The use of travel survey data in road safety analysis

F. Van den Bossche, G. Wets and T. Brijs

PROMOTOR ▶ Prof. dr. Geert Wets
ONDERZOEKSLIJN ▶ Kennis verkeersonveiligheid
ONDERZOEKSGROEP ▶ LUC, PHL, VUB, Vito
RAPPORTNUMMER ▶ RA-2005-72

UNIVERSITAIRE CAMPUS
GEBOUW D
B 3590 DIEPENBEEK
T ▶ 011 26 87 05
F ▶ 011 26 87 00
E ▶ info@steunpuntverkeersveiligheid.be
I ▶ www.steunpuntverkeersveiligheid.be

The use of travel survey data in road safety analysis

RA-2005-72

F. Van den Bossche, G. Wets and T. Brijs

Onderzoekslijn Kennis verkeersonveiligheid

DIEPENBEEK, 2005.
STEUNPUNT VERKEERSVEILIGHEID.

Documentbeschrijving

Rapportnummer:	RA-2005-72
Titel:	The use of travel survey data in road safety analysis
Ondertitel:	
Auteur(s):	F. Van den Bossche, G. Wets and T. Brijs
Promotor:	Prof. dr. Geert Wets
Onderzoekslijn:	Kennis verkeersonveiligheid
Partner:	Universiteit Hasselt
Aantal pagina's:	19
Trefwoorden:	Exposure, road safety, travel survey, loess regression
Projectnummer Steunpunt:	1.3
Projectinhoud:	Analyse van de impact van mobiliteit op de verkeersveiligheid

Uitgave: Steunpunt Verkeersveiligheid, December 2005.

Steunpunt Verkeersveiligheid
Universitaire Campus
Gebouw D
B 3590 Diepenbeek

T 011 26 87 05
F 011 26 87 00
E info@steunpuntverkeersveiligheid.be
I www.steunpuntverkeersveiligheid.be

Samenvatting

Mobiliteit en verkeersveiligheid zijn van nature met elkaar verbonden. Nochtans is het niet altijd duidelijk hoe deze relatie in kaart kan worden gebracht, en welke hiervoor de meest geschikte gegevens zijn. In deze studie wordt een decompositie van verkeersslachtoffers voorgesteld in termen van blootstelling en risico. Deze decompositie werd uitgevoerd op de resultaten van de mobiliteitsenquêtes die in 2000 voor Vlaanderen werden opgesteld, samen met de ongevallengegevens voor hetzelfde jaar. De analyse verbetert het inzicht in het risico en de blootstelling van weggebruikers volgens leeftijd en geslacht en volgens transportmodus.

De resultaten van dit onderzoek werpen een licht op de relatie tussen mobiliteit en verkeersveiligheid. De decompositie in de tijd toont aan dat de trend in het aantal slachtoffers niet enkel wordt bepaald door een toename in de blootstelling, maar ook door een wijziging in het risico over de tijd. De decompositie volgens leeftijd en geslacht toont een lager risico en een lagere blootstelling voor vrouwelijke weggebruikers, en een schommelend patroon over de verschillende leeftijden. Als de transportmodus in rekening wordt gebracht, dan wordt duidelijk dat het aantal slachtoffers bij fietsers en voetgangers vooral wordt bepaald door een hoger risico, terwijl een hogere blootstelling aan de grond ligt van het aantal slachtoffers bij automobilisten. De conclusies op dit niveau van detail zijn nuttig wanneer men rekening wil houden met de verschillen in blootstelling en risico voor verschillende combinaties van geslacht en leeftijd en voor de grote diversiteit van transportmodi.

Summary

Mobility and traffic safety are, by nature, related. However, in traffic safety research, it is not always straightforward how this relation can be clarified, and what available data is best suited to do so. In this study, we present a decomposition of road victims in exposure and risk. This decomposition is applied to data from travel surveys for Flanders (Belgium) for the year 2000, combined with the accident records for the same year. This leads to models that enhance the insights in risk and exposure differences according to the age and gender of road users, as well as to the modal split.

The results from the analysis shed a light on the relationship between mobility and traffic safety. The decomposition in time shows that the trend in the number of victims is not only determined by the increase in exposure, but also by the level of the risk over time. The decomposition by age and gender show a lower risk and exposure for female road users, and a fluctuating pattern over the different ages. If modal split is considered, it becomes clear that the number of bicycle and pedestrian victims is mainly determined by a higher risk factor, while car user victims have a higher level of exposure. These detailed insights are useful to take into account the differences in exposure and risk for various gender-age combinations and for the diversity of modal choices.

