The safety effect of exchanging car mobility for bicycle mobility

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Summary

This report describes the analysis of the effect of exchanging passenger car mobility for bicycle mobility on the number of fatalities and serious road injuries in the Netherlands. A precise calculation of this effect is not possible due to a lack of information, but we were able to give a first and rough approximation of the safety effect.

The analysis considers a substitution of 10% of car trips shorter than 7.5 km by bicycle trips. The analysis is done *ceteris paribus,* thus, all relevant parameters are assumed to remain equal (except of course mobility). Assuming that the increase in bicycle trips is distributed equally over the network, time of day etc., as current bicycle mobility is, the increase in the number of fatalities and serious road injuries in crashes involving bicycles can be estimated. In the same way, the decrease in the number of fatalities and serious road injuries in crashes involving cars is estimated, assuming that the mobility decrease has the same safety properties as the remaining car mobility.

Firstly, the amount of mobility exchanged (short trips) is calculated, and then expressed as a percentage-change in the total mobility (all trips) of cars and bicycles. Secondly, the effect of extra bicycle mobility on crashes involving bicycles is calculated. The same is done for crashes involving cars. These calculations are disaggregated by age and gender of the driver, because risks strongly correlate with driver age and gender, both for car drivers and bicycle riders.

The results of the procedure described above show, by age group, the net gain or loss in road safety, related to the mobility exchange. For each driver age group, the increase or decrease in the number of fatalities and serious road injuries is calculated. For hospitalized cyclists in a single vehicle crash we only consider casualties with an injury severity of at least 2 on the internationally used Maximum Abbreviated Injury Scale.

Based on the assumptions given, the calculations suggest an annual increase of 4 to 8 fatalities and of approximately 500 serious road injuries, when 10% of the short car trips are exchanged for bicycle trips for all ages. Further, the results indicate that the number of fatalities decreases if young car drivers (<35 years) switch to bicycles, but when older car drivers do the same, this increases the number of fatalities. The number of serious road injuries increases for practically all ages due to the car-bicycle mobility shift. Only for 18- and 19-year-old males, it is beneficial to switch to cycling. The overall increase is a consequence of the very large number of cyclists that are treated in hospital as a consequence of a single vehicle crash with a bicycle.

Contents

1. Introduction

1.1. Background

The National Institute for Public Health and the Environment (RIVM) was commissioned by the Dutch Ministry of Housing, Environmental and Spatial Planning (VROM) to start a project on 'sustainable traffic'. The aim of this project is to assess and integrate the potential health aspects of transport interventions for air pollution, noise, physical activity and road safety, in order to identify measures that will most effectively reduce the traffic-related disease burden in the Netherlands (Van Kempen et al., 2010).

A first exemplary assessment of a transport intervention was carried out in 2005. It estimated the possible health benefits of speed limit reductions at nine highway sections in urban areas (Van Kempen, Knol & Schram-Bijkerk, 2006). The effects of traffic reallocation from a densely to a less densely populated area by the introduction of a new highway section (Schram-Bijkerk et al., 2006) were also evaluated. In both studies it was recommended to evaluate the health benefits of interventions influencing bicycle use.

As an example of such an intervention, Van Kempen et al. (2010) assessed the possible health benefits of the substitution of short-distance car trips (shorter than 7.5 km) with short-distance cycling trips in the Netherlands. Substituting short-distance car trips with bicycle trips has several advantages in the sphere of health and environment. An increase in the number of people using a bicycle instead of a car for short trips will lead to an increase of the overall level of physical activity, which is good for public health, and to a decrease of traffic-related noise and air pollution.

A change in modal split might affect road safety, because the chance of road users getting injured or even being killed in a road crash is not equal for all modes of transport. Therefore, RIVM asked SWOV to estimate the effect of the change in modal split described above. This estimation is the subject of this report. To emphasize the special case of a change in modal shift, namely the substitution of short-distance car trips with bicycle trips, we will speak about the mobility shift from car to bicycle, of mobility shift or of car-bicycle shift.

1.2. Aim of this report

The safety of cyclists differs from the safety of car occupants. Cyclists are vulnerable road users, who are easily injured when involved in a crash, especially when a motorized vehicle is also involved. Car occupants are far less vulnerable than cyclists. On the other hand, cyclists do not endanger other road users as much as passenger car drivers do, because of their much lower speed and mass. In single vehicle crashes, cyclists are often injured (annually, 5000 serious road injuries in the Netherlands), but seldom killed (annually,10 in the Netherlands), whereas car drivers are less often seriously injured (1500 hospitalized a year) but far more often killed than cyclists (200 a year). So what would happen if people rode their bicycles more often instead of using their cars?

It is not instantly clear how road safety is influenced by a mobility shift from car to bicycle, because it could have both a positive and negative impact on road safety. When people ride a bicycle instead of driving a car, the risk that they run over and kill someone is minimal. On the other hand, the chance that they get killed in a crash increases. The aim of this report is to determine the safety effect when a relatively small number (10%) of the short car trips (< 7.5 km) in the Netherlands in the period 1999-2006 is replaced by bicycle trips. The effect of this exchange on the expected number of casualties (killed and hospitalized) is computed in order to find out whether there is a net gain (less casualties) or loss (more casualties).

A precise calculation of the effect of this exchange on the expected number of casualties is not possible due to a lack of information. However, the subject is important, as the issue relates to public health and environmental policies. Knowledge about the safety effect of more cycling instead of car driving may be used in policy decisions. Therefore, a first and rough approximation of the safety effect is given in this report.

1.3. Other applications of the method

Although the method in this report was developed especially for answering the question of RIVM, it can be, and has been, applied in other cases. In general, the method can be applied in order to answer all research questions about the road safety effect of mobility shifts.

For example, Schermers & Reurings (2009) estimated the safety effect of Different Payment for Mobility (DPM, road pricing). Because motorcycles are exempt from DPM, it is possible that DPM leads to a shift from car to motorcycle. Due to the much higher crash rate of motorcycles, even a small increase in the total number of motorcycle kilometres can result in a large decrease of road safety. A similar method as the one given in this report was used to calculate the safety effect of this shift.

1.4. Structure of the report

In *Chapter 2,* the method is discussed, both globally and in detail. The data used are given in *Chapter 3*, followed by the results of the application of the method on these data in *Chapter 4*. The report ends with a discussion and conclusions (*Chapter 5*).

2. Method

2.1. Principles of the method

Car mobility is associated with several different risks, for example the risk of becoming a casualty in a single vehicle car crash, a two-car crash or a crash between a car and a bicycle. Not only car drivers run a risk, other road users may also become car crash casualties. Bicycle mobility is also associated with risks, such as the risk to become a casualty in a single vehicle bicycle crash or a crash between a bicycle and another party. Assuming that the replaced car mobility and the added bicycle mobility have the same risks as the remaining car mobility and the bicycle mobility before the addition, the change in the number of casualties due to a car-bicycle shift can be calculated.

