Compatibility of cars in the Netherlands

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Statistical analysis of frontal collisions in the framework of the European research project “Improvement of crash compatibility between cars”, Workpackage 2a

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Contents of the project: Compatibility is defined as the capability of vehicles to protect both their own occupants and occupants of opponent vehicles during crashes. Vehicles are called compatible when they offer equal amounts of protection to both their own occupants and to occupants of crash-opponent vehicles.

This study aimed at detecting vehicle factors that influence occupant and opponent safety, in order to evaluate the amount of compatibility between cars in crashes, especially frontal collisions. This was done by performing statistical analyses of car accidents in The Netherlands, based on data from police registration which were linked to data describing the vehicles involved.

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Summary

Within the scope of the European project ‘Improvement of crash compatibility between cars’, SWOV carried out analyses of car accidents in The Netherlands, based on data from police registration which were linked to data describing the vehicles involved. The purpose of this study was to detect vehicle factors that influence occupant and opponent safety, in order to evaluate the amount of compatibility between cars in crashes, especially frontal collisions.

Compatibility is defined as the capability of vehicles to protect both their own occupants and occupants of opponent vehicles during crashes. Furthermore, compatible vehicles should offer equal amounts of protection to both their own occupants and to occupants of crash-opponent vehicles.

Since theoretically occupant safety is strongly related to vehicle weight (the greater the better), the first part of the study was based on statistical data concerning the Dutch car park and its development over the years with respect to vehicle (kerb)weight. The data shows that the kerb weight of cars has increased considerably over the years and will continue to do so. This increase is caused mainly by the autonomous increase of weight of almost every single car model in the fleet. The average car weight has increased from about 900 kg in the mid 1980s to little less than 1000 kg now.

The scope of the problem of incompatibility between cars is greater than illustrated by numbers of casualties from frontal collisions alone. Since the front end of cars are also involved in various other collisions types (side impacts, rear-end impacts, fixed obstacle impacts), as well as in collisions involving other vehicles and road users, casualties from these other collision types and vehicle categories are also relevant. Therefore, even if the scope of this specific study is limited to frontal collisions in particular, the full scope of the problem of incompatibility should always be monitored, in order to control for negative interactions between these other collisions.

A subset of all available Dutch accident data was selected to analyse effects on injury severity of drivers of cars and vans involved in frontal collisions. This selection narrowed the accident sample to two vehicle collisions only, and to those only involving vehicles with front-end damage. Thus, a total of 5,014 frontal accidents (1992-1997) representing 10,028 vehicles, of which 9% were vans, was studied in more detail.

As criterion to evaluate compatibility capability of individual vehicle types, two indices were developed: OS (Occupant Safety) and AI (Aggressivity Index), in which the number of seriously injured drivers (respectively in the vehicle type studied, and in opponent vehicles) was divided by the total number in the sample of the vehicle type studied.

First, influence of mass and mass ratio on outcome was analysed, using area (either urban or rural) as control variable. Mass ratio was expressed as the quotient of the kerb weight of each vehicle, and the kerb weight of its opponent vehicle. It was found that both in urban and rural areas, mass and especially mass ratio, had a considerable effect on outcome. In both urban

and rural area, the percentage of seriously injured drivers (those killed or admitted to hospitals) increased with more than a factor 5 with increasing mass ratio: driver safety was very low for mass ratios under 0.6 and very high for mass ratios of 1.7 and higher. Area in itself also made a big difference, since the share of seriously injured drivers in rural areas was about three times as high as in urban areas.

Sex appeared to be another factor having considerable influence on outcome of frontal collisions. Female drivers showed a far higher proportion of seriously injured and not-seriously injured, and consequently, a far lower proportion of not-injured than male drivers. This conclusion was reached after controlling for area (representing accident severity), and vehicle mass (kerb weight). This big difference with regard to injury severity (injury susceptibility) between male and female drivers justifies further, more in-depth research.

The results of the ranking of individual vehicle models, using OS and AI scores as mentioned, proved also to be in line with the theory that smaller and lighter cars offer less protection to their occupants than bigger and heavier cars; while at the same time these smaller and lighter cars are far less aggressive to other vehicles than bigger and heavier cars.

With these results we come to the very essence of (in)compatibility: in practice the vehicle models studied appear all but compatible, regarding the big range of OS and AI scores. If cars (and vans) were to be really compatible, these scores should be both far more equal, and preferably also far lower than they are now. It is reasoned that to reach that goal, the current legislation, especially the current EU-Directive concerning frontal collisions, is not appropriate since the barrier test used does not reflect relevant properties of opponent vehicles, and is therefore not able to yield results concerning aggressiveness of the tested car.

It is recommended to develop an additional crash test, that will measure aggressiveness of the tested car. It is also recommended to apply such a test within the scope of the current successful Euro NCAP programme, before it becomes part of the Directive.

Another recommendation is to study in more detail the developments of the car market in Europe, as far as they relate to changes of models and to changes (increase) of mass.

Further analyses based on bigger databases (more years, larger selections of cases per year) are recommended for a more controlled analysis.

For the further study of other relevant vehicle factors such as geometrical and structural (stiffness) aspects, and more detail about damage and injury, the use of data from in-depth accident studies is recommended.

Contents

1. Introduction

The accident analysis presented in this report is part of an extensive international project commissioned by the EU: ‘Improvement of crash compatibility between cars’. ‘Accident analysis’ is the second workpackage of this project, in which INRETS (workpackage leader), INSIA, and BASt carry out separate accident analyses both with respect to in-depth data and statistical data, while SWOV reports on statistical data only.

This SWOV project is concerned with data based on national (police registration based) accident data, linked to vehicle data. The advantage of statistical data is that the study object (incompatibility between cars) can be placed in perspective with respect to other road safety problems and that sufficient numbers of cases are available to study the problem.

This perspective and the scope of the problem will be presented in Chapter 3, after an introduction of the data sources in Chapter 2. Chapter 4 discusses the method of ranking (rating) car safety, and Chapter 5 gives a detailed analysis of frontal collisions. In Chapter 6, a brief summary of a separate study concerning other collision types is given, after which follows Chapter 7 with a discussion of the results of the study. Conclusions and recommendations are given in Chapter 8.

2. The data used

The official real number of annual traffic accident casualties in the Netherlands is about 250,000. Of these, about 1,100 are fatalities, about 19,000 people are hospitalised, some 100,000 visit an A&E Department of a Dutch hospital, and all other casualties are less severely injured. These ‘real’ numbers of casualties are known since data from different sources (police based registration; hospital data; A&E data) have been combined and analysed to calculate the numbers for the different severity groups. The real numbers, especially with respect to low severity accidents, are far greater than the official numbers used until 1997, which were based on police registration only. However, this police registration based accident data is still a major source for the study of traffic accidents in The Netherlands. They contain sufficient and reliable data on major aspects of the accidents. Especially for serious accidents (resulting in fatalities and hospitalisation), they are considered (almost) complete and representative, as far as accidents involving motor vehicles are concerned.

Therefore, in this report, police registration based data from the Dutch Accident Registration System from the Ministry of Transport (the data are called VOR for short) are used to study compatibility aspects with respect to car (to car) collisions and with emphasis on a severe accident outcome.

With regard to vehicle information, VOR-data is limited to type of vehicle only. However, since the original police data yield also information about the licence number of the car, it is possible to link VOR-accident data to the individual vehicle data as available from the National Vehicle Registration System of RDW Vehicle Technology and Information Centre. Vehicle data from this source include make, type, kerb weight and year of registration. They had been linked originally to the accident data for the years 1992-1996 in order to study frontal and side collisions involving cars in more detail. Since the time frame of the study period was somewhat extended, data from 1997 became available and were added tot the study sample as used in Chapters 5 to 7.

3. The scope of the problem of incompatibility

3.1. What is compatibility?

In general terms, compatibility may be described as the capability of vehicles to protect occupants in case of collisions, and at the same time offer as little aggressiveness as possible to crash-opponent vehicles. This general definition may be further specified in terms of injury outcome, stating that regardless of accident circumstances, both parties involved should have more or less the same *low* probability of injury.

Apart from the fact that important external influences exist (such as speed, and collision type), mass or mass difference has already been identified as an important (though almost unchangeable) vehicle factor. Since incompatibility also exists between vehicles of the same mass category, even between vehicles of the same make and type, it is clear that mass or mass difference is not the only mechanism to be studied. It is not even clear that mass difference is the actual working mechanism, since the relation between mass and size of vehicles is very strong in most respects. Therefore, both mass and size will be considered as part of the same mechanism regarding incompatibility.

Throughout the scientific world (even within the group of researchers working on the current EU compatibility project), compatibility and incompatibility are still not well defined. The problem is both fundamental and practical, and little specific knowledge is already available. This is a fact which is also mentioned in the literature review (final product of workpackage 1) of the current project (Van der Sluis, 2000).
The three main aspects of the problem of incompatibility however are established, and are as follows:

- mass incompatibility
- stiffness incompatibility
- geometrical incompatibility.

With respect to stiffness, both overall stiffness (normally related to mass and size of the vehicle) and local stiffness are relevant. Local stiffness, especially local stiffness differences, may in fact be the most important cause for incompatibility during impact. Local stiffness (differences) are related to the construction and orientation (differences) of such important vehicle parts as engine, suspension, longitudinal, cross member, door sill, bumper etcetera.

There is also a direct link to geometrical incompatibility if constructions designed to be active in collisions do not engage (fork effect or mismatch) or do not function as designed (bending instead of crumpling).