Table of contents

1. INTRODUCTION

In Flanders (Belgium), people make 2.8 trips per day on average (Zwerts & Nuyts, 2002). On one day, they travel 33 kilometres in about 70 minutes. In itself, this is not problematic. It is impossible to do all activities at home. Mobility has become part of our social life, and we can't do without it. People have to travel to go to school, to go to work or to participate in any social or cultural activities. In fact, this is a favourable thing: the more people can move, the more they can participate in all sorts of activities, and the more they can broaden their horizons.

On the other hand, traffic also has negative consequences. As long as people travel along public roads, there have been road crashes and victims. Although the local and federal governments in Belgium put in a great effort to increase traffic safety, also in the context of their sustainable transport policy, Belgium is still one of the most unsafe countries in Europe as far as traffic is concerned. Road crashes restrict people in their own social activities, and they limit other road users in their mobility. Not to mention the high material and immaterial costs associated with road crashes.

In many countries, the main difficulty when studying the relationship between mobility and traffic safety is the availability of appropriate data. This is the main reason for writing this paper. Given the available data in Belgium and in Flanders, we investigate the possibilities to study the relationship between mobility and traffic safety. In this paper, we introduce a relatively simple model to enhance the insight in the relation between road safety and mobility. More specifically, we present some possible exploratory analyses that combine mobility and traffic safety data. In a first part, we use the yearly number of vehicle-kilometres and fatalities to decompose the traffic safety problem in a risk measure and an exposure measure. Next we use Flemish travel survey data (Zwerts & Nuyts, 2002) and accident data for the year 2000 to study the factors of mobility that determine traffic safety.

2. BACKGROUND

The basic pieces of information needed for traffic safety research are the number of crashes, the number of victims and a measure of exposure. In the COST329 report (2004), a decomposition of the number of victims is proposed in terms of exposure and risk. The classical decomposition is as follows:

$$victims = exposure \times \left(\frac{victims}{exposure} \right) = exposure \times risk$$

If exposure and risk are modelled separately, then the model is called "indirect". Estimations for the number of victims are then obtained by recombining these two parts. This approach is also followed in Bijleveld & Commandeur (2004), where an evaluation model is proposed that is based on the decomposition of fatalities in exposure and risk, using a special case of state space methods for the analysis of time series. The advantage of an indirect approach is that the number of victims can be seen as the upshot of two forces working at the same time. The outcome of an accident results from the exposure to the risk and the probability of an accident, given a certain level of exposure. Even if the risk has decreased over time, the number of victims may still be high because of an increase in exposure. Using a direct approach, these forces remain hidden.

The main objective of these models is to monitor the evolutions in traffic safety. For policy makers, it is important to explain the trends in traffic safety and, if possible, to quantify the impact of other influencing factors. These models allow predicting the trends in the number of crashes and victims, giving an indication of the effectiveness of their policy. Insight in the road accident system can be seen as a critical success factor to realise sustainable mobility and safety. In order to develop a sustainable policy towards traffic safety, trends in traffic safety should be depicted. It is well-known that different user groups (in terms of transport mode, age and gender) can have different patterns of traffic and a corresponding level of risk and exposure. When sustainable transport modes are promoted, policy makers have to make sure that these are safe and useful for the target group. It is important to find out whether a transport means is unsafe for a given user group because of a high level of exposure, or rather because of a higher level of risk. The models presented in this paper therefore try to analyse the traffic safety problem by an indirect approach in terms of exposure and risk. Examples of decomposition in time and decomposition using travel survey data will be presented. Note, however, that other methods for deriving a risk indicator are available, as demonstrated for example in deLeur & Sayed (2002).

3. DATA

For the studies in this paper, we have various sources of data at our disposal. First, we have accident data from 1973 up to 2002. These are the official numbers, published by the National Institute for Statistics. They include the number of crashes and victims, split up according to severity. If more details on crashes are required, we can use data from the detailed (Flemish) crash database, containing all information from the crash report, including gender and age of the victims.