For example, the change in the number of casualties in a single vehicle car crash equals the decrease in car mobility, multiplied by the risk to become a casualty in a single vehicle car crash before the mobility change. The decrease in the number of casualties is determined in the same way for each type of casualty (e.g., casualties among cyclists as a consequence of a car crash). The total decrease of the number of casualties due to the decrease of car mobility equals the sum of the decreases in the number of casualties for all types of casualties. Subsequently, the total increase of the number of casualties due to the increase of bicycle mobility is determined analogously. In this way not only car drivers and cyclists themselves are considered, but also the other road users, whose risk to become casualties will change with the mobility shift.

As casualties we will consider fatalities (i.e., persons who died within 30 days after a road crash as a result of that crash) and those who were hospitalized for at least one night. The method as described above means that we compare the safety of the two scenarios:

- Nothing changes in the use of passenger cars and bicycles.
- A small number of car trips is substituted with bicycle trips.

In other words, we compare the expected number of fatalities and serious road injuries in the second scenario to the actual number of fatalities and serious road injuries in the first scenario. The differences are an estimate of the net change of the modal shift from cars to bicycles.

In the analyses mobility and safety data are stratified by age and gender of the driver. This is important, because the probability of becoming involved in a road crash is very inhomogeneously distributed over age and gender of the drivers. Further, the short car trips that will be substituted in our computations will not be uniformly distributed over driver ages and gender. So we need to stratify them by age and gender as well. In the approach chosen here, we stratify crash data and mobility data by age and gender wherever possible.

Three major problems arise when calculating the effect of a mobility shift from car to bicycle:

– The risk per traffic mode, which we define as the number of casualties per distance travelled, is not constant under all circumstances, but it depends on many factors. For example, car mobility does not bear a uniform risk for every road, day of week, age of driver, etc. The same holds for bicycle trips.
– A given car trip will hardly be replaced by a bicycle trip along exactly the same route. This will result in differences in trip length and risk.
– The replaced car trips will not be evenly distributed over the road network.

Accurate data on the properties of the car trips to be substituted, and of the bicycle trips that replace them is lacking in the Netherlands. In order to proceed with the research question, assumptions have to be made to get round this lack of data. The main assumption is that the specific fraction of car mobility to be substituted with bicycle mobility has the same safety properties as the remaining car mobility. Subsequently, the added bicycle mobility is also supposed to have exactly the same properties as the bicycle mobility before this addition. "The same properties" means that for each characteristic (except age and gender), such as time of day or road type, the car mobility decreases by the same factor and bicycle mobility increases by the same factor. For example, every road type loses the same factor of car mobility and gains the same factor of bicycle mobility.

Car trips always relate to a driver aged 18 or older. We only replace driver trips and not passenger trips. Although one car trip can be replaced by multiple bicycle trips, the possible car-bicycle shift of car passengers will be left out of the computation. This introduces a small error.

In crashes with more than two vehicles (which are rare) the existence of the third party is neglected.

2.2. The different groups of casualties

As described in the previous section, the basic principle of the method is that the change in the number of casualties (fatalities and serious road injuries) is calculated per crash type, subdivided into road user type (car, bicycle or other party). This section lists the crash and road user types.

Only the number of casualties in three types of crashes are influenced by a car-bicycle shift. These crash types are:
1. crashes where at least one car is involved, but no bicycles;
2. crashes where at least one bicycle is involved, but no cars;
3. crashes where at least one bicycle and one car are involved.

Crashes where neither a car nor a bicycle is involved, are assumed to remain as they were: their number is not influenced by a change in car and bicycle mobility.

Within these crash groups, we can distinguish the following groups of casualties:
1a casualties among drivers in single vehicle car crashes.
1b casualties among car drivers, resulting from crashes with other parties than a car or bicycle.
1c casualties among other road users than car occupants and cyclists, resulting from crashes with a car.

1d casualties among car occupants, resulting from two-car crashes.
2a casualties in single vehicle bicycle crashes.
2b casualties among cyclists, resulting from crashes with other parties than a car or bicycle.
2c casualties among other road users than car occupants and cyclists, resulting from crashes with a bicycle.
2d casualties among cyclists, resulting from two-bicycle crashes.
3a casualties among cyclists, resulting from a crash with a car.
3b casualties among car occupants, resulting from a crash with a bicycle.

The number of casualties is presumed to be proportional to car mobility (Group 1) or bicycle mobility (Group 2) or both (Group 3). In 1d (and 2d) the number of casualties is supposed to be proportional to the square of car or bicycle mobility.

2.3. Detailing the method

2.3.1. *The change in car and bicycle mobility*

Let $M_c(a,g)$ be the distance travelled by car drivers of age *a* and gender *g* and let $M_b(a,g)$ be the distance travelled by cyclists of age *a* and gender *g*, both before the car-bicycle shift.

The first step in calculating the change in the number of casualties is to determine the change in mobility. To do so we first calculate the amount of car mobility that will be exchanged by bicycle mobility, $\mu(a,g)$. Thus, $\mu(a,g)$ is 10% of the sum of the lengths of all car trips by drivers of age *a* and gender *g*, shorter than 7,5 km. The car and bicycle mobility after the car-bicycle shift, $M'_c(a,g)$ and $M'_b(a,g)$, depend on the original car and bicycle mobility and the exchanged mobility, $\mu(a,g)$:

$$M'_c(a,g) = M_c(a,g) - \mu(a,g);$$
$$M'_b(a,g) = M_b(a,g) + \mu(a,g).$$

The fractional change in car and bicycle mobility, φ_c and φ_b, is the ratio between the exchanged mobility and the original car or bicycle mobility:

$$\varphi_c(a,g) = \mu(a,g) / M_c(a,g);$$
$$\varphi_b(a,g) = \mu(a,g) / M_b(a,g).$$

Although the absolute change $\mu(a,g)$ in mobility is the same for cars and bicycles, the relative changes, φ_c and φ_b, are not necessarily equal.

The consequences of the car-bicycle shift are calculated as a fractional increase in the number of casualties, proportional to φ_c and φ_b. Because of this, the value of mobility is no longer relevant, once φ_c and φ_b are known. Note that if only $\varphi_c(a,g)$ and $\varphi_b(a,g)$ were available (e.g. when we do not want to first distinguish between short and long trips), this makes no difference for the proceeding assessment.

2.3.2. *The change in the number of casualties*

Below, it is shown how the expected change in the number of fatalities resulting from the car-bicycle shift is computed for each type of casualty. The computations for the expected change in the number of serious road injuries can be carried out analogously, and are therefore not written out explicitly in this report.