Therefore, the vehicle properties to be influenced (changed) are, apart from mass or mass difference, stiffness (both overall and local) and geometry, especially concerning important structures as mentioned above. All of these properties together should prevent intrusion and limit deceleration of the passenger compartment of either vehicle, which compartment itself should be built as strong as possible. Of course, crash safety devices, such as seat belts and airbags, will still have to be further improved and tuned in order to keep in line with changes of the car structures, even more so if intrusion is successfully prevented at the cost of a stiffer compartment structure, yielding higher compartment deceleration.

The existing balance between occupant safety and opponent safety (aggressiveness) is at stake. If only occupant safety was concerned, improvement of occupant safety might lead to stiffer (frontal) structures of vehicles, also dependent on the speed range to be covered. Increasing vehicle mass would also be a safety improvement. On the other hand, if only opponent safety was aimed at, cars would definitely be less stiff, less heavy, and less aggressive with respect to geometrical positions of specific structures.

In the broad sense of the meaning of incompatibility, almost all accidents are relevant, even if seen only from the viewpoint of car occupant safety. On the one hand we have accidents involving cars and opponents of lesser mass and size than cars (such as pedestrians, cyclists, mopeds, and motorcyclists), for most of whom the car tends to be an aggressive opponent. As a study object, these types of accidents are dealt with in other (European) projects, among others concerning the improvement of the construction of the front end of the car with respect to pedestrians and cyclists.

On the other hand we have accidents involving cars and opponents of higher mass and size than cars (heavy trucks etc.) in which these are the aggressors. These types of accidents are also dealt with elsewhere in European projects, with emphasis on improvement of underrun-protection. Thirdly, we have collisions of cars against obstacles, usually a serious type of accident, to be compared with collisions against heavy goods vehicles. As part of normal procedures in designing cars for structural safety, fixed obstacles are still very much part of the test programme, even if the collision test of a car against a concrete barrier is no longer the standard for frontal collisions.

Lastly, we have the accidents in which we are now primarily interested because of the specific study object: cars against cars. Both scientific, public, and commercial interest in this subject are increasing rapidly. Traditionally, car safety was mainly a matter of improving occupant safety, while the new dimension, sometimes called aggressiveness, is very much concerned with opponent safety. Compatibility, therefore, is concerned with both: occupant safety and aggressiveness (or opponent safety) at the same time.

As has been stated, in all of these accident types, one or more aspects of incompatibility are apparent and it should be noted that in many cases, changes of structure, stiffness or geometry (aimed at in all of the separate projects) may influence each other. Therefore it is necessary that separate results from the different studies mentioned, are compared and carefully weighed in order to prevent negative overall effects.

Compatibility between the most vulnerable (for instance cyclists) and the least vulnerable (for instance truck drivers) is not feasible in terms of vehicle construction alone. The mass difference is far too big. Other measures, such as influencing driving speed, infrastructural design, or ultimately, the complete separation of traffic, would be necessary. In view of the opinion described above, the link with these other subjects should be guarded however, especially if structural alterations are considered.

3.2. Focus on incompatibility between cars

Even restricting the problem of incompatibility to collisions between cars only, imposes hardship, in view of the mass range to be considered (see also section 3.5.), the different car types, geometrical dimensions and stiffness, the speed range and last but not least the different collision types. Another example of interaction between structures to be guarded, is apparent for rear-end accidents: if front-end design would generally lead to stiffer structures (as might well be the case for a majority of vehicles), this would cause more damage and probably more injury in the opponent cars that are struck from behind. As a consequence, rear ends of cars would have to be made stiffer as well.

Emphasis in this European compatibility study is on frontal and side collisions, for good reasons with respect to the numbers of serious casualties. In that case some interactions should be monitored. Changes to the frontal construction of the cars with respect to frontal collisions should be weighed against its effect on the sides of cars. This means in practice that the recently introduced EU-Directives with respect to the testing of the front and the side should be somehow linked. Apart from the reason given above (viz. that changes to the front in frontal collisions influence the outcome of side collisions as well), the second reason to link the two subjects is that in both collision types a considerable amount of casualties occur.

3.3. Compatibility concept

The best (theoretical) concept of compatibility is to make proper use of structures of both parties involved as long as there is room for collapse (energy dissipation) and stop intrusion when this limit is reached by a very strong ‘bulkhead’ (Steyer, Delhommeau & Delannoy, 1998; Zobel, 1998). Since ‘by nature’ structures of smaller (lighter) vehicles are less stiff than those of greater (heavier) vehicles, thereby causing only the weaker of the two constructions to collapse, this theoretical concept asks for new types of structural design to equalise (at least for part of the given space for collapse) the levels of stiffness or force during impact. It appears easier to increase force levels in the smaller types of vehicles than to decrease force levels in the greater cars, since such change may decrease the level of occupant protection in those heavier cars. Other possible improvements such as a more homogeneous front end to spread the load may be more beneficiary to other opponents, but are still only theoretical concepts.
It has been discussed that increasing the stiffness of (smaller) cars may decrease the level of occupant safety since the average deceleration of the car (compartment) might increase. If so, this disadvantage has to be taken care of by alternative means, especially by further improvement of the seat belt and airbag systems.

3.4. Accidents and casualties

The question is: how many of the annually 40,000 injury accidents, as registered by the Dutch police, are relevant to the problem of incompatibility?

	1992	1993	1994	1995	1996	Total
All injury accidents in The Netherlands (N)	41,051	40,218	41,765	42,641	41,041	206,716
Injury accidents involving at least one M1 or N1 vehicle (N)	25,590	25,289	25,888	26,418	25,233	128,418
M1 or N1 vehicles involved in all injury accidents (N)	43,935	44,837	46,407	47,387	45,556	228,122
Casualties in M1 or N1 vehicles (N)	19,741	20,913	21,664	22,478	21,660	106,456
Severity distribution of casualties in M1 or N1 vehicles (%)						
Fatal	3.4	3.1	3.1	3.1	2.9	
Hospitalised	24.2	23.8	22.9	22.8	24.1	
A&E	39.9	37.6	36.7	34.4	33.9	
Other	32.5	35.5	37.3	39.7	39.1	
Total	100	100	100	100	100	

Table 1. *Numbers of injury accidents, vehicles and casualties in The Netherlands 1992-1996.*

In the accident analysis for this report, we will use data of the years 1992-1996 (the year 1997 will be added in a later chapter).

As *Table 1* shows, the annual number of 41,000 accidents has been fairly stable throughout these five years in The Netherlands. About 25,000 are accidents involving at least one M1 or N1 vehicle (M1 means passenger cars and N1 means vans, both having a maximum weight of less than 3500 kg). An annual total of more than 45,000 M1 or N1 vehicles (the share of N1 vehicles being somewhat less than 10%) is involved in these accidents, though not all of those vehicles have been damaged: a small percentage is registered only because of their relevancy to the occurrence of the accident. Annually, more than 20,000 casualties occur in these M1 or N1 vehicles, of whom 65% are drivers.

As far as injury severity of these casualties is concerned, about 3% are fatalities, almost 25% is hospitalised, a third have been treated at A&E Departments, and the others have been less severely injured.

The numbers of casualties in M1 or N1 vehicles represent about half of all traffic casualties in The Netherlands. We therefore look at more specific accident data, specifying the vehicle parts that are damaged.

3.5. **Accident types**

Table 2 shows the number of M1 and N1 vehicles that are damaged in injury accidents, distributed over the areas of the car that are damaged.

Damaged area	1992	1993	1994	1995	1996
Centre front	16,434	16,814	17,660	17,843	16,962
Centre side	8,221	8,210	8,746	8,976	8,781
Corner front/side	10,214	10,006	9,813	9,530	9,003
Corner rear/side	2,208	2,170	2,048	2,094	1,866
Front+rear	1,540	1,887	2,087	2,110	2,108
Centre rear	3,095	3,417	3,971	4,291	4,321
Other parts	2,223	2,333	2,082	2,543	2,515
Total	43,935	44,837	46,407	47,387	45,556

Table 2. *Numbers of M1 or N1 vehicles involved in injury accidents according to the damaged area of the vehicles, 1992-1996.*

In the first 5 categories of *Table 2*, the front or the side of the vehicle is involved. With respect to damage at corners of the vehicle, most of these vehicles have been involved in side collisions, probably in most cases as bullet vehicle, but some as target vehicle. The actual collision type may only be specified in more detail if the number of accidents is restricted to those involving two cars only (see further). *Table 2* shows further a vast increase in the number of vehicles having either rear-end damage or front+rear damage, indicating that the number of rear-end collisions is rapidly increasing over the years. This is a considerable problem in The Netherlands, mainly due to the increasing amount of traffic, and it might be expected to be a problem in the rest of Europe too.

As we are primarily interested in vehicles having frontal or side damage resulting from frontal or side collisions, the fifth category (front+rear-end damage) may be considered not relevant. This is shown nevertheless, to indicate the relevance of what was written earlier about the interaction of possible front end changes with respect to the effect on rear-end collisions. Also, the data shown include collisions with other types of vehicles as well as collisions between cars only. In order to specify collision type and damaged area for each of the parties involved, it is necessary to restrict the data sample to collisions involving two parties only, thereby deleting accidents involving more then two parties (such as multiple collisions). Parties may be both road user categories and fixed obstacles. Doing this for the total amount of 41,041 accidents (the 1996 number), we are left with 31,041 accidents involving two parties only.

The distribution of the parties (A and B) involved is shown in *Table 3*.

Party A	Party B					
	Car/Van	Fixed obstacle	HGV/Bus	Two-wheeler	Other	Total
Car/Van	6,209	2,573	474	7,294	2,078	18,628
HGV/Bus	334	56	38	368	136	968
Two-wheeler	16,133	930	299	2,900	1,103	11,365
Other	102	21	10	192	115	440
Total	12,814	3,580	821	10,754	3,432	31,041

Table 3. *Combinations of parties in injury accidents involving only two parties, 1996*.