Second, data on the mobility of road users are needed. Researchers use various indicators of exposure like the total distance travelled, the duration of travel or the number of trips. For Belgium, we have the yearly number of vehicle-kilometres from 1970 up to now (Verkeerstellingen 2002, 2003). If, however, more detailed mobility data is desirable, travel surveys can be used (Wolfe, 1982). In the Flemish travel survey 2000-2001 (Zwerts & Nuyts, 2002), trips of road users (car drivers, car passengers, pedestrians, bike and motorbike riders, public transport users) were registered in the period from January 2000 to January 2001. It is based on a random sample of 2823 households, including 7638 people who were more than 6 years old. In total, 21031 trips were registered. All people in the survey were given diaries to record the details of trips made during two specified days of the survey period, but only the data of the first registration day is used in the analysis. Since data was recorded on person level, also the age and gender of the respondents is available. From the travel survey data, an exposure measure (the number of kilometres travelled) is derived for various user groups based on the average daily number of kilometres and available population statistics (population density for each age-gender combination).

Given the accident statistics and exposure measures, it seems that all necessary ingredients for a traffic safety analysis are on hand. However, there are still some remarks. First, mobility and accident information are two different data sources. Usually there are no mobility data available related to the exact place and time of an accident. Therefore it is not always possible to find a clear link between both. Second, travel surveys consist of samples of road users, while accident counts are observed statistics. Both sources have their own problems and limitations. For surveys, it is sometimes difficult to guarantee that all groups of road users are present in the same proportions as in the population. Accident counts are distressed by problems of under-registration and wrong or incomplete accident information. Third, travel surveys are conducted with the objective to gain insight in the travel habits of citizens, and rarely if ever to increase (the knowledge on) traffic safety. Some questions will be irrelevant for traffic safety research, and other important questions will not be asked. Fourth, depending on the frequency of the surveys, not all kinds of safety analysis can be conducted. If the surveys are not repeated on a regularly basis, they are useless in evolutionary studies of mobility and traffic safety, as is typically done in time series analysis, like for example in COST329 (1999) and Van den Bossche et al. (2005).

4. Classical Decomposition in Time

The exposure, the risk and the number of victims in Belgium, for the period 1973-2002 are presented in Figure 1. The thick solid lines are the observed values. The exposure is measured in vehicle kilometres (Verkeerstellingen 2002, 2003). The risk is calculated as the ratio of the number of victims and exposure. Starting from the curves for the number of victims, the exposure and the risk, we can model the relationship between these dimensions.

Oppe (1989) describes the number of fatalities as the product of mobility and risk. For the exposure, V_t, he uses a logistic function of time. It is assumed that exposure will still continue to grow, but at a lower and lower pace. Because of practical reasons, there must be a sort of "maximum capacity" for the traffic system. That is why an S-shaped curve like the logistic is interesting. The fatality rate R_t is assumed to be exponentially decreasing over time. This may be seen as a collective learning process (COST329, 2004), caused by the ever-increasing knowledge of the traffic safety problem and the constant improvement of the safety performance of the road transport system. In comparison with some decades ago, cars and roads are better equipped, traffic safety education has improved and legislation and enforcement have increased. The number of fatalities is then modelled as the product of exposure and risk. This approach has been applied to the yearly Belgian data on the number of persons killed and seriously injured (F_t), the exposure in terms of vehicle-kilometres driven (V_t) and the risk (R_t), being the ratio of the number of victims and exposure. The fitted curves for risk and exposure are as follows:

$$\left.\begin{array}{l} R_t = e^{at+b} + c \\ V_t = \dfrac{V_{\max}}{\left(1 + e^{pt+q}\right)} \end{array}\right\} \Rightarrow \quad F_t = R_t \times V_t$$

The values a, b, c, p, q and V_{max} are parameters to be estimated, and t is an indication of time (1973 is put equal to 1). The estimated values for the parameters are given in Table 1, together with the standard error and a 95% confidence interval for the parameters.

Table 1: Parameter estimates for exposure and risk (Belgium, 1973-2002)

Parameter	Estimate	Standard error	95% confidence limits
a	-0.0796	0.0060	[-0.0920; -0.0672]
b	4.3368	0.0225	[4.2907; 4.3829]
c	7.5908	2.0627	[3.3586; 11.8231]
p	-0.0633	0.0053	[-0.0742; -0.0525]
q	1.1685	0.0944	[0.9749; 1.3621]
V_{max}	139.5	12.2843	[114.3; 164.7]

The results are shown in Figure 1. The full lines are the estimated outcomes from the models, surrounded by the 95% confidence intervals. The curves show the decisive factors in the evolution of traffic safety. While exposure is still increasing, risk is going down. As a result, fatalities are going down, but the decrease is getting smaller. The better the traffic safety situation, the more efforts are needed to make further improvements.