2.3.2.1. Crashes involving cars but no bicycles

Group 1a: fatalities among drivers in single vehicle car crashes
The car-bicycle shift changes the number of fatalities in single vehicle car crashes from N_{cs} to N'_{cs}. Stratification by age and gender gives $N_{cs}(a,g)$, which denotes the number of drivers of age *a* and gender *g* killed in single vehicle car crashes. Let the risk to get killed in a single vehicle car crash as a function of age and gender, $R_{cs}(a,g)$, be defined as:

$$R_{cs}(a,g) = N_{cs}(a,g) / M_c(a,g),$$

where $M_c(a,g)$ is, as before, the distance travelled by car drivers of age *a* and gender *g*. Assuming that $R_{cs}(a,g)$ doesn't change if $M_c(a,g)$ changes, we can compute $N'_{cs}(a,g)$ resulting from the change in mobility. Indeed,

$$\begin{aligned} N'_{cs}(a,g) &= R_{cs}(a,g) \cdot M'_c(a,g) \\ &= R_{cs}(a,g) \cdot \left(M'_c(a,g) - \mu(a,g)\right) \\ &= R_{cs}(a,g) \cdot M_c(a,g) \cdot \left(1 - \varphi_c(a,g)\right) \\ &= N_{cs}(a,g) \cdot \left(1 - \varphi_c(a,g)\right). \end{aligned}$$

From this, it follows that the increase (which is in fact a decrease, hence the minus sign) in the number of casualties due to the car-bicycle shift, $n_{cs}(a,g)$, is given by:

$$\begin{aligned} n_{cs}(a,g) &= N'_{cs}(a,g) - N_{cs}(a,g) \\ &= -\varphi_c(a,g) \cdot N_{cs}(a,g). \end{aligned}$$

Denoting the *total* increase in the number of fatalities in single vehicle car crashes for all ages and both genders as n_{cs}, we get:

$$n_{cs} = -\sum_{a,g} \varphi_c(a,g) \cdot N_{cs}(a,g).$$

Group 1b: fatalities among car drivers, resulting from crashes with other parties than a car or bicycle
The number of fatalities in this group is written by $N_{co}(a,g)$ (where *o* denotes "other"). Here, *a* and *g* denote age and gender of the driver of the involved car. Because of the assumption that the mobility of other vehicles than cars and bicycles is not changing, the change in N_{co} (denoted by n_{co}) is again proportional to the change in car mobility, so, analogously to the computations for group 1a, we get:

$$n_{co}(a,g) = -\varphi_c(a,g) \cdot N_{co}(a,g) \quad \text{and} \quad n_{co} = -\sum_{a,g} \varphi_c(a,g) \cdot N_{co}(a,g).$$

Group 1c: fatalities among other road users than car occupants and cyclists, resulting from crashes with a car

We denote the number of fatalities in group 1c as $\tilde{N}_{oc}(a,g)$ where we again stratify by age and gender of the car driver, who was not killed, so therefore we added a tilde (~) to the symbol *N*. We get:

$$\tilde{n}_{oc}(a,g) = -\varphi_c(a,g)\cdot\tilde{N}_{oc}(a,g) \text{ and } \tilde{n}_{oc} = -\sum_{a,g}\varphi_c(a,g)\cdot\tilde{N}_{oc}(a,g).$$

Group 1d: fatalities among car occupants, resulting from two-car crashes

Here we have to stratify by age and gender of two different drivers. One drives car c_1 of which the driver is killed, the other drives car c_2. After a car-bicycle shift, both drivers drive less, by an amount $\varphi_c(a_1,g_1)$ and $\varphi_c(a_2,g_2)$ respectively (with a_1 and g_1 the age and gender of the driver of car c_1, and a_2 and g_2 the age and gender of the driver of car c_2). This gives a double effect on the expected new number of fatalities. Both effects are calculated separately. We first calculate the decrease in fatalities due to a change in mobility of possible casualties. Let $N_{cc}(a_1,g_1)$ be the number of fatalities in cars c_1 resulting from a crash with another car (c_2, of which not necessarily an occupant is killed). The changes in this number due to the car-bicycle shift is denoted by n_{cc} and computed as follows:

$$n_{cc} = -\sum_{a_1,g_1}\varphi_c(a_1,g_1)\cdot N_{cc}(a_1,g_1).$$

Next, let $\tilde{N}_{cc}(a_2,g_2)$ be the number of fatalities in the other car (c_2). So it is the number of fatalities among occupants of cars which crashed in which at least one occupant was killed (c_1). The effect of the change in car mobility in this number is denoted by $\tilde{n}_{cc}$ and computed as follows:

$$\tilde{n}_{cc} = -\sum_{a_2,g_2}\varphi_c(a_2,g_2)\cdot\tilde{N}_{cc}(a_2,g_2).$$

The total effect is the sum of n_{cc} and $\tilde{n}_{cc}$, equal to

$$n_{cc} + \tilde{n}_{cc} = -\sum_{a,g}\varphi_c(a,g)\cdot\left(N_{cc}(a,g) + \tilde{N}_{cc}(a,g)\right).$$

Note, however, that this is *not exactly* equal to the decrease of the number of fatalities in car-car crashes resulting from a change in car mobility. Indeed, fatalities in crashes in which both drivers shift to cycling are counted twice. As long as φ_c is small, this is a negligible error. The error yields a small overestimation of the assessed decrease in the number of car-car casualties.

2.3.2.2. Crashes with bicycles but not with cars

The next four groups concern cyclists. The computations are exactly the same as the computations for car drivers. Similar notations are used, the index c is however replaced by b for bicycle. For each group only the resulting changes in the number of fatalities are given.

Group 2a: fatalities in single vehicle bicycle crashes

$$n_{bs} = \sum_{a,g} \varphi_b(a,g) \cdot N_{bs}(a,g).$$

Group 2b: casualties among cyclists, resulting from crashes with other parties than a car or bicycle

$$n_{bo} = \sum_{a,g} \varphi_b(a,g) \cdot N_{bo}(a,g).$$

Group 2c: casualties among other road users than car occupants and cyclists, resulting from crashes with a bicycle

$$\tilde{n}_{ob} = \sum_{a,g} \varphi_b(a,g) \cdot \tilde{N}_{ob}(a,g).$$

Group 2d: casualties among cyclists, resulting from two-bicycle crashes

$$n_{bb} + \tilde{n}_{bb} = -\sum_{a,g} \varphi_b(a,g) \cdot \left(N_{bb}(a,g) + \tilde{N}_{bb}(a,g)\right)$$

2.3.2.3. Crashes with bicycles and cars

For casualties in crashes between bicycles and cars, the effects of the decreasing car mobility and the increasing bicycle mobility have to be taken into account. We still assume φ_c and φ_b to be small, so that we can assume that the effects are linear. We thus assume that the number of car drivers does not change when estimating the effect of a car-bicycle shift on the number of casualties among cyclists and vice versa.

Group 3a: fatalities among cyclists, resulting from a crash with a car
The number of cyclists killed due to crashes with cars is influenced by the mobility of bicycles as well as the mobility of cars. The increasing bicycle mobility will lead to an increase in the number of fatalities, whereas the decreasing car mobility will lead to a decrease in this number. Let $N_{bc}(a,g)$ denote the number of fatalities among cyclists of age a and gender g in a crash with a car and let $\tilde{N}_{bc}(a,g)$ denote the number of fatalities among cyclists in a crash with a car, where the driver of that car has age a and gender g. Then, analogously to the computations for crash group 1d (and crash group 2d), the increase in the total number n_{bc} of fatalities among cyclists in crashes with cars is computed as follows:

$$n_{bc} = \sum_{a,g} \left(\varphi_b(a,g) \cdot N_{bc}(a,g) - \varphi_c(a,g) \cdot \tilde{N}_{bc}(a,g)\right)$$

Again, a small error occurs, as the extra cyclists of age *a* and gender *g* cannot crash with themselves in a car. Due to this error we perforce slightly underrate the decrease in the number of fatalities.