Although cars are involved in a majority of all two-party accidents (either as party A or as party B), *Table 3* shows that car to car collisions represent 20% of these accidents. The total number of casualties in these 31,041 accidents is 39,808, of whom more than 25% are seriously injured (937 fatalities and 9,431 hospitalised).

In order to properly specify the collision types of cars involved in car-to-car collisions, we have to further restrict the sample with respect to damaged area:

- As far as frontal damage is concerned, all frontal areas are considered (including corners).
- As far as side collisions are concerned, only damage to the centre side area of the target vehicle is considered (excluding corners).
- As far as rear-end damage is concerned, only the centre rear area is considered (excluding corners).

In *Table 4*, the numbers of the remaining accidents (and vehicles) are shown. The selection is made purely to be able to study different collision types separately. The numbers do strongly under-represent the total scope of the problem as presented in previous tables.

Collision type	1992	1993	1994	1995	1996	Total
Frontal-frontal	819	882	901	872	831	4,305
Side-frontal					1,850	1,850
Rear-frontal					2,015	2,015
Fixed obstacle (frontal)					2,006	2,006
Total	819	882	901	872	6,702	10,176

Table 4. *Numbers of selected injury accidents involving cars and vans only, according to collision type, 1992-1996.*

The number of cars in the selected accidents shown in *Table 4*, are twice the number of accidents, apart from the last collision type (fixed obstacle). This means that in frontal collisions we count 8,610 cars (1992-1996), in side collisions we count 3,700 cars (of which 1,850 have side damage and the others frontal damage), in rear-end collisions we count 4,030 cars (of which 2,015 have rear-end damage and the others frontal damage), and we also count 2,006 cars with frontal damage from collisions with obstacles.

The total number of cars with frontal damage in this sample therefore is 10,176.

On an annual base (1996) we count 7,533 cars with frontal damage, against 1,850 cars with damage to the sides (centre), and 2,015 to the rear (centre). This shows that the front of cars is more important (in terms of damage frequency) than sides or rear, even though in case of rear-end collisions, the injury effect might be considered minor for occupants in cars having frontal damage.

With respect to injury severity, *Table 5* shows the severity distribution of the accidents (determined by the severity of the most severely injured person in an accident) according to collision type.

Collision type	Accident severity			
	Fatal (%)	Hospital (%)	Other (%)	Total (%)
Frontal-frontal	3.7	30.8	65.5	100
Side-frontal	1.8	24.8	73.5	100
Rear-frontal	0.4	11.4	88.3	100
Fixed obstacle (frontal)	6.7	35.4	57.8	100

Table 5. *Severity distribution of selected accidents involving cars and vans only, according to collision type, 1992-1996.*

(Frontal) collisions against obstacles are by far the most severe accidents (42% are serious), followed by front-to-front collisions (35% are serious). Side collisions produce 27% serious outcome, while rear-end accidents are the least serious of all types, producing 15% serious outcome.

3.6. The Dutch car fleet and its (kerb weight) development

As in most other European countries, new cars in the Netherlands tend to have a higher kerb weight than older ones of the same type. The reason is a mix of different mechanisms, such as safety regulations asking for more structural safety than before; consumer demands for more comfort and space; and a tendency towards higher performance (more engine power, engine size). Despite the increasing use of lightweight materials for the design of new cars, the net result of all these mechanisms is a weight (and size) increase of individual types.

Even the apparent increase of new car models at the lower size categories is not reflected in a decrease of the average kerb weight of all cars in the Dutch car fleet, probably because at the same time other new models at the upper end of the mass range appear on the market, such as big luxury cars, sports utility vehicles, and space cars; the latter type becoming popular in almost any size category as well. The net effect of all these developments is a steady increase of kerb weight over the years.

As far as the Dutch car fleet is concerned, this development can be shown quite clearly, using the available data from the Dutch Central Bureau of Statistics.

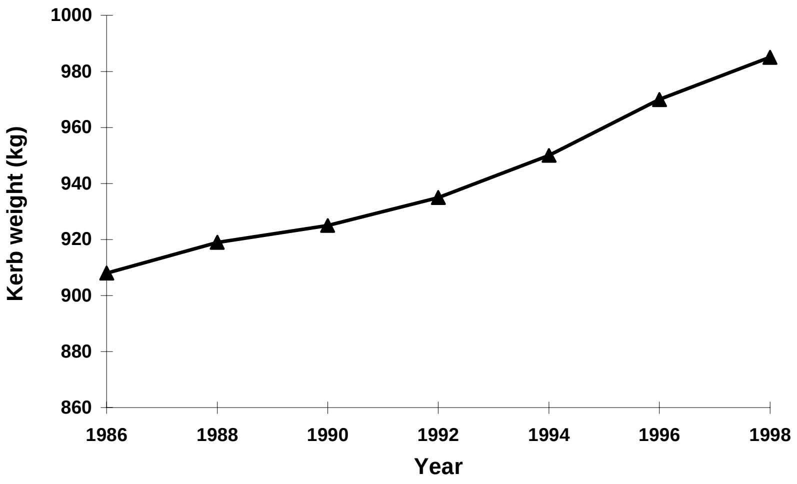

Figure 1. *Development of the average kerb weight of passenger cars in The Netherlands, 1986-1998.*

In *Figure 1*, the overall increase of kerb weight is illustrated quite clearly. Regardless of the fact that a number of new small cars have been introduced over the last ten years or so, the overall average kerb weight is nearing the 1000 kg limit, and will pass this within a short time, probably before 2000.

In the *Figure 2*, where also the years of the road admittance of cars are shown, we can see that indeed modern cars are far more heavy (and big) than older ones. The data are derived from accident data (not from car fleet data), since only accident data contain information about year of road admittance of individual cars.

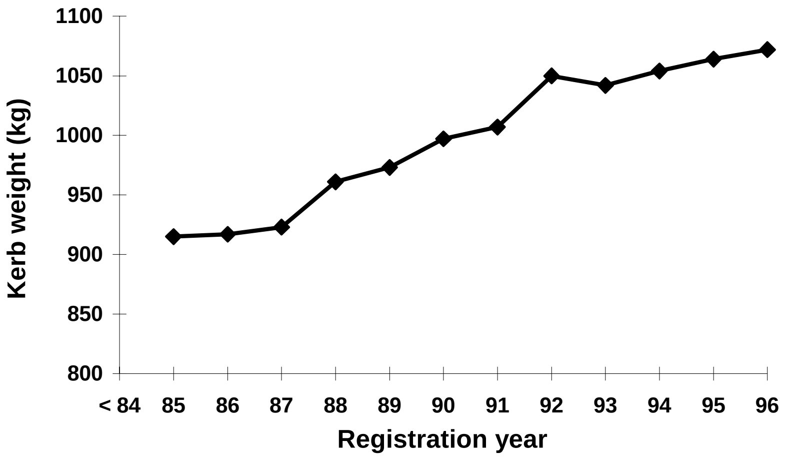

Figure 2. *Development of average kerb weight of passenger cars according to year of registration, frontal collisions 1992-1996.*

Figure 2 shows that cars from more recent years (involved in frontal collisions during the years 1992-1996) have an average kerb weight of over 1,050 kg. The increase started after the mid 1980s, before which time the average kerb weight remained fairly stable at around 900 kg.

Not only do individual car types show an increase in size and weight, there is another fairly strong development of car types that until now did not exist at all. We are confronted by a change from the normal size 2, 3, 4 or 5-door cars to the ‘family oriented’ space car, currently available in almost all car size categories. Though they appear more or less comparable in properties to normal sized cars, they might well represent a new field of investigation regarding the problem of incompatibility. Another change (and challenge) is the increasing number of sport utility vehicles (SUV) and light trucks and vans (LTV), but contrary to the enormously spectacular development in the USA and Canada, their overall proportion is still well under 10% of the current total car fleet in The Netherlands.

3.7. Limits of accident statistics

Whatever the problem caused by these recent changes in the Dutch (and European) car fleet, accident statistics will not reflect this type of change, since the shares of these newer car types are still very small and prevent statistical analysis.

Practically, the result of kerb weight developments mentioned is not only the increase of the average, but also the increase in mass range. It is to be expected that the lower and upper boundaries of car mass (and size) will become further separated than before. It is therefore to be expected that cars involved in collisions may encounter both heavier and lighter crash opponent cars than before.

Other known limitations of accident statistics that are police based, are the absence of certain useful data: collision speed, detailed damage measurements and injury details. Instead, some surrogates have to be used such as *area* (urban/rural) and *road speed limit*, both to find some measure of accident severity. An indication of the damaged area has to be used to reconstruct collision type, and maximum severity categories (fatal, hospitalised, A&E, and other) have to be used to indicate injury severity.

3.8. Summary of the scope of the problem

In The Netherlands, there are each year some 41,000 registered road accidents resulting in injury. The real number is much higher (up to 250,000) since especially accidents resulting in minor injury and accidents not involving motor vehicles are under reported. With respect to those 41,000 accidents, a total of 45,000 cars or vans is involved somehow. In these vehicles, each year some 22,000 casualties occur, 27% of whom are seriously injured. About half of these of these vehicles have frontal damage, either from frontal collisions or from other types of collisions, regardless of collision partner.

These numbers of accidents and casualties as summarised above are to be seen as the full scope of the problem of incompatibility of cars and vans, even though the current study on compatibility of cars is restricted to specific collision types (i.e. frontal and side, between cars/vans only).

Compatibility should be considered to be a wide range subject, not limited to any particular vehicle type or collision type. Only for practical reasons, we limit the scope of our efforts to incompatibility problems between cars, and narrow this subject down to only frontal and side collisions. But we risk (possibly negative) interactions of car structure changes in case of collisions with other vehicle types or in other not-considered collision types within the field of car collisions.