The graphs also show the predictions up to the year 2010. The European Commission, as well as the Federal and Flemish government in Belgium, formulate the objective to reduce traffic fatalities by 50% (European Commission, 2001; SGVV, 2001; Mobiliteitsplan Vlaanderen, 2001). Looking at our model, the estimated number of persons killed or seriously injured for the reference year 1999 is 1455. In 2010 this number amounts to 1222, which is still more than the target. This shows that it will require a great deal of effort to achieve the objectives.

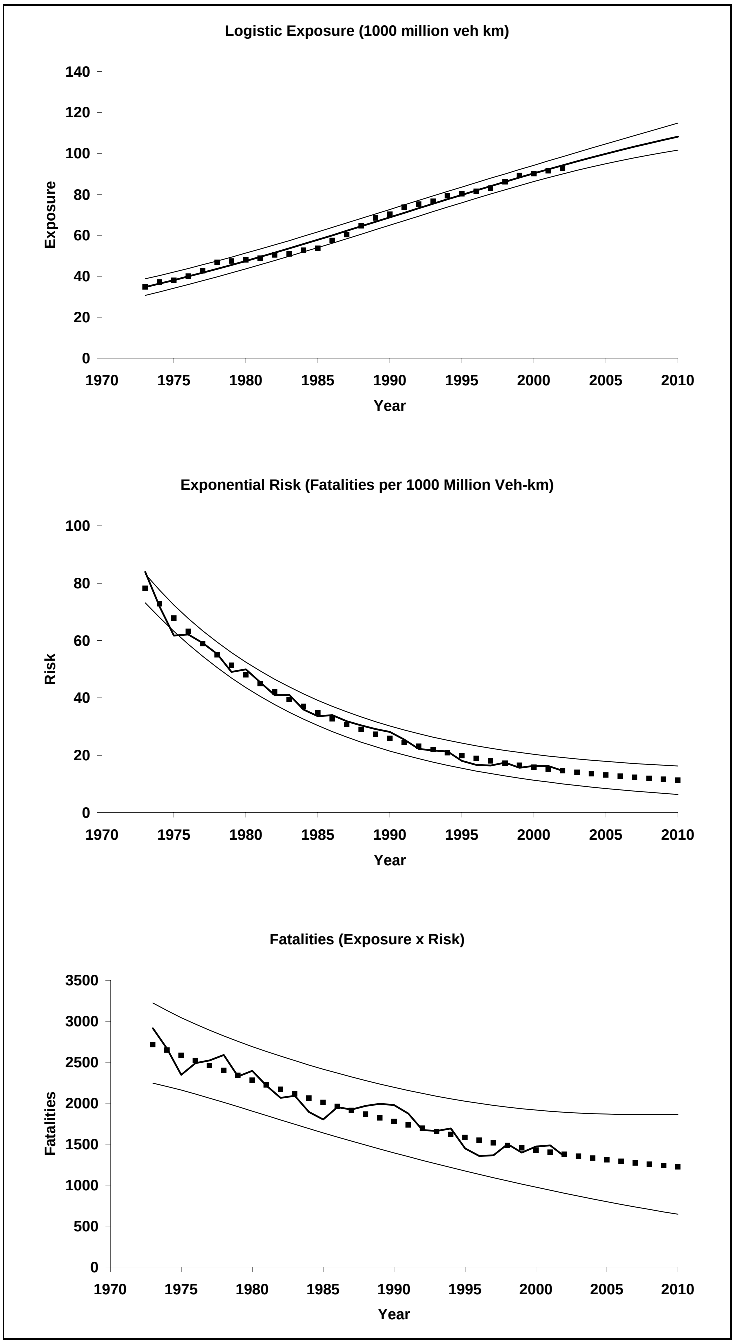

Figure 1: Decomposition of the Number of Victims (Belgium, 1973-2002)

5. TRAVEL SURVEYS AND ROAD CRASHES

When data over time are not available, it is impossible to study trends as was done above. However, even without time series data, interesting aspects of the relationship between exposure and risk can be discovered. In this section, we show that the decomposition principle can also be applied to criteria other than time. For example, if we are interested in the distribution of fatalities over age and gender, we can calculate a measure of exposure and an indicator of risk for each age-gender category. The product of exposure and risk will again provide an estimate of the fatalities. This approach can be useful to extend the insight in the accident generating process for a given age category. A similar study was presented in deLeur & Sayed (2002) and in Toomath & White (1982), where information on driving patterns is used in association with reported injury crashes to determine exposure-adjusted accident rates by age and gender group.