Group 3b: fatalities among car occupants, resulting from a crash with a bicycle.
This is a very small group because usually, in a collision between a bicycle and a car, the cyclist is hurt, and the car occupants are not. Nevertheless we estimate these numbers. In the same way as in Group 3a we find:

$$n_{cb} = \sum_{a,g} \left(\varphi_b(a,g) \cdot N_{cb}(a,g) - \varphi_c(a,g) \cdot \tilde{N}_{cb}(a,g) \right)$$

In this formula, $N_{cb}(a, g)$ denotes the number of fatalities among car drivers with age *a* and gender *g* and $\tilde{N}_{cb}(a,g)$ denotes the number of fatalities among car drivers who crashed with a cyclist of age *a* and gender *g*.

3. Data

In this chapter we discuss the data that is used for the actual computations. *Section 3.1* describes the mobility data and *Section 3.2* the data about casualties.

3.1. Mobility data

The mobility data for the computations is obtained from the National Travel Survey (OVG, DVS). The OVG uses a sample of households, and each person within these households is requested to record all journeys made on a particular day. Age and gender of the persons are known, where age is binned in age groups. Some other variables recorded are trip length and mode of transport. Road type is not available.

To calculate the safety effect of a car-bicycle shift, we analysed data on mobility, in two biennial periods: 1999-2000 and 2005-2006. The total car and bicycle mobility in these two periods is given in *Table 3.1*, expressed in distance travelled in billions of kilometres. The table distinguishes short and long trips. Except for short car trips, mobility increased.

	1999-2000	2005-2006
Car 0-7.5 km	191.51	185.90
Car >7.5 km	1,521.40	1,649.81
Bicycle 0-7.5 km	117.06	126.62
Bicycle >7.5 km	63.56	70.19

Table 3.1. *Distance travelled (in billions of kilometres) by cars and bicycles on short and long trips for the periods 1999-2000 and 2005-2006.*

For the computations in this report we need to separate the distance travelled for males and females, as well as for different age groups. This is also available in OVG. *Figure 3.1 and Figure 3.2* show the numbers. From *Figure 3.1* it follows that males travel a far larger amount of kilometres by car than females, especially in long car trips. *Figure 3.2* shows a completely different picture. Females travel a far larger amount of kilometres by bicycle than males. It follows that most bicycle trips are shorter than 7.5 km.

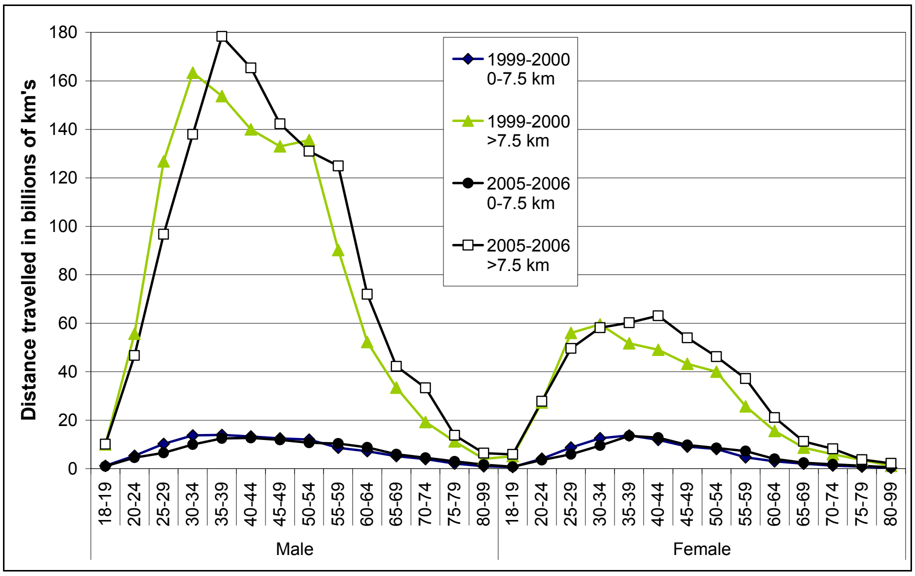

Figure 3.1. *Distance travelled on short and long car trips in 10^9 km for males and females in different age groups and for the periods 1999-2000 and 2005-2006 (OVG).*

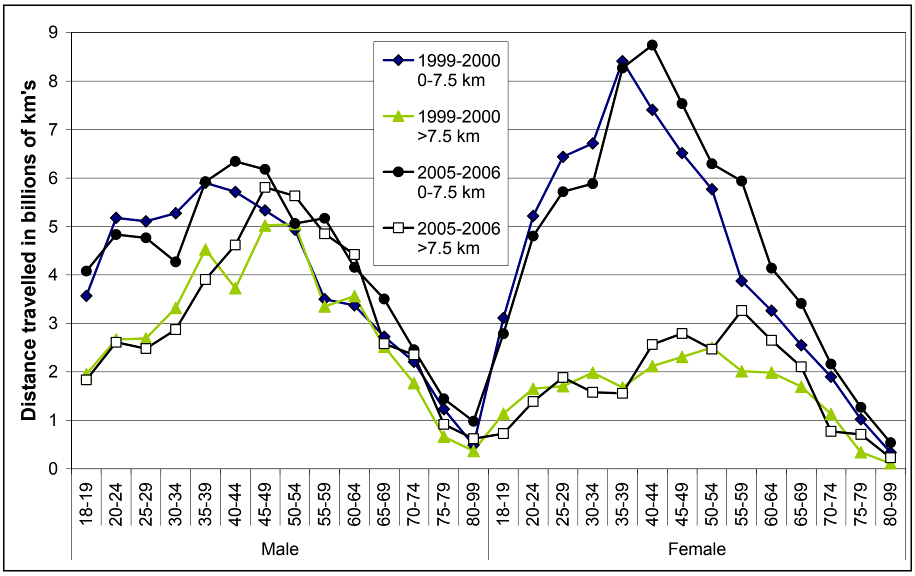

Figure 3.2. *Distance travelled on short and long bicycle trips in 10^9 km for males and females in different age groups and for the periods 1999-2000 and 2005-2006 (OVG).*

3.2. The number of casualties

The number of fatalities and of serious road injuries can be obtained from police record data (BRON, DVS). For all crashes, age, gender and traffic mode of the parties involved are registered. Thus, the conflict types are also known. For most of the conflict types, the number of casualties registered in the police registration are reasonably accurate (registration rate of 93% for fatalities, and 80% or more for the severely injured), except for hospitalized cyclists in crashes in which *no* motor vehicle is involved. These numbers are grossly underestimated by police registration, possibly because they are often not reported to the police in the first place. Recent research indicates that only 4% of these casualties are registered by the police (Reurings & Bos, 2009). Therefore, these numbers are estimated by a different method.