Even if we consider the limited scope and try to solve the problem, we have to deal with interactions at least with regard to the front of cars in frontal collisions as opposed to side collisions. It is advisable, therefore, to monitor these changes and to monitor accident data and test results in that respect, as well as the developments already mentioned with respect to car type and kerb weight. Changes that have possibly negative effects with respect to other collision types and other road users are not imaginary, since the current (in itself proper) design of relatively light, new cars is basically to become more stiff at the front to cope with opponents of a higher mass category.

The scope of the problem of incompatibility, is far greater than indicated by the study sample selected to analyse both accident and vehicle data in the next chapters. The selected numbers of accidents and vehicles show that the front of vehicles is far more frequently involved in collisions than the sides (and the rear), despite the fact that cars are not as frequently involved in frontal collisions as they are in side collisions. The main reason is that in all side collisions between cars (as well as in all rear-end collisions) the front of a bullet car is involved in all cases. This also illustrates the fact that any structural change to the front will have both effect on frontal as well as on side collisions (as well as on rear-end collisions and obstacle collisions).

3.9. Summary with regard to the definition

To summarise the observations in this chapter with respect to the definition of compatibility and incompatibility, we can now state that incompatibility is caused by differences of: mass, (local) stiffness and geometry.

Compatible cars should offer equal amounts of occupant safety and external safety.
Since these properties are more or less inversely proportional to each other and related to vehicle size and mass, compatibility may always be a compromise of these two important properties.

Compatible cars should also offer a minimum of injuries and injury severity to occupants and other road users.
In this respect optimisation of structures and compartment safety devices (seat belt, airbag etc.) are both necessary.

We should also develop instruments to measure (in)compatibility of individual car models. With respect to the data used in this study, we will develop one for occupant safety and another one for external safety (aggressivity). These instruments are described in Chapter 4.

4. Criteria for ranking or rating

In order to be able to weigh the outcome of accidents, especially to do so for different individual car types or for cars from different size or weight categories, a criterion has to be available.

Already, a variety of rating systems of passive safety of cars exist, such as the Folksam data based system in Sweden, the IIHS-system in the USA, and the system of the Monash University in Australia. However, although all of these systems are based on real world accident data, they are primarily consumer-oriented and already too sophisticated for the purpose of scientific research as specified in this report. Another rating system, based on crash test data and used in the well-known Euro NCAP programme, is not suited for our purpose since it only rates cars according to occupant safety, however useful this programme is for the further development of passive car safety.

Therefore, since an appropriate system was already developed in the USA for NHTSA, we will use that same system (Gabler & Hollowell, 1998), as indeed agreed upon within the working group on accident analysis (workpackage 2) of the current EU-project.

The US-system uses the available information on accident outcome (that is the number of casualties specified according to severity) as numerator, and either the number of cars in the car fleet, or the number of cars involved in the selected accidents as denominator.

In the current study we have chosen for the following two criteria:

1. Occupant safety (OS)
Occupant safety is defined as: the number of seriously injured car drivers in the vehicle type(s) concerned, divided by the number of cars of the vehicle type(s) concerned, both numbers derived from the same accident sample.

2. Aggressivity index (AI)
Aggressivity index is defined as: the number of seriously injured car drivers in opponent vehicles, divided by the number of cars of the vehicle type(s) concerned, both numbers derived from the same accident sample.

It should be noted that in both indexes, the same denominator is used.

Contrary to expectation, a high value of OS (representing a high share of seriously injured drivers) represents a low protection level for occupants. In fact we could have named OS occupant UNsafety instead of occupant safety. A high value of AI represents a high level of Aggressivity (a high proportion of seriously injured opponent drivers).

Ideally, both values should be similar and as low as possible, following our definition of compatibility (section 3.9). Based on the theory of mechanics however, it is to be expected that the bigger and heavier car types will yield low OS levels (high level of occupant safety) and high AI levels (high level of aggressivity to others).

5. Analysis of frontal collisions

5.1. Selection criteria

In Chapter 3 we already showed the number of frontal accidents selected for the analysis, the number being 4,305, representing 8,610 vehicles. The accident sample was originally derived from 5 years (1992-1996). However, as has been stated in Chapter 1, data from 1997 became available during the study period and was added to the sample. The total study sample of frontal collisions 1992-1997 is now 5,014 accidents, representing 10,028 vehicles, of which 871 (8,7%) are vans.

The selection criteria, already given in Chapter 3, limit the study sample to:
- collisions involving only cars or vans,
- two-vehicle collisions only,
- each vehicle having frontal damage only.

5.2. Mass range

Figure 3 shows the distribution of the kerb weight of all cars (not vans) in the study sample.

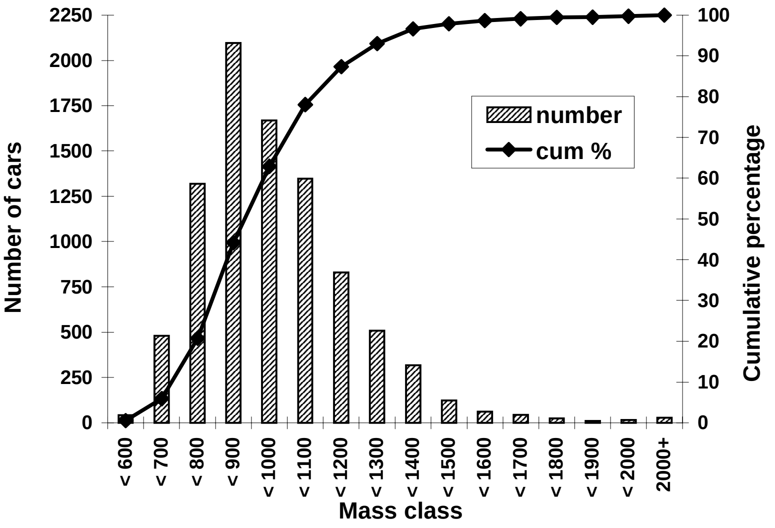

Figure 3. *Number and cumulative frequency of cars by kerb weight category, frontal collisions 1992-1997.*

Clearly, the most common mass category is 800-900 kg, in which are nearly 2,250 cars. Looking at the cumulative percentage, we observe that 90% of the cars have a kerb weight of less than 1,300 kg. The other 10% is formed by a number of categories (up tot the maximum of 3,500 kg).

5.3. General characteristics of the sample

In the police registration, vehicles and their drivers are registered in a specific order. The first mentioned (vehicle 1) is considered the party ‘at fault’, while the second party (vehicle 2) is not, or only partly. Although in this project we are not concerned with this aspect of accidents, we must at least consider the possibility that a bias is introduced concerning make and model of car and other vehicle properties relevant to the scope of the study. So, before we may consider treating the sample as a whole, consisting of 10,028 cars, we look at possible differences between vehicle 1 and vehicle 2, as they appear in the police registration.

Registration year	Vehicle 1	Vehicle 2
Before 1985	30.4	25.4
1985-1990	36.4	40.3
1990-1992	15.1	15.6
1992-1997	15.0	16.6
Unknown	3.2	2.2
Total	n=5,014	n=5,014

Table 6. *Relative distribution (%) over registration year of vehicle 1 and vehicle 2, frontal collisions 1992-1997.*

Table 6 shows that vehicles registered before 1985 are more often represented as vehicle 1 than as vehicle 2, while this trend is reversed with respect to vehicles admitted between 1985 and 1990. For more recent years the differences are very small.

Driver age (years)	Vehicle 1	Vehicle 2
18-42	25.7	18.3
25-24	29.3	29.9
35-44	17.1	21.7
45-54	12.4	16.1
55-64	7.3	8.5
65+	7.7	5.2
Unknown	0.5	0.3
Total	n=5,014	n=5,014

Table 7. *Relative age distribution (%) of drivers of vehicle 1 and vehicle 2, frontal collisions 1992-1997.*

Table 7 shows that drivers of vehicle 1 are generally younger than those of vehicle 2, especially in view of the difference in the age group 18-24 years. The police may have had a bias towards younger drivers as being the party ‘at fault’, or on the other hand, these drivers may really have caused the accident because of negative aspects regarding driver behaviour (such as speeding, not giving right-of-way etc.). In that case, for instance, the average driving speeds of all vehicles 1 may have been higher than the average driving speeds of all vehicles 2 .

This is of cause relevant to the problem of incompatibility, even though the police data does not allow to check its importance, since no data concerning speed are available.

There is a link between the data in *Tables 6 and 7*, since younger drivers tend to drive more often in older cars than older drivers.

The differences with regard to the distribution of sex is very small, as is shown in *Table 8*.

Sex of driver	Vehicle 1	Vehicle 2
Male	74.1	73.5
Female	25.4	26.2
Unknown	0.5	0.4
Total	n=5,014	n=5,014

Table 8. *Relative distribution (%) of sex of drivers of vehicle 1 and vehicle 2, frontal collisions 1992-1997.*

Injury severity of driver	Vehicle 1	Vehicle 2
Fatal	1.8	1.9
Hospitalised	18.1	16.4
Other	37.9	41.9
Not-injured	42.2	39.8
Total	n=5,014	n=5,014

Table 9. *Relative distribution (%) of injury severity of drivers of vehicle 1 and vehicle 2, frontal collisions 1992-1997.*

Table 9 shows some differences between the two injury severity distributions, but these are not really consistent, since drivers of vehicle 1 appear to be slightly more seriously injured, and at the same time more often not-injured than drivers of vehicle 2.