Using the data of travel surveys for Flanders (Zwerts & Nuyts, 2002), we can create a measure of exposure for different age and gender groups for the year 2000. Together with the road accident records for the same period, a risk indicator can be constructed, and decomposition can be done. For example, the product of risk and exposure for male persons of 25 years old should result in a corresponding number of victims. In comparison with the decomposition over time, the curve-fitting exercise is more complex. It is expected that exposure will be higher for the working category of people, and lower for younger and older persons. Also the risk will not be continuously decreasing, but will be higher for younger and older people and for vulnerable road users in general. Therefore, the nonparametric LOESS method for estimating regression surfaces is used (Cleveland et al., 1988; Cleveland & Grosse, 1991). This method can be used for situations in which no suitable parametric form of the regression surface can be found.

Assume that a dependent variable y_i and an independent variable x_i are related by $y_i = g(x_i) + \varepsilon_i$, where g is the regression function and ε_i the random error, then g can be locally approximated by fitting a regression surface to the data points within a chosen neighbourhood of the point x. Weighted least squares is used to fit linear or quadratic functions at the centres of the neighbourhoods. Each neighbourhood contains a fraction of the data, which is determined by the smoothing parameter. Data points in a given local neighbourhood are weighted by a smooth decreasing function of their distance from the centre of the neighbourhood (Cohen, 1999). The selection of the smoothing parameter determines the fit of the model. If this parameter is too low, the data is overfitted. If it is too high, an overly smooth fit is obtained, loosing essential features of the data.

In the study, the smoothing parameter is chosen to minimize AICC, a bias corrected AIC criterion (Hurvich et al., 1998), which balances between smoothness of the fit and complexity of the model. The LOESS model fitting is done in SAS (SAS Institute, 2004). The dependent variables are exposure and risk, for male and female road users respectively. The independent variable is the age of the road users, starting at 10 and ending at 69 (due to data restrictions in the travel survey). Table 2 contains the parameter estimates for exposure and risk, for both male and female road users.

Table 2: Model characteristics for exposure and risk (Flemish data, 2000)

Group	**Equation**	**AICC**	**Smooth**
Male	Exposure	11.1995	0.5250
	Risk	-5.1154	0.1417
Female	Exposure	10.6536	0.2750
	Risk	-4.9823	0.2250

Figure 2 shows a decomposition of the number of victims in risk and exposure, for each age and gender combination.