Data from the National Medical Registration (LMR, Prismant) is used to estimate the number of hospitalized cyclists in crashes in which *no* motor vehicle is involved. The hospitalized are registered in the LMR by age, gender and several other variables such as traffic mode and injury severity. The LMR distinguishes between crashes in which motor vehicles are involved and crashes in which no motor vehicles are involved. According to emergency room surveys, 70% of the crashes where *no* motor vehicles are involved are single vehicle bicycle crashes (Van Kampen, 2007). The remaining part of these are mostly crashes between two bicycles. Of the latter group, we do not know the age of the other cyclist. We therefore cannot treat this group as group 2d (the number of casualties among cyclists, resulting from two-bicycle crashes). Instead, we treat all hospitalized cyclists as if belonging to group 2a (casualties in single vehicle bicycle crashes). By doing so, we perforce slightly underrate the effect of extra cycling because we ignore the quadratic effect of mobility on the increase in the number of bicycle-bicycle crashes.

An exploratory analysis showed that about one fourth of the hospitalized cyclists registered in the LMR as a casualty of a crash in which *no* motor vehicles were involved actually had a crash with a car (Reurings, Bos & Van Kampen, 2007). Therefore, 75% of the number of LMR registered, hospitalized cyclists in crashes in which *no* motor vehicles were involved, were used in this analysis.

The number of hospitalized cyclists in a single vehicle crash is very large. In fact it strongly dominates the assessment for hospitalized cyclists. To make sure that all those hospitalized are really seriously injured (something we do not know if we use police registered data (BRON, DVS) only), we only use the number of injured persons with an injury severity of at least 2 on the internationally used injury severity scale (MAIS). For all *other* serious road injuries in this calculation, we do not make this correction. This overestimates the number of other serious road injuries, as compared to cyclists, because, in those cases, also minor injuries (less than 2 on the MAIS) are counted. On the other hand, these data are not corrected for police underreporting, as the cyclist data are. The hospital data on cyclists are more accurate (there is less underreporting) than the police record data. We assume that the effects of overestimation and underreporting approximately level out.

As some of the numbers of casualties are quite small, we used police record crash data for the period: 1999-2006. For serious road injuries we used data for 1997-2005, as these were the only data available. By doing this, we ignore the fact that the development in time might be different for different groups. Still, as a first estimation of the order of magnitude of the effect, this approximation is a useful indication. The number of casualties (fatalities and serious road injuries) per group (see *Section 2.2*) are given in the appendix.

4. Results

4.1. Mobility change

The fractional decrease of car mobility as a function of age and gender is computed for the situation in which 10% of the short trips (less than 7.5 km) by car drivers are substituted with bicycle trips, see *Figure 4.1*. Mobility related to short trips is a small percentage of total mobility (10% - 20%), so that a 10% shift of these short trips from car to bicycle reduces car mobility by just 1 or 2 %. The fractional decrease in car mobility becomes stronger with age, both for males and females. The mobility change for women is larger than for men, indicating that female car mobility generally consists of shorter trips than male car mobility.

The fractional decrease of car mobility is computed for two periods, namely 1999 and 2006. The mobility exchange fractions were almost alike for both periods. Thus, for mobility, averaging over eight years does not have any consequences.

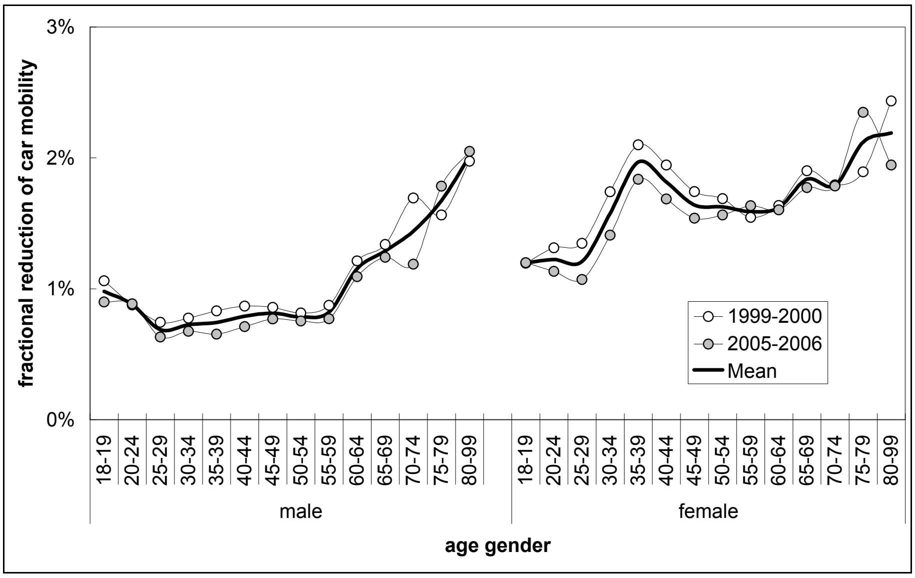

Figure 4.1. *The fractional reduction of car mobility by age and gender, if 10% of the short passenger car trips (shorter than 7,5 km) are substituted with bicycle trips.*

A small reduction in car mobility (between 1% and 2%) results in a large increase of bicycle mobility (about 10%), see *Figure 4.2*. The relative increase in bicycle mobility is much larger than the relative decrease in car mobility, since the total mobility of bicycles is roughly one tenth of that of passenger cars. For cyclists, the relative increase is highest for 30- to- 40-year-old men and women, and lower for young drivers and elderly drivers. For young drivers the relative increase is relatively low, because they cycle a lot.

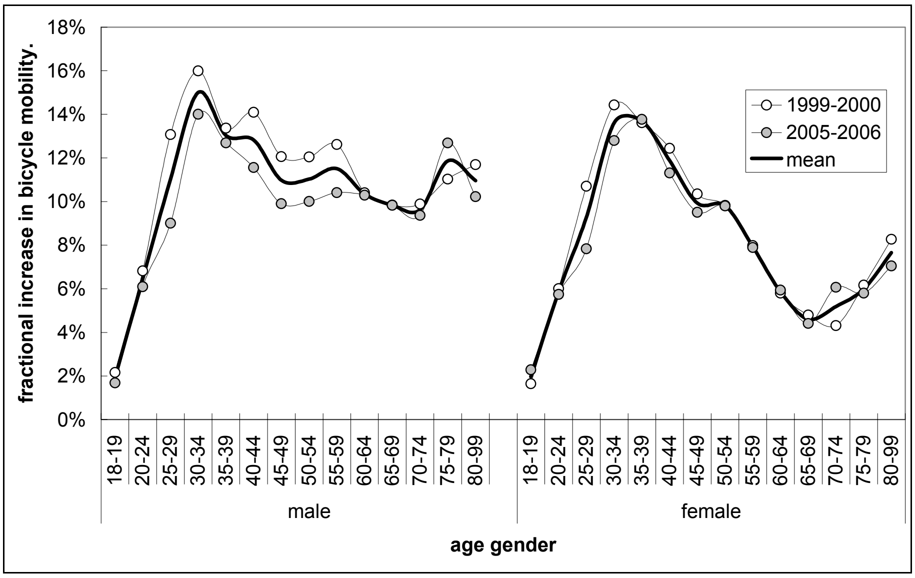

Figure 4.2. *The fractional increase of bicycle mobility by age and gender, if 10% of short passenger car trips (shorter than 7,5 km) are substituted with bicycle trips.*

4.2. The change in the number of fatalities and serious road injuries

For every group of casualties mentioned in *Section 2.4.3*, the change in the number of fatalities and serious road injuries due to the car-bicycle shift is determined. This is done for the same time period 1999-2006. The change in the number of fatalities and serious road injuries is a fraction, or a sum of fractions of the current number of casualties (which are given in the appendix) according to the equations in *Section 2.3.2*. These fractions, derived from the exchange in mobility, are given in *Section 4.1*.