Finally, we look at vehicle make and model and we restrict our effort to those models having a share of at least 1% in order to avoid as much as possible fluctuations due to low numbers. See *Table 10*.

Table 10 shows that the two distributions are in line with each other, having fluctuations of never more than 0.7 percent-point per individual model. Since we have seen that the combination of older cars and younger drivers is over-represented in vehicle 1, the table seems to suggest that this is particularly true for older models such as BMW-3, Ford Escort, Opel Kadett, and some others. However, some fluctuations may also still be due to the relatively low numbers of individual vehicle models. Thus, in view of the relatively small differences, we conclude that the distributions are sufficiently alike.

Vehicle make and model	Vehicle 1	Vehicle 2
BMW-3 series	1.8	1.5
CITROEN BX	1.4	1.8
FORD Escort	5.3	4.8
FORD Fiesta	1.4	1.8
FORD Sierra	2.5	2.4
HONDA Civic	1.3	1.2
MAZDA 323	1.9	1.9
MAZDA 626	1.4	2.1
MB-190	1.0	1.0
NISSAN Sunny	1.8	1.7
OPEL Ascona	1.7	1.7
OPEL Astra	1.2	1.6
OPEL Corsa	2.4	2.2
OPEL Kadett	8.0	7.5
OPEL Vectra	1.2	1.5
PEUGEOT 205	2.4	2.5
SUZUKI Alto	1.4	1.2
TOYOTA Corolla	1.5	2.0
VW Golf	6.2	5.8
VW Passat	1.0	1.1
VOLVO 340/360	1.1	1.1
Other	52.1	53.6
Total	n=5.014	n=5.014

Table 10. *Relative distribution (%) of make and model of vehicle 1 and vehicle 2, frontal collisions 1992-1997.*

5.4. Summary of differences between vehicles 1 and 2

We found that for most of the variables considered, there was good likeness of the distributions of vehicle 1 and vehicle 2. However, we found some differences, that could be considered relevant to the current study of (in)compatibility, since they might have caused a bias (i.e. different distributions of relevant variables for vehicle 1 and vehicle 2) with respect to the severity of the accidents.

The most apparent differences found are those with respect to driver age and vehicle age, the two being connected. The resulting theory in this case would be that the average (driving) speed of all vehicles 1 is higher than that of all vehicles 2 due to driver (miss)behaviour. However, since we did not find evidence that these apparent differences between drivers and vehicles resulted in differences of injury severity distribution (the most important dependant variable in the sample), we now conclude that we may consider the separate groups of vehicles (1 and 2) as comparable for the purpose of studying incompatibility further.

Practically, this means that we totalize all vehicles and consider the total number as a new sample to study influence of vehicle properties on outcome. Of course, we will also keep information about each of the two individual vehicles involved in a particular accident, as far as it relates to differences (such as mass difference) that are important for the injury outcome of the drivers.

5.5. Control variables

Since we are interested in effects on outcome (injury severity of drivers) of different vehicle properties, we must try to study these effects without influences from other directions or biases.

Probably the most influential factor regarding severity of collisions is collision speed (of both vehicles involved). Since we do not have data on driving speed, let alone collision speed in the sample, we must try to control the analysis by other means. We will therefore use the word ‘area’ (urban/rural) as surrogate, assuming that accidents in rural areas where speed limits are normally 50 km/hour or less, are far less severe than accidents on urban roads.

We also know that seat belt usage has an important effect on the outcome of collisions, but we have no data concerning this. On the other hand, we know from yearly observations that the average usage rate of seat belts is higher in rural areas than in urban areas. So, if we use area as control variable, we also control for seat belt usage rate difference.

Other factors such as age and sex of driver may well influence outcome, and we will look at these factors when appropriate.

5.6. Effects regarding vehicle mass

Before we come to study individual car models, we look at the influence of vehicle mass. We know from literature that vehicle mass (or rather vehicle mass and mass difference with respect to the opponent vehicle) is one of the most important factors influencing outcome. At the same time, we know that vehicle mass and vehicle size are closely linked, and may normally not be separated, except for cases of very specific vehicles, in which the relation between mass and size has changed.

We start using vehicle mass (kerb weight) before looking at mass difference. In *Figure 4*, to indicate injury severity, we have used the share of seriously injured drivers within each mass category. The graph clearly shows the considerable influence of mass on outcome, both for rural and urban roads. The average severity percentage on urban roads is 10%, while on rural roads it is 28%, almost three times as much. We see this reflected in the graph, since the difference remains more or less stable for all different mass categories.

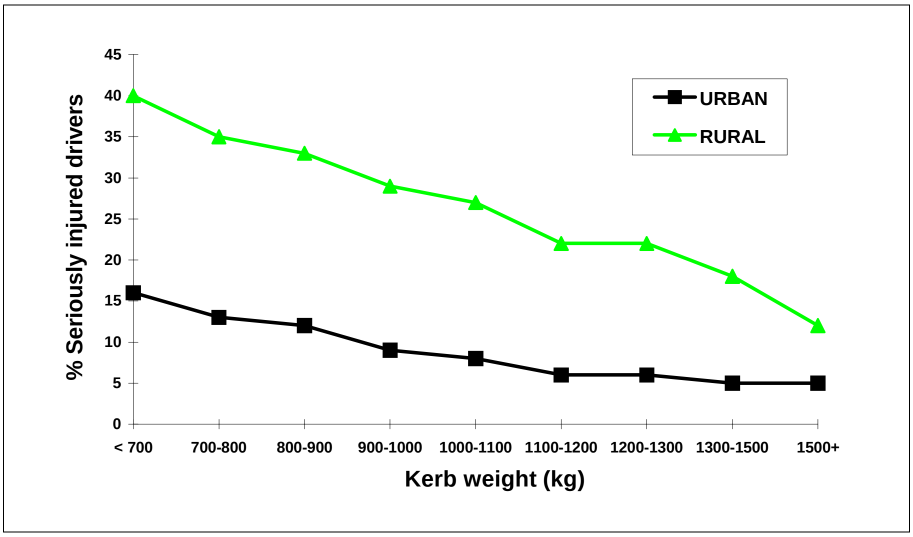

Figure 4. *Relation between kerb weight of vehicles and percentage of seriously injured drivers from accidents on urban and rural roads, frontal collisions 1992-1997*.

5.7. Mass difference

We used vehicle mass (kerb weight) to predict driver injury severity, and found a considerable influence, as illustrated by *Figure 4*. However, theoretically it is not mass as such, but mass difference that should be considered. In the following we will use this property, expressed as mass ratio (the kerb weight of vehicle 1 divided by the kerb weight of vehicle 2). In view of the mass range of the vehicles concerned (as illustrated in *Figure 3*, section 5.2) we categorise this ratio into 10 groups, running from 0.6 and less to 1.7 or more in such a way that the centre group are vehicles of more or less equal kerb weight (ratio is 0.9-1.1). See *Table 11.*

Since we have 5,014 accidents in the sample, we should have 5,014 ratios. However, since we would like to study the influence of mass ratio for all 10,028 vehicles involved, we calculated ratios for all 10,028 vehicles, as if they all were vehicle 1 (and consequently all were vehicle 2).

Five percent of the ratios is unknown, caused by missing data of either or both vehicles concerned.

Mass ratio	Number	Percentage
< 0.6	918	9.2
0.6-0.7	846	8.4
0.7-0.8	1,128	11.2
0.8-0.9	1,244	12.4
0.9-1.1	2,227	22.2
1.1-1.3	1,470	14.7
1.3-1.5	811	8.1
1.5-1.7	426	4.2
> 1.7	452	4.5
Unknown	506	5.0
Total	10,028	100%

Table 11. *Distribution of mass ratio of all vehicles, frontal collisions 1992-1997.*

Figure 5 shows the same type of relation as already shown in *Figure 4*, but now using mass ratio instead of mass.

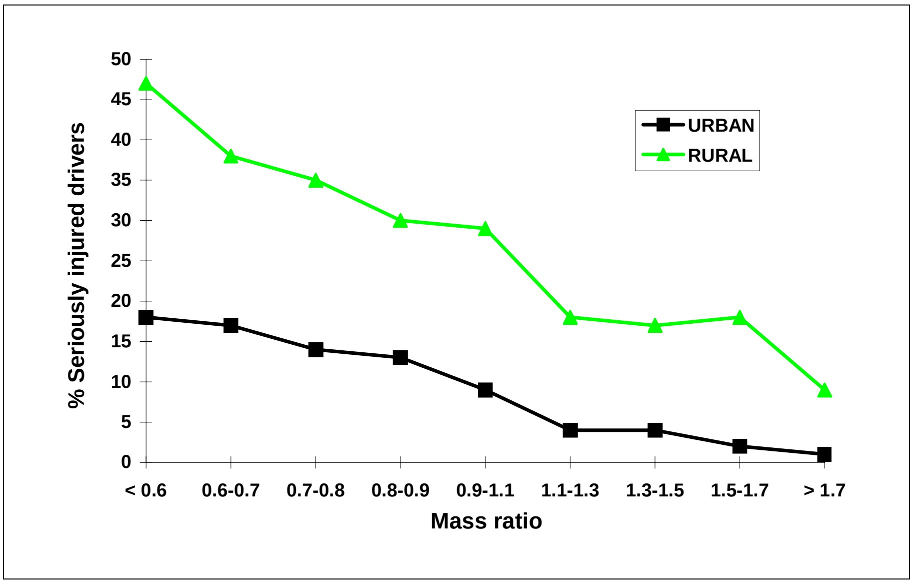

Figure 5. *Relation between mass ratio of vehicles and percentage of seriously injured drivers from accidents on urban and rural roads, frontal collisions 1992-1997.*

Figure 5 shows a somewhat greater range concerning the share of seriously injured drivers than when we used mass sec, when we look at the lowest and highest ratio categories. Of course, we are still talking about the same type of relation as in *Figure 4*, since we consider the same vehicles and their drivers. In fact, we must conclude that both mass sec and mass ratio produce similar results with respect to their influence on the injury severity of drivers.