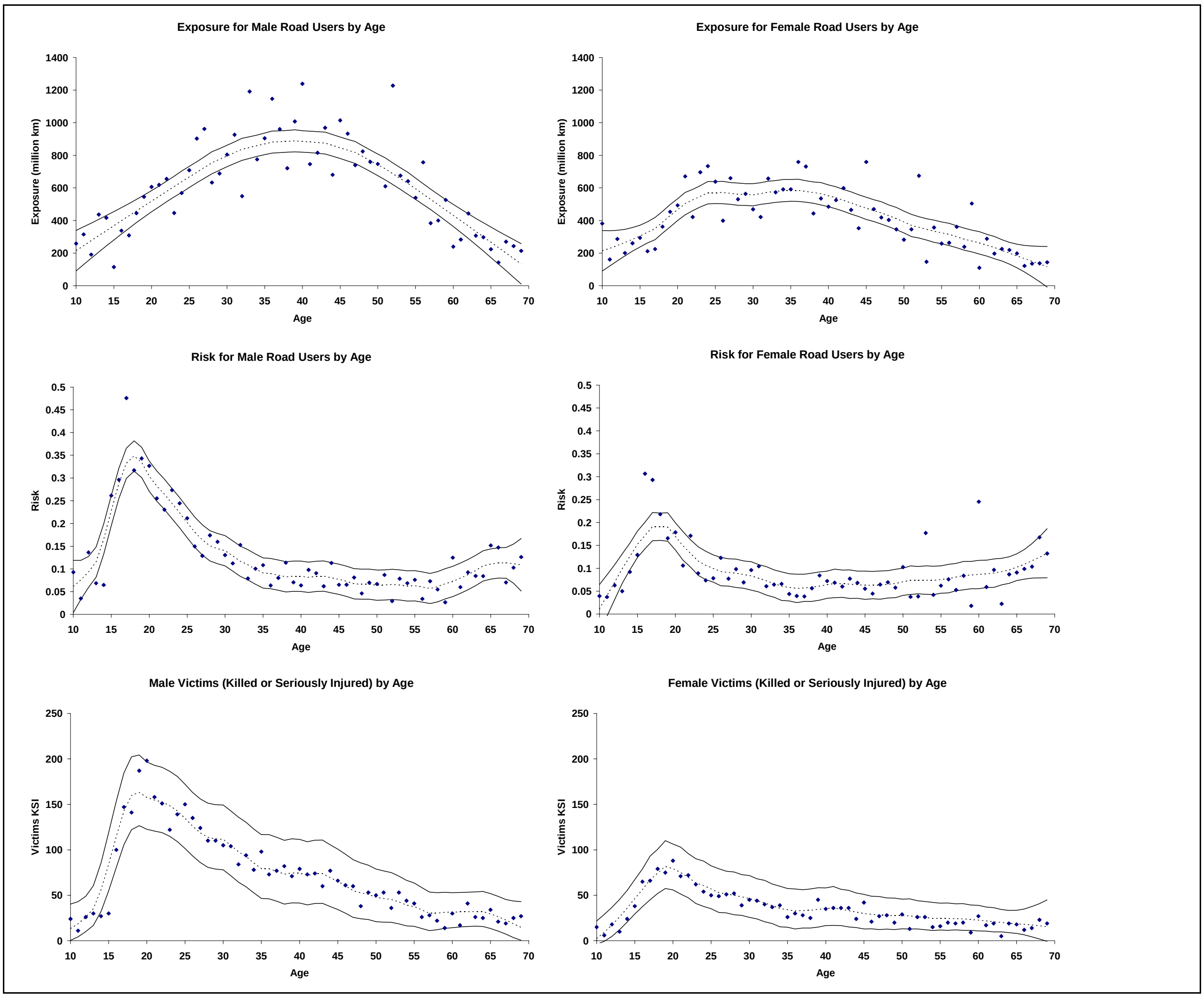

Figure 2: Exposure for Male and Female Road Users (Flemish Data, 2000)

The curves give an acceptable fit with the data. For exposure, it is reasonable to assume that both younger and older people are less exposed to risk, because of their lower frequency of travel. The estimate for the victims is again the product of the estimates for exposure and risk. Some interesting insights can be gained from this decomposition. First, persons between 15 and 25 years old are high risk road users. The risk stays at more or less the same level from age 40 up to age 60 and starts going up then for the elderly. Even if their exposure is lower, they have a higher probability of being killed or seriously injured. These risk pictures clearly show how vulnerable the younger and older road users are. Second, the highest exposure is found for people between 30 and 50 years old. This is the class of people who is working and is at the same time socially active. Their activities result in a higher number of kilometres driven. For this group of persons, the number of victims is more determined by exposure than by risk. Third, the risk and exposure for female road users is lower than for male road users of the same age. This indicates that women are less frequent road users, and if they are, their probability of being killed or seriously injured in an accident is lower.

6. Modal Split and Road crashes

Another advantage of travel surveys is that detailed information on travelling choices is available, like for example the modal split, for each category of age. It is expected that younger people will travel more as passenger of a car, while at later age they will go by bike or drive a car themselves. This information can also be linked with the number of victims of the various modes of transport. In Figure 3, we show the risk, the exposure and the number of victims for car drivers, car passengers, bicyclists and pedestrians, split up by age. Because of the higher level of detail, and in order to reduce sampling errors, we use categories of ages instead of the ages themselves. The victims are again the number of killed or seriously injured people, while exposure is the number of kilometres travelled using a specific mode of transport.