The results stratified by age are shown in *Table 4.1* for male casualties and *Table 4.2* for female casualties. For example, the effect of the increase of bicycle mobility on fatalities among male drivers aged 18-19 is an increase of 0.4 fatalities, whereas the effect of the decrease of car mobility on the same fatalities is a decrease of 2.4 fatalities. Overall, the mobility shift considered in this report will lead to a decrease of two fatalities among male car drivers aged 18-19.

In this first approximate assessment, the total gain is negative for fatalities, which means that there is an increase. The car-bicycle shift is beneficial for young drivers, and detrimental for elderly drivers. Also, it is more beneficial for males than for females. The turning point lies approximately around the age of 35. For serious road injuries, due to the strong influence of the many hospitalized cyclists in non motorized vehicle crashes, there is a strong negative overall effect, and only the car-bicycle shift for 18- and 19-year-old males would result in a positive effect.

	Male drivers, fatalities			Male drivers, hospitalized		
Age	Effect of φ_b	Effect of φ_c	Net effect	Effect of φ_b	Effect of φ_c	Net effect
18-19	0.4	2.4	-2.0	17.1	25.6	-8.5
20-24	2.5	6.6	-4.2	101.7	66.6	35.1
25-29	2.0	3.2	-1.2	158.3	40.6	117.7
30-34	3.1	3.6	-0.4	241.2	39.8	201.3
35-39	5.3	2.5	2.9	247.5	35.3	212.2
40-44	4.5	2.4	2.1	278.8	31.2	247.6
45-49	4.6	2.0	2.6	258.6	26.0	232.6
50-54	5.5	1.9	3.6	278.5	23.0	255.5
55-59	5.6	1.5	4.2	251.1	20.6	230.5
60-64	5.0	1.3	3.7	183.0	19.7	163.3
65-69	7.5	1.4	6.1	171.5	18.1	153.4
70-74	8.1	1.6	6.5	184.3	17.9	166.4
75-79	11.7	1.4	10.4	250.7	15.4	235.3
80+	15.7	2.8	12.8	250.8	17.4	233.4
Total	81.6	34.6	47.0	2872.9	397.2	2475.8

Table 4.1*. The expected change in the number of killed and hospitalized male casualties (in eight years) due to an increase in bicycle mobility (φ_b) and decrease in car mobility (φ_c).*

	Female drivers, fatalities			Female drivers, hospitalized injured		
Age	Effect of φ_b	Effect of φ_c	Net effect	Effect of φ_b	Effect of φ_c	Net effect
18-19	0.3	0.5	-0.2	13.9	9.0	4.9
20-24	1.1	1.6	-0.6	68.0	34.5	33.5
25-29	1.6	1.6	-0.1	97.9	32.4	65.5
30-34	2.3	1.7	0.6	140.8	42.9	97.9
35-39	1.9	2.0	-0.1	166.7	49.3	117.4
40-44	2.4	1.7	0.7	183.5	37.0	146.5
45-49	2.4	1.5	0.9	163.9	27.0	136.9
50-54	2.7	0.9	1.8	201.9	21.1	180.8
55-59	2.8	1.1	1.7	187.1	17.4	169.7
60-64	2.5	0.6	1.9	131.0	11.1	119.8
65-69	2.2	0.7	1.5	129.0	10.3	118.7
70-74	2.3	0.6	1.8	169.4	7.5	161.9
75-79	3.9	0.7	3.2	186.4	8.0	178.4
80+	3.4	0.7	2.8	163.6	6.4	157.2
sum	31.9	16.0	16.0	2003.1	313.8	1689.3

Table 4.2*. The expected change in the number of killed and hospitalized female casualties (in eight years) due to an increase in bicycle mobility (φ_b) and decrease in car mobility (φ_c).*

5. Discussion and conclusion

5.1. Discussion

The presented assessment of the effect of a car-bicycle shift is to be considered a first rough estimate. The assumptions on which the presented calculations are based, may give an incomplete picture of what actually happens in a mobility exchange. Several effects have not been taken into account. Some of them have already been mentioned in *Section 2.1*. Below, it will be indicated what the consequences are of ignoring these effects on the estimates.

5.1.1. *Road type*

Stratification of crashes and mobility by road type has not been applied. It is known that a large part of car mobility takes place on motorways, while most of the severe crashes take place on urban roads and urban streets. It is highly probable that short trips hardly influence motorway mobility, so the reduction of the number of fatalities and serious road injuries is expected to be significantly higher. Unfortunately, there are no accurate data available on mobility by road type, age and gender.

A simple estimation of the order of magnitude of this effect would be, that the effect on the reduction of car-involving crashes would be doubled, as if φ_c were doubled. This estimation is based on the assumption that about half of the car mobility takes place on motorways, and the simplification that the relevant crashes occur on non-motorways. This would approximately double the positive effect on car-involving casualties, and therefore reveal a possibly indifferent effect for fatalities, instead of a negative effect. The negative effect on serious road injuries would possibly still be very large, because relatively many casualties occur in crashes where no motorized traffic is involved (falling off one's bike, bicycle-bicycle crashes etc.). These crashes might, as far as we know, occur even on very safe roads.

As a first improvement of what would happen if we could accurately stratify our data by road type, it could be assumed that motorways are not used for short trips. Combined with gross estimations of the amount of mobility on motorways (42%, see e.g. Schermers & Reurings (2009), p107-108), an improved calculation is possible. Then, the stratification of mobility by age and gender has to be assumed equal for different road types.

Based on these assumptions, we calculated the effect of a 10% exchange of short car trips for bicycle trips. To do so, we considered crashes on roads with a speed limit of up to 80km/h only. Further, in our calculation, we replaced φ_c as used in *Figure 4.1* by higher values: the original values were divided by 0.58 (=1-0.42).

The results are shown in *Tables 5.1 and 5.2.* As compared to *Tables 4.1 and 4.2* (where short trips were supposed to take place on all roads proportionally), the net effect of a car-bicycle shift is less negative. The increase in the number of fatalities has about halved. The increase in the number of serious road injuries, however, has hardly changed. This is because this number is dominated by bicycle crashes in which no motorized vehicle is involved.