In *Figure 4*, the mass of the other vehicle may not be apparent but it is implicitly represented. This may be explained as follows. In road accidents, every individual vehicle will encounter vehicles of all sizes and weights, as represented by the car fleet. So, if the average weight of the car fleet is, for instance, about 950 kg, the average weight of opponent vehicles of every individual vehicle will also be about this fleet's average, independent of the case vehicle weight. This ideal situation may not exist in reality, since different vehicle models may be used under different circumstances and meet different sets of opponents. Furthermore, the current sample size is definitely not big enough to cover all different vehicle types in sufficient numbers. Therefore we must expect some fluctuations around this theoretically pure image. But it still means that every separate mass category represents also a separate mass ratio, more or less following the pattern of *Figure 5*, thereby explaining the similarities of the two graphs.

The difference between the two approaches is that, while mass categories represent certain models and classes of vehicles, mass ratios do not. So the individual vehicles situated in a certain mass category in *Figure 4*, may be anywhere situated in *Figure 5,* dependant on the mass of their individual opponents. It would therefore be interesting to look at sub-categories of vehicle mass categories within mass ratio categories, in order to determine whether smaller and lighter vehicles are still different from larger and heavier vehicles within having the same ratio. This relation is shown in *Figure 6*, leaving for the moment influence of area (urban or rural) out of the analysis.

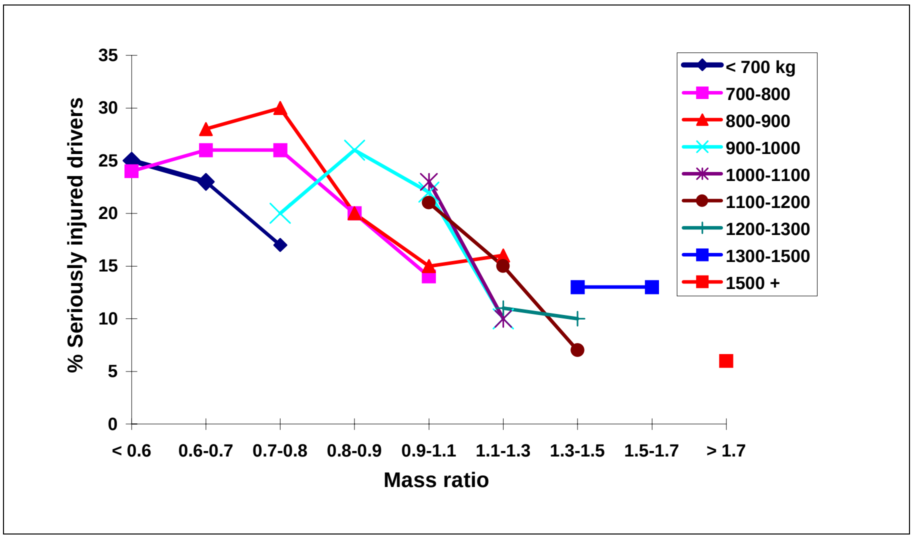

Figure 6. *Relation between vehicle mass ratio and percentage of seriously injured drivers controlled for vehicle mass categories, frontal collisions 1992-1997.*

Obviously, we find several groups with very small numbers of cases, and also non-existing groups, since for instance very heavy cars will not produce ratios under 1.0. We therefore have admitted only groups of mass ratios of over 75 cases each. The graphs clearly shows evidence (gaps) because of this.

If we expected that lighter vehicles would yield higher rates of seriously injured drivers than heavier cars, within the same ratio category, we are disappointed. Often, the opposite seems more to be the case.

Roughly, we see a decreasing share of seriously injured drivers through all of the mass ratios. Looking at the picture from this more statistical viewpoint, we might conclude therefore that mass ratio is the working mechanism, regardless of vehicle mass. At the same time, we must realise that we have stressed the possibilities of this type of statistical analysis to its limits, mostly because of too small a sample.

5.8. Summary of major factors influencing accident outcome

Up to now, we found two major independent factors of influence on injury severity of drivers: (1) the accident severity, represented by two classes of area (urban and rural), and (2) the vehicle factor mass ratio.

Area accounts for a range of about a factor 3 (from 10% to 28% of seriously injured drivers), while mass ratio accounts for an even wider range (a factor 6) of injury severity (from 33% for the smallest ratio group to 5% of seriously injured drivers for the highest ratio group). These percentages all exactly circle around the average of the total group of vehicles/drivers: 19% of all 10,028 drivers are seriously injured.

Other contributing factors, such as driver sex and age may have independent influence on outcome, but we have to check this to be sure that they do not completely interact with vehicle factors. This could for instance be the case if all women drivers tend to drive small cars, and all male drivers tend to drive large cars, in which case the influence we found for vehicle mass ratio could be mainly due to sex difference.

5.9. Differences between sexes

We start our analysis with an overview of injury severity for both male and female drivers in *Figure 7*. This figure shows that women drivers have higher proportions of seriously injured and non-seriously injured than men, and consequently, a lower proportion of not-injured.

Evidently, we would first suspect that the accident circumstances of these groups are different; therefore we will look both at area, and at vehicle mass (kerb weight), assuming that these two variables will make a big difference with respect to sex. *Table 12* shows that this assumption is true. The average kerb weight of vehicles of women drivers is considerably less than that of male drivers, both on rural and urban roads; there is also a (smaller) difference in average kerb weight concerning area itself, both for female and male drivers.

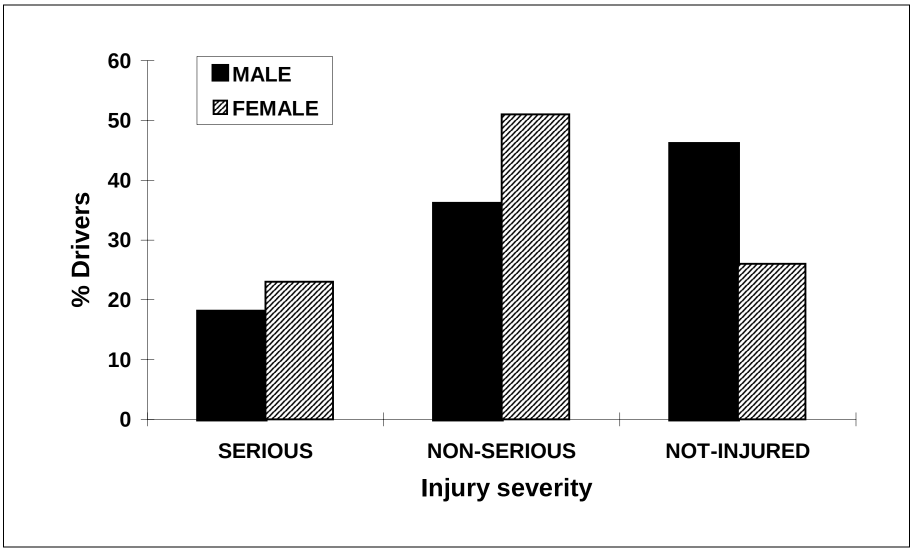

Figure 7. *Relative number of drivers by sex and category of injury severity, frontal collisions 1992-1997.*

Sex	Average kerb weight in driving area (kg)	
	Urban roads	Rural roads
Male	1014	1042
Female	887	917

Table 12. *Average kerb weight of vehicles by sex of driver and area, frontal collisions 1992-1997.*

Table 13 shows the distribution of the number of male and female drivers over the driving area. Female drivers are only slightly less represented in accidents on rural roads than on urban roads.

Sex	Area					
	Urban roads		Rural roads		Total	
	Number	%	Number	%	Number	%
Male	3,610	72.8	3,789	74.8	7,399	73.8
Female	1,326	26.7	1,261	24.9	2,587	25.8
Unknown	24	0.5	18	0.4	42	0.4
Total	4,960	100	5,068	100	10,028	100

Table 13. *Number and share of male and female drivers in accidents on urban and rural roads, frontal collisions 1992-1997.*

The differences presented in *Tables 12 and 13* imply that an analysis of sex influence on accident outcome should be controlled for at least kerb weight, while area may still make some smaller difference since it is clearly linked to accident severity. Therefore, in *Figures 8 and 9* we present the results of an analysis on sex of drivers, controlled by both kerb weight and area.

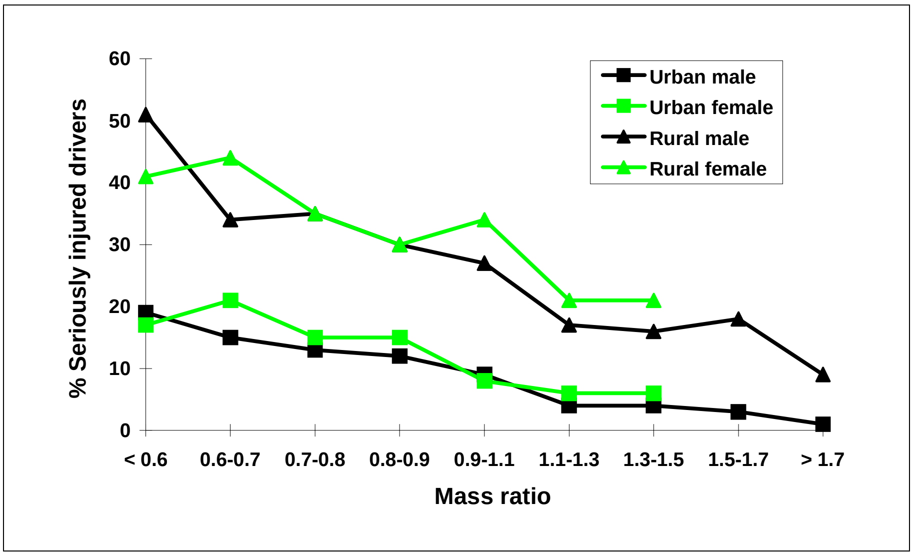

Figure 8. *Relation between vehicle mass ratio and percentage of seriously injured male and female drivers according to area, frontal collisions 1992-1997.*

Figure 8 shows that both male and female driver experience comparable influence from mass ratio and area, while at the same time the percentage of seriously injured female drivers is somewhat higher than for male drivers. This is far better reflected by the average percentages of seriously injured drivers. On urban roads this percentage is for male drivers 9%, for female drivers 13%, and on rural roads for male drivers 27%, and for female drivers 33%. Female drivers have 20% to 40% higher percentages of seriously injured than male drivers.