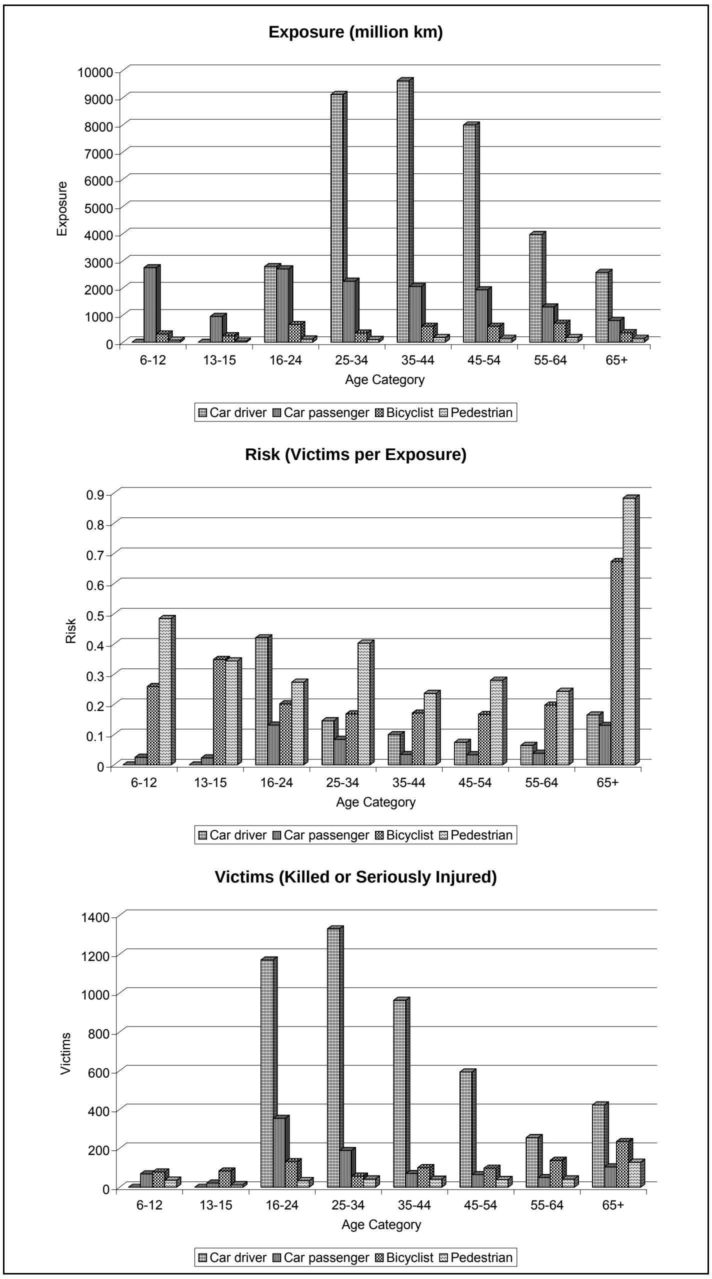

Figure 3: Decomposition of the number of victims by modal split (Flemish data, 2000)

Some interesting results are found. First, the car drivers have the highest number of victims. Exposure is largest for drivers between 25 and 54 years old. The risk is higher for young drivers, but decreases with age. This is perhaps a kind of learning effect, showing that older drivers are more experienced than younger ones. On the other hand, elderly people show a higher risk. Although studies have shown that specific driver performance skills decline with increasing age (Warshawsky-Livne & Shinar, 2002), indicating that they become less proficient in driving a car, it is reasonable to assume that the higher risk of elderly drivers stems from their reduced ability to survive injury crashes. As explained by Evans (2004), the risk of being killed in a crash is higher for older than for younger drivers. Older drivers involved in a crash are more likely than younger drivers to suffer serious injury or death. The number of victims is higher for younger people, mainly because of higher risk. For the working category of drivers, the number of victims is more determined by the higher level of exposure.

Second, car passengers show high exposure in the youngest age category. Very young children are mostly taken by car to their social or educational activities. The children of age 13-15 are less seen as passenger. They probably prefer the bike or go on foot. From the next age category on, car passengers are again more frequent, but their level decreases further with age. The risk for car passengers is highest for young (16-24 years old) and elderly people. Many young people travel together and passengers of this age category will probably be accompanied (and driven) by peers. The highest number of car passenger victims is found for youngsters between 16 and 24, mainly because of the higher risk. Third, bicyclists and pedestrians show a relatively low level of exposure over all ages. The number of victims is especially high for older bicyclists and pedestrians. Their number is still relatively low compared to car users, but the risk of vulnerable road users is remarkably high. Evans (2004) showed that, after the age of 60, the risk of pedestrian death per person increases steeply, and