	Male drivers, fatalities			Male drivers, hospitalized		
Age	Effect of φ_b	Effect of φ_c	Net effect	Effect of φ_b	Effect of φ_c	Net effect
18-19	0.4	4.0	-3.5	18.2	41.6	-23.4
20-24	2.3	10.2	-7.9	107.4	104.1	3.3
25-29	2.0	4.7	-2.7	165.1	61.1	104.0
30-34	3.1	5.1	-2.0	248.5	59.5	189.0
35-39	5.5	3.3	2.1	257.6	53.1	204.5
40-44	4.5	3.3	1.2	290.3	46.8	243.5
45-49	4.8	2.6	2.2	269.7	39.2	230.4
50-54	5.6	2.6	3.1	288.9	34.9	254.0
55-59	5.3	2.1	3.2	259.7	31.4	228.4
60-64	4.8	1.9	2.8	187.6	30.6	157.0
65-69	7.3	2.0	5.2	174.2	28.4	145.8
70-74	8.0	2.4	5.6	187.9	27.6	160.3
75-79	11.7	2.2	9.5	253.3	24.5	228.9
80+	15.6	4.2	11.4	254.1	27.1	227.0
Total	81.0	50.7	30.2	2962.6	609.9	2352.7

Table 5.1. *The expected change in the number of killed and hospitalized male casualties (in eight years) due to an increase in bicycle mobility (φ_b) and decrease in car mobility (φ_c), assuming that short car trips take place on roads with speed limits of up to 80 km/h only.*

	Female drivers, fatalities			Female drivers, hospitalized injured		
Age	Effect of φ_b	Effect of φ_c	Net effect	Effect of φ_b	Effect of φ_c	Net effect
18-19	0.3	0.8	-0.5	14.3	14.2	0.1
20-24	1.1	2.4	-1.3	71.6	52.9	18.7
25-29	1.6	2.3	-0.7	100.2	49.0	51.2
30-34	2.3	2.5	-0.2	145.9	65.1	80.8
35-39	1.9	2.8	-0.9	172.0	77.6	94.4
40-44	2.4	2.5	-0.2	188.0	58.5	129.5
45-49	2.4	2.1	0.3	168.4	42.3	126.1
50-54	2.6	1.3	1.3	206.4	32.9	173.5
55-59	2.7	1.6	1.1	190.3	27.8	162.5
60-64	2.5	0.9	1.6	132.2	17.7	114.5
65-69	2.2	1.0	1.2	130.4	16.3	114.1
70-74	2.2	0.9	1.3	171.0	12.2	158.8
75-79	3.9	1.2	2.8	188.0	12.7	175.3
80+	3.4	1.1	2.3	165.6	10.3	155.3
sum	31.4	23.4	8.1	2044.4	489.5	1554.9

Table 5.2. *The expected change in the number of killed and hospitalized female casualties (in eight years) due to an increase in bicycle mobility (φ_b) and decrease in car mobility (φ_c), assuming that short car trips take place on roads with speed limits of up to 80 km/h only.*

The assumption that no short car trips are made on motorways is clearly an underestimation of reality. Thus, the calculation as presented above can be seen as an approximation of the lower limit of the effect of the car-bicycle shift. On the other hand, the calculation given in *Chapter 4* can be seen as an approximation of the upper limit of the effect.

5.1.2. *Bicycle friendly infrastructure*

Perhaps a car-bicycle shift is more likely where there is sufficient specific bicycle-friendly infrastructure. In that case, the shift may lead to both shorter bicycle trips and more safe bicycle routes. This would lead to a reduction of casualties after the shift.

The estimates in this report would be different if the risks for cyclists were decreased by making the infrastructure safer for them. This can be done by reducing speeds on intersections and by bicycle facilities along roads.

5.1.3. *Bicycle trips are shorter than the car trips they replace*

A Dutch study (AVV, 2005), aimed at a similar estimation of the effect of a car-bicycle shift, suggests that bicycle trips are generally 20% shorter than the car trips they replace. In this report this possibility was not researched, but the assumption may be valid, in which case the net result of the mobility exchange would be 20% more positive.

5.1.4. *Car passengers*

When some short car trips with a driver *and a passenger* are replaced by two or more bicycle trips, this would have different safety effects. The passenger, who does not have to be of the same age and gender as the driver, bears a different risk. Such a calculation is therefore much more complicated than a calculation involving drivers only. It can be carried out with the data available, if it can be assumed that a *driver and passenger* car trip are replaced by two bicycle trips. However, it is not clear that this assumption will influence the result in a negative way. A trip with two car occupants might either lead to two bicycle trips, or to one bicycle trip. For an accurate calculation, we are required to know the reason of the car trips with passengers, and what would actually happen when these trips are exchanged for bicycle trips.

5.1.5. *Time of day*

The subject of this report originated from environmental issues (*Section 1.1*). The subject is also interesting, however, from another point of view: more cycling instead of driving will probably decrease traffic jams in rush hours. The effect on road safety of more cycling in rush hours can also be computed. This could be done analogously to the computations in this report, needing not only stratification by age and gender, but also by time of day. Again, both the mobility effect and the effect on the number of casualties are expected to depend on time of day. As both crash and mobility data are available, for age groups, gender and time of day, the computations are possible.

5.1.6. *Comparison to literature*

In 2005 the Transport Research Centre (AVV, now Centre for Transport and Navigation) conducted research to answer a similar question (AVV, 2005; van Boggelen & Everaars, 2006). Their conclusion is that a shift from car to bicycle mobility will not lead to an increase in road casualties, which is a different result than the result in this report. They used a slightly different approach to calculate the safety effect of this modal shift, which might lead to slightly different outcomes. The difference of their conclusion can, however, not be entirely explained by the difference of approach. A more likely explanation for their unchanging number of road casualties is the number of serious road injuries used in their computations. AVV (2005) only included serious road injuries registered by the police. In *Section 3.2* we explained that this is reasonable for casualties in crashes involving motor vehicles, but that hardly any serious road injuries in other crashes are registered by the police. So the risk of cyclists getting injured in a road crash used in the AVV report is far too low.

5.2. **Conclusions**

It turned out to be possible to give a first approximation of the effect on road safety of a mobility shift from car to bicycle. This approximation indicates that, in general, road safety does not benefit from this mobility shift. When 10% of the short car trips are exchanged for bicycle trips for all ages, our calculations suggest an annual increase of 4 to 8 fatalities and of approximately 500 serious road injuries.

The effect of the mobility shift is different for gender and age groups. For example, the research shows that, after a car-bicycle shift, the number of fatalities decreases for young car drivers (<35 years) but increases for older car drivers. So, especially elderly drivers are safer inside a car than on a bicycle. For the number of serious road injuries, the mobility shift increases the number of casualties for practically all ages. Only for 18- and 19- year-old males, it seems beneficial to switch to cycling. Even if the numbers mentioned above are an overestimation by a factor 2, the annual increase in the number of hospitalized injured patients would still be 250, although in this calculation only 10% of the short trips, which is just 1% of car mobility, was exchanged.