The distribution from *Figure 7* also pointed to (larger) differences between male and female drivers with regard to non-severe injury and not-injured drivers. Therefore, to complete the analysis, we look again at these differences for not-injured drivers, controlled for by both mass ratio and area, as is shown in *Figure 9*.

Figure 9 shows clearly that female drivers always have a lower proportion of not-injured than male drivers, both on urban and rural roads. The average differences are substantial, as already shown in *Figure 7*, and are maintained through all different mass ratio categories, barring some statistical fluctuations.

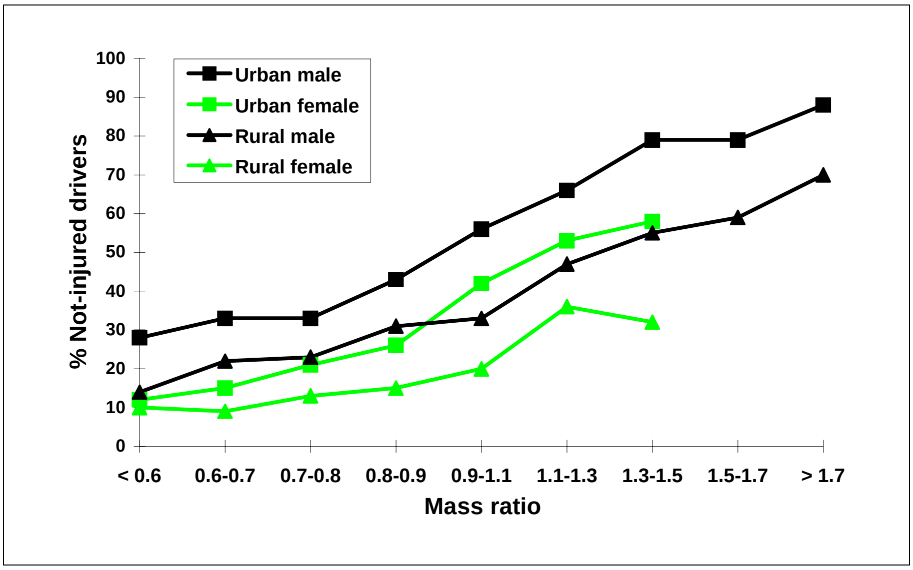

Figure 9. *Relation between vehicle mass ratio and percentage of not-injured male and female drivers, according to area, frontal collisions 1992-1997.*

There may be at least three different mechanisms working together producing this difference between male and female drivers. Firstly, women drivers may drive differently from male drivers (i.e. lower driving speeds, more carefully) for which we cannot control the analysis, but this probably accounts for less severe accidents for women drivers. Secondly, it is also known from observation studies that women drivers use seat belts more often than male drivers in The Netherlands. This however would also account for a lower level of injury severity. Thirdly, women may have a different biomechanical structure from males, possibly accounting for more injury or more severe injury.

So, if all these mechanisms are more or less working together, we have to assume that the latter (biomechanical differences) is far stronger than the first two to explain the resulting differences.

We must assume that there is considerable structural difference with respect to outcome for both sexes, which is not primarily caused by differences of vehicle size or accident severity. On the other hand, there may be some (minor) influence from still remaining vehicle size differences within groups of the same mass ratio, since female drivers tend to drive cars that are considerably smaller than vehicles of male drivers. Due to the limited sample size, we are not able to study this aspect in more detail. We recommend however to study this subject further using in-depth data in which accident circumstances are better known, or to enlarge the sample to more years and greater selections for each year.

5.10. Conclusions regarding sex differences

Even when controlled for by mass ratio and area, differences with respect to injury severity between male and female drivers remain. Female drivers experience more serious injury, and more non-serious injury, and are less often not-injured than male drivers in frontal collisions. These differences are considerable and range from 20 to 50%, depending on the injury severity category.

Though part of the differences still may be due to remaining vehicle size factors and other accident factors that cannot be further analysed because of sample size and data limitations, the data indicates some structural differences between males and females with respect to injury susceptibility. This type of difference was observed before, with respect to rear-end collisions and (neck) injury (Van Kampen, 2000) but from the data available in the current study, it is not clear in which biomechanical direction injury severity differences with respect to frontal collisions may be explained.
A possible theory could be that, as is apparently the case for rear-end collisions, female drivers also experience in frontal collisions more neck injury than males. This is another matter that could be further studied using in-depth data of accidents.

5.11. Ranking of individual car models

For the ranking of differences between individual vehicle types, we developed criteria as described in Chapter 4 (OS and AI). We will now use these criteria as planned. To prevent fluctuations due to sample size, we limit the individual vehicle types to those of which there are at least 100 in the total vehicle sample. This means that 20 individual vehicle types remain, representing 47% of all vehicles in the sample.

In *Table 14*, these 20 vehicle types are presented, including their share, their average mass (kerb weight), and their overall OS and AI indices. In this case, ‘overall’ means that no distinction yet is being made for area. The individual types described in *Table 14* still represent a number of car generations (such as Opel Kadett, VW Golf etc.); this has been done primarily to have as many vehicle types as possible.

The OS score represents the number of seriously injured drivers divided by the total number of vehicles of the type studied. By far the best OS score is observed for Opel Vectra (OS score = 9) and the worst for Opel Corsa, Suzuki Alto and Volvo 340/360 (OS score = 24).

If we look for more OS scores in the lower range, we can only find VW Passat (OS score = 13), and a little higher we find BMW-3 series (16), Ford Sierra (16), Mazda 626 (16). At the other end we find several vehicle types scoring almost as ‘bad’ as the three mentioned above: Opel Kadett (23), Honda Civic (22), Nissan Sunny (22) and Opel Astra (22).

Both Opel Vectra and VW Passat are vehicles of over 1000 kg kerb weight, as well as all of the other vehicle types scoring relatively good, up to 16, while the vehicles having high OS scores all (except Opel Astra) have kerb weights (far) under 1000 kg. Thus we find (as expected) a relation between injury severity and kerb weight, though some of the vehicle types having low kerb weights do not score as ‘bad’ as expected. For instance, Peugeot 205 (average kerb weight 792 kg) scores 18 (a little better than average), while Toyota Corolla (average kerb weight 961 kg) and Mazda 323 (average kerb weight 913 kg) both score 17 (both better than average).

Vehicle make	Vehicle type	Share (%)	Average kerb weight (kg)	OS score	AI score
BMW	3 series	1.7	1078	16	26
CITROEN	BX	1.6	956	21	23
FORD	Escort	5.0	886	20	19
	Fiesta	1.6	765	21	15
	Sierra	2.5	1103	16	18
HONDA	Civic	1.2	839	22	16
MAZDA	323	1.9	913	17	17
	626	1.7	1117	16	23
NISSAN	Sunny	1.8	960	22	21
OPEL	Ascona	1.7	984	20	15
	Astra	1.4	1002	22	25
	Corsa	2.3	767	24	17
	Kadett	7.7	862	23	17
	Vectra	1.4	1057	9	18
PEUGEOT	205	2.4	792	18	11
SUZUKI	Alto	1.3	617	24	5
TOYOTA	Corolla	1.7	961	17	17
VW	Golf	6.0	875	20	18
	Passat	1.1	1123	13	19
VOLVO	340/360	1.1	981	24	18
Other		52.9	-	-	-
Total		100	995	19	19

Table 14. *Distribution of individual vehicle models (n >100) according to share, average kerb weight, OS score and AI score, frontal collisions 1992-1997.*

With respect to AI scores, we find the lowest score (the least aggressive) for Suzuki Alto (5), while the next lowest is Peugeot 205 (11). On the other end of the scores we find BMW 3-series (26) and Opel Astra (25) as the most aggressive vehicle types. The first two mentioned vehicle types are well under 1000 kg kerb weight, while the last two are well above. In this respect the theory holds again.

On the other hand there are vehicle types well over 1000 kg, but not scoring particularly high AI-indices, such as Ford Sierra (18), Opel Vectra (the type with the best OS score of 9) scores only 18 for AI. It is also contrary to expectation that Opel Astra (having one of the highest aggressivity scores of 25) has also a rather high OS score of 22.

5.12. Further observations concerning OS and AI scores

There are two vehicle models scoring each the same OS and AI scores (both scores are 17); these are Mazda 323 and Toyota Corolla. These vehicle types are indeed rather similar in design, weight, etc. In fact, looking at the definition of compatibility as expressed in section 3.9, we would like all cars to have such similar scores for both occupant safety and aggressivity, while at the same time these scores are as low as possible (preferably lower than 17).

The only vehicle type that behaves fully according to theory is Suzuki Alto (the smallest and lightest car in the sample) having by far the highest OS score (24) and by far the lowest AI score (5).

