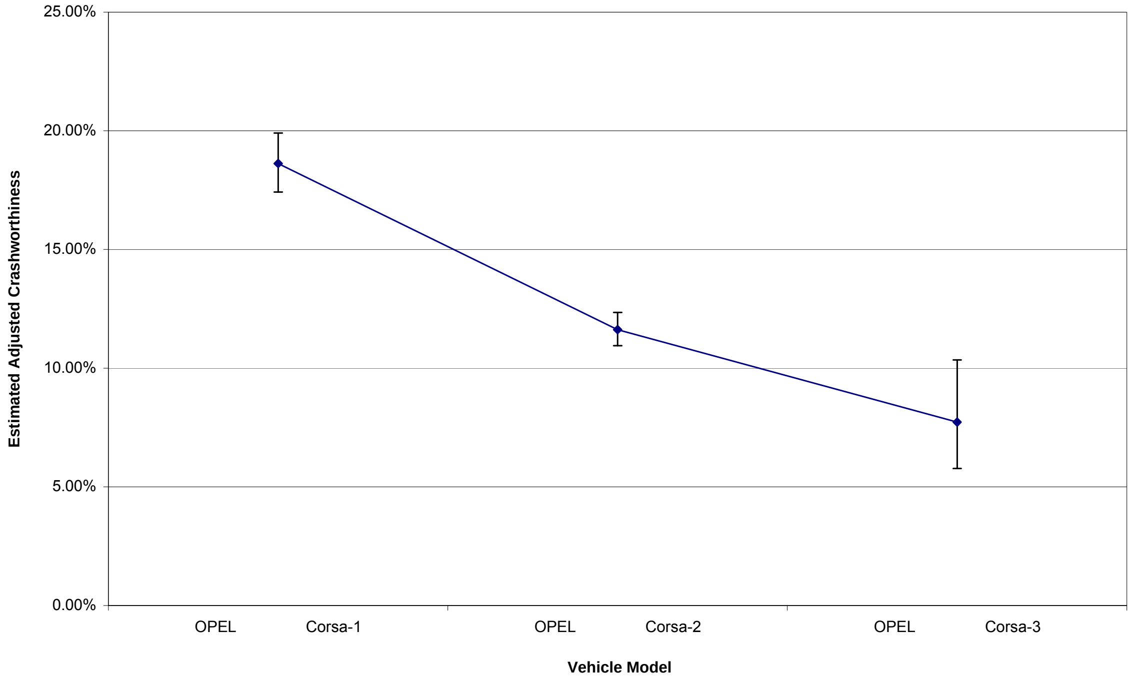


**Figure 8. Estimated crashworthiness of the Toyota Corolla over four model generations.**

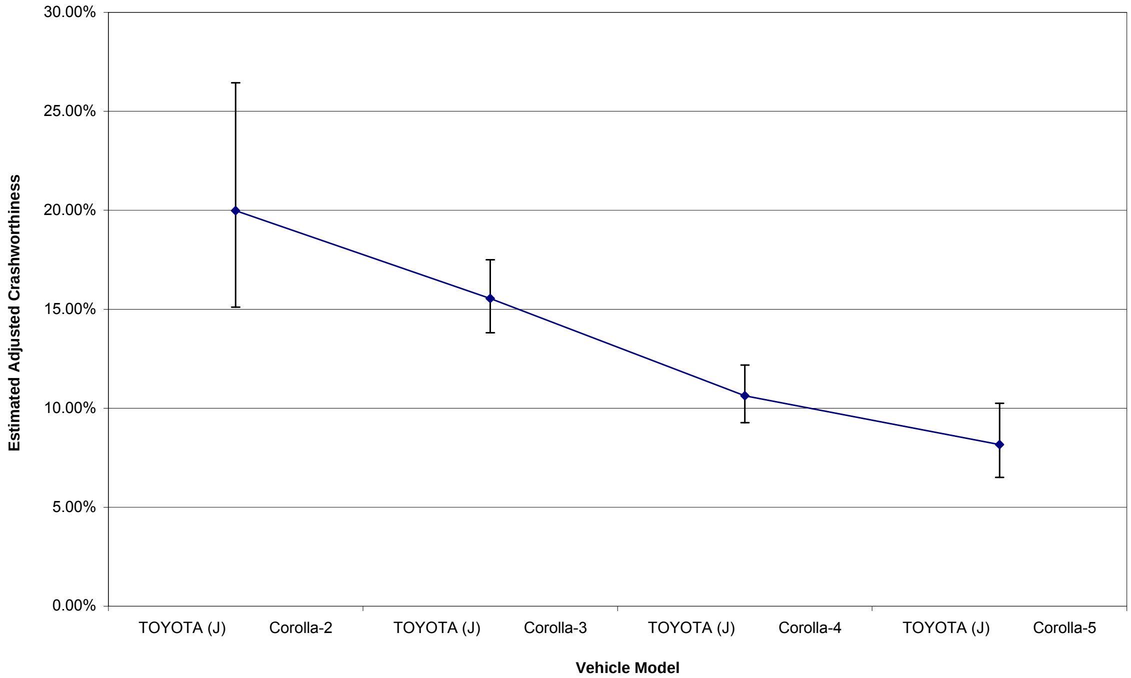



**Figure 9. Estimated crashworthiness of the VW Golf over 4 model generations.**

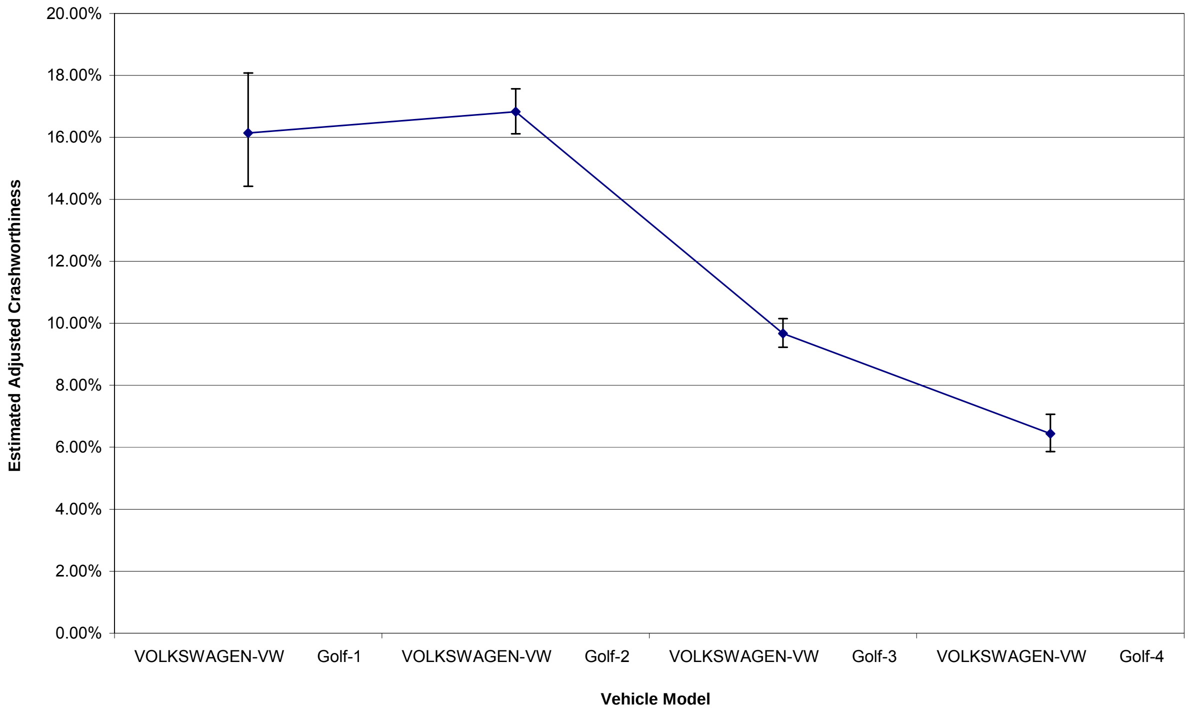
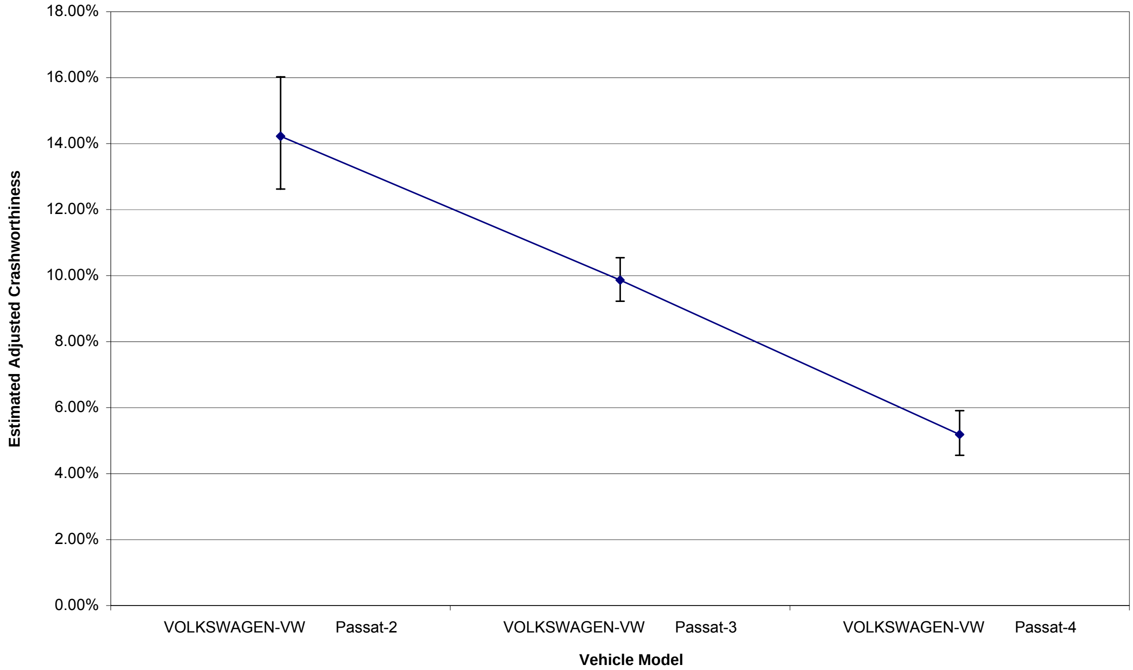


**Figure 10. Estimated crashworthiness of the VW Passat over 3 model generations.**




It is clear that, for the majority of vehicle makes and models considered, there is strong evidence of an improvement in estimated crashworthiness over successive model generations. Further, in a large number of cases these results are statistically significant. These results support the original hypothesis that a new generation vehicle model would have better safety performance than the previous generation of the same vehicle model.