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Appendix Casualties in crashes with cars or bicycles

	1a	1b	1c	1d		2a	2b	2c	2d		3a		3b	
age	N_{cs}	N_{co}	$\tilde{N}_{oc}$	N_{cc}	$\tilde{N}_{cc}$	N_{bs}	N_{bo}	$\tilde{N}_{ob}$	N_{bb}	$\tilde{N}_{bb}$	N_{bc}	$\tilde{N}_{bc}$	N_{cb}	$\tilde{N}_{cb}$
18-19	113	10	43	16	31	1	7	1	0	3	11	32	1	0
20-24	319	64	130	42	87	2	16	2	1	2	15	108	0	0
25-29	164	44	77	36	70	0	7	1	1	2	6	76	0	1
30-34	144	47	101	33	105	4	5	0	0	1	10	65	0	1
35-39	80	41	83	17	67	4	14	1	5	3	14	44	0	0
40-44	77	34	59	37	60	4	13	3	0	2	12	37	0	1
45-49	64	38	49	21	41	4	12	2	6	3	15	29	1	0
50-54	61	36	50	23	42	6	23	1	2	1	17	31	0	0
55-59	37	25	35	26	45	10	20	1	0	1	17	13	0	0
60-64	23	20	22	19	11	6	14	2	2	1	23	18	0	0
65-69	28	20	20	19	13	8	32	2	1	2	30	10	0	1
70-74	18	37	10	23	12	4	30	2	4	1	43	10	0	0
75-79	21	25	7	20	3	6	39	0	2	1	51	6	0	0
80+	31	38	15	35	9	6	52	0	0	0	85	13	0	0

Table A.1 *Data on male driver or cyclists, fatalities in 8 years, corresponding to the groups mentioned in Section 2.3.2, and stratified by age.*

	1a	1b	1c	1d		2a	2b	2c	2d		3a		3b	
age	N_{cs}	N_{co}	$\tilde{N}_{oc}$	N_{cc}	$\tilde{N}_{cc}$	N_{bs}	N_{bo}	$\tilde{N}_{ob}$	N_{bb}	$\tilde{N}_{bb}$	N_{bc}	$\tilde{N}_{bc}$	N_{cb}	$\tilde{N}_{cb}$
18-19	13	6	3	4	5	0	7	1	0	0	9	13	0	0
20-24	37	18	27	16	15	0	13	1	0	0	4	21	0	0
25-29	28	15	30	17	26	0	7	1	0	0	9	19	0	0
30-34	18	13	23	13	21	0	11	1	0	0	5	21	0	0
35-39	19	16	25	12	19	1	10	1	0	0	2	11	0	0
40-44	13	18	21	11	13	1	7	1	0	0	11	17	1	0
45-49	22	13	17	10	16	2	14	2	1	0	5	12	0	0
50-54	9	9	11	4	14	3	12	0	1	0	12	10	0	0
55-59	16	9	12	11	10	3	18	1	0	0	13	9	0	0
60-64	9	6	8	6	3	1	24	0	0	0	18	4	0	0
65-69	6	8	7	9	5	7	20	0	6	0	15	3	0	0
70-74	3	12	3	5	4	4	14	0	1	0	26	5	0	0
75-79	4	13	5	8	2	2	25	0	1	0	38	3	0	0
80+	7	6	6	6	0	2	19	0	0	0	24	6	0	0

Table A.2. *Data on female drivers or cyclists, fatalities in 8 years, corresponding to the groups mentioned in Section 2.3.2, and stratified by age.*

	BRON														LMR
	1a	1b	1c	1d		2a	2b	2c	2d		3a		3b		2a
age	N_{cs}	N_{co}	$\tilde{N}_{oc}$	N_{cc}	$\tilde{N}_{cc}$	N_{bs}	N_{bo}	$\tilde{N}_{ob}$	N_{bb}	$\tilde{N}_{bb}$	N_{bc}	$\tilde{N}_{bc}$	N_{cb}	$\tilde{N}_{cb}$	N_{bs}
18-19	670	113	525	321	673	17	60	45	20	55	159	312	3	3	415
20-24	1668	423	1661	927	1840	34	112	68	38	83	261	1045	6	4	764
25-29	1126	357	1393	779	1486	28	105	47	33	64	192	765	6	3	749
30-34	863	337	1274	742	1472	24	93	47	34	62	231	800	2	2	857
35-39	684	285	1194	624	1246	52	115	43	50	63	238	727	5	3	1046
40-44	470	230	1086	544	1045	66	125	43	53	69	277	579	3	6	1208
45-49	331	190	852	458	899	85	155	49	64	65	319	463	5	1	1281
50-54	276	209	814	388	786	69	153	41	94	59	323	456	5	5	1395
55-59	236	158	680	360	666	69	121	29	68	35	297	402	2	1	1225
60-64	133	106	471	251	459	52	98	18	45	29	245	292	1	3	1001
65-69	130	109	367	232	348	21	125	26	36	22	240	219	6	1	976
70-74	123	122	309	235	279	35	131	18	33	12	259	176	3	2	1099
75-79	109	104	190	200	193	25	118	18	31	11	281	133	2	7	1243
80+	107	103	182	190	162	36	117	6	19	4	280	125	1	3	1397

Table A.3. *Data on male drivers or cyclists, hospitalized in 8 years, corresponding to the groups mentioned in Section 2.3.2, and stratified by age. LMR denotes hospital patient registration.*

	BRON														LMR
	1a	1b	1c	1d		2a	2b	2c	2d		3a		3b		2a
age	N_{cs}	N_{co}	$\tilde{N}_{oc}$	N_{cc}	$\tilde{N}_{cc}$	N_{bs}	N_{bo}	$\tilde{N}_{ob}$	N_{bb}	$\tilde{N}_{bb}$	N_{bc}	$\tilde{N}_{bc}$	N_{cb}	$\tilde{N}_{cb}$	N_{bs}
18-19	164	52	125	153	158	11	89	35	13	13	196	104	1	2	273
20-24	528	237	542	619	524	22	148	29	25	48	274	376	4	7	478
25-29	362	229	546	626	535	18	111	29	29	24	210	384	1	4	491
30-34	337	226	592	594	572	26	90	23	36	14	203	401	5	0	505
35-39	287	199	608	483	487	30	104	12	29	23	220	441	4	2	625
40-44	216	152	504	391	425	36	143	14	44	21	250	350	2	2	806
45-49	146	140	410	365	334	41	123	7	64	22	261	252	4	3	884
50-54	130	113	295	287	257	41	156	12	65	21	284	220	5	5	1144
55-59	106	98	264	254	197	45	158	19	74	19	310	180	1	2	1334
60-64	80	69	136	135	127	31	149	7	51	4	252	143	2	3	1327
65-69	46	60	110	148	108	39	126	7	90	13	309	87	1	0	1694
70-74	61	40	71	105	42	40	143	10	85	7	315	104	1	3	2030
75-79	51	40	70	99	58	33	123	3	76	7	276	62	3	3	1975
80+	31	31	37	102	42	26	68	2	44	4	184	48	2	1	1377

Table A.4. *Data on female drivers or cyclists, hospitalized in 8 years, corresponding to the groups mentioned in Section 2.3.2, and stratified by age of the driver. LMR denotes hospital patient registration.*