One of the reasons that we find for individual types less conformity with theory than we found by looking at mass and mass ratio in the previous sections, is that we averaged vehicle mass for each of the different types. For instance, a 3-door car is normally lighter than a 4-door or station car of the same model. But in the list of OS and AI scores we have put all of these different models together, although they differ sometimes more than 100 kg in kerb weight.

5.13. Summary regarding frontal collisions

At first we have looked at possible differences between vehicles considered by the police as being ‘at fault’ and those considered ‘not at fault’. Since the differences found were only small or not relevant, we have put all 10,028 vehicles and their drivers in the sample in one database as more or less independent of each other, keeping of course information about the other party involved.

This way we studied influence of mass on driver injury severity, followed by mass ratio. Since accident severity could be simulated by using area (urban or rural) we used area as control variable, at the same time correcting somewhat for difference in seat belt use rate which is generally higher on rural roads than on urban roads. It was supposed that other biases, such as different accident circumstances were statistically dealt with by using a big enough sample size.

Mass and mass ratio (represented by kerb weight) still proved to be an enormous influential factor with respect to injury severity of drivers, after controlling for area. A more detailed analysis concerning vehicle weight categories within each mass ratio category proved probably to be too much for the limited sample size. The results seem to indicate however that mass ratio is far more important than mass as such.

A specific analysis was carried out with respect to sex. Women drivers appear to be far more often injured, both seriously and non-seriously than male drivers, even when the analysis is controlled for by vehicle size and area. Since women drivers are known to drive more carefully than male drivers and have higher seat belt use rates than male drivers, factors which tend to influence outcome positively, the resulting negative effect must mainly be due to biomechanical differences between males and females. A similar effect was recently found after the study of rear-end accidents in which women drivers had far more (neck) injury than male drivers.

As far as individual vehicle types are concerned, we have ranked 20 of the most frequent available types (n > 100) according to their OS and AI score, giving respectively the rate of seriously injured drivers within the vehicle type concerned, and the rate of seriously injured opponent drivers. Only one vehicle type (Suzuki Alto) appears to fully ‘behave’ according to theory, since it is by far the smallest and lightest car, having by far the highest OS score (24) and the lowest AI score (5). It must be noted at this time that Suzuki Alto is a type of car far more often driven by female drivers than by male drivers, so part of the effect found may be due to sex differences.

The vehicle type having the highest average weight within the selected 20 types, VW Passat, did not have the lowest OS score or the highest AI score. The lowest OS score was for Opel Vectra (9), while the highest AI score was for BMW 3-series (26); both types having average kerb weights of well over 1000 kg.

Thus we may conclude that, in general terms, the theory has been proven valid (cars having a high mass show a high level of occupant protection and a high level of aggressiveness, while cars having low mass show the opposite). Since we combined types of different generations and of different models (3-door, 4-door, etc.), we automatically combined vehicles of different mass, thereby obstructing somewhat the possibility to rank car types properly.

6. Other collision types

Analyses of other collision types have been carried out without the scope of the current study (Van Kampen, 2000), concerning specifically side collisions, rear-end collisions and collisions against fixed obstacles. The numbers of cases studied for the year 1996 have already been shown in Chapter 3 of this report, in *Table 4*. As in the current study, data for the year 1997 were added.

In all collisions types except one, the major influence of vehicle mass (kerb weight), both in terms of vehicle mass sec and mass ratio, was established in much the same way as in the current project. In case of collisions against fixed obstacles, however, no apparent influence of vehicle mass on the outcome of the collisions was found. For all different vehicle mass categories, more or less the same (high) ratio of seriously injured drivers was established. This result will be discussed in Chapter 7.

7. Discussion on compatibility aspects

Even the best accident data or the most sophisticated analysing methods do not provide answers to scientific problems, unless some hypotheses have been generated beforehand. The data and the analyses are then used to test these hypotheses. Since we seem to be more or less at the very beginning of understanding what compatibility between cars may be, the hypotheses available at the moment are only general and incomplete. In the case of general (national) accident data such as used in this report, the hypotheses can anyhow only be rough and general because of the character of the data used.

Since we assumed that mass (or mass ratio) would be an important factor regarding injury outcome, we have not been disappointed. For frontal collisions, we observe that the smallest, lightest cars have indeed the highest proportion of seriously injured drivers, while drivers of the heaviest and biggest cars are far better off; there is a factor of about 3 difference with regard to occupant safety as expressed by the proportion of seriously injured drivers, both on urban and on rural roads. Area (urban or rural) proves to be a distinct controlling variable, since on average, injury severity is nearly three times higher on rural roads than on urban roads.

Mass ratio is an even better predictor of injury severity than mass sec. This is in line with the theory of mechanics of collisions between masses. It could be called indeed spectacular that mass (ratio) works as well is it does in the analyses, since we used kerb weight instead of real mass (including driver, passengers, luggage etc.). Furthermore, much what is found as influence of mass (ratio) may be attributed to size as well, as already mentioned before. Implicitly, we undoubtedly also found influence of (differences of) the geometrical and stiffness nature.

It is almost impossible to control statistical data based on police registration for all of these other relevant vehicle factors, instead of which they all have been incorporated in the individual ranking of vehicle types. Statistical data would however yield results in this respect if more data about individual vehicle damage would be available. This might only be the case if in the future devices such as black boxes (collisions recorders) would be generally available.

The results of the ranking procedure are somewhat disappointing, since in few cases are they exactly in line with the theory of mechanics. Fluctuations are large and frequent, due to the small sample size of the data selected. Probably the most disturbing factor has been the fact that we combined model years (generations) as well as models of the same vehicle type, thereby combining vehicles of different mass.

We recommend further analyses based on bigger databases (more years, larger selections of cases per year) for more controlled analysis. For the further study of influence of geometrical aspects, as well as other structural aspects such as stiffness, we recommend the use of in-depth data, where at least registration of the parts damaged is available. Nevertheless, we have shown that a ranking instrument (the OS and AI scores) can be used to measure both occupant safety and aggressivity.

We conclude from the wide range of these scores that cars (and vans) should become far more compatible than they apparently are. In view of the major influence of mass (kerb weight) in this respect, improvement of compatibility asks for very sophisticated changes of the current vehicle construction, in order to offer all cars the higher safety levels of the larger cars, and at the same time offer the lower aggressivity levels of the smaller cars.

More or less the same influence of vehicle mass on outcome was also found in a separate study of other collision types (side and rear-end collisions). However, almost no influence of vehicle mass on outcome was found for collisions against fixed obstacles. Theoretically, this appears a quite sound result, since current car design is such that cars comply, regardless of mass with the requirements regulated for instance in the current Directive on frontal collisions. In this, the current EEVC barrier test is still more or less comparable to a fixed barrier test, even though the barrier face has been made deformable.

A one-car barrier test is in principal not suited to test aggressivity of the tested cars to others, since difference of outcome in a car-to-car collision is a matter of both mass difference, geometrical difference, and stiffness difference. Even the suitability of such tests in testing the aggressivity to opponent cars of the same mass, or even the same model, is questionable because of local geometrical differences and local stiffness differences of structures that actually engage in real-world collisions.

It is therefore to be expected that current regulations (especially those concerning the front end of cars) will not lead to more compatibility between cars without considerable change. Such a change may be reached by developing and applying an additional crash test for frontal impacts, in which aggressivity to other cars is measured.

It is recommended that such an additional frontal barrier test is developed and applied in the current Euro NCAP programme, since this programme has proven to be able to influence car design much faster than through the normal legislation channels.

8. Conclusions and recommendations

The scope of the problem of compatibility is found to be greater than represented by frontal collisions only. Front end design is also of (major) influence on the outcome of side collisions, rear-end collisions, and other types of collisions also involving other types of road users than cars and vans.

Mass as represented by kerb weight is still increasing throughout the years: average kerb weight of all cars is increasing since kerb weight of individual cars is increasing. This may cause new problems, especially since also new car models are introduced, having different properties from current car models as presented in this statistical study.

Car size or car mass differences represent by far the most influential factor on outcome of accidents apart from accident factors such as collision type and collision speed. Both on rural roads and urban roads, mass ratio influences the share of seriously injured drivers (fatalities and hospitalised) by a factor 3, using a mass ratio range with runs from about 0.6 to about 1.7: the higher the mass ratio, the better the occupant safety.

After controlling for vehicle size and area (urban or rural) there remained substantial difference with regard to the share of seriously injured male drivers and female drivers in frontal collisions. It is concluded that these differences must be mainly due to biomechanical differences between males and females, such as already have been found with regard to neck injury resulting from rear-end collisions (these injuries are more frequently found with women).

Ranking of individual car models, using two criteria at the same time, occupant safety (OS) and opponent safety or aggressivity (AI), yielded results that were generally in line with the theory that small and light cars always have both high occupant severity and low aggressivity, while large and heavy cars have the opposite scores. The analyses show that the OS and AI scores may be used together as an instrument for the rating of the overall compatibility aspects of cars.

It is concluded from these scores that compatibility between cars with respect to frontal collisions should be improved considerably. This should be done by bringing the OS and AI scores of a particular vehicle type on a comparable level, and by bringing both scores on a lower level than shown for most types.

It is recommended:

- to study developments of car mass (kerb weight) for all European countries, with emphasis on newer models and with regard for the sort of use (such as business, lease, family transport etc.).

- to further study typical effects as found in this study but still not fully understood: sex differences, vehicle model differences. It is recommended to incorporate more accident detail in such studies.

- to add more cases to the current database, either by gathering more (recent) years, or by selecting a wider range of cases, or by doing both.

- to develop a collision test, to be additionally used in the Euro NCAP programme, in which the aggressivity of the tested cars towards other cars can be measured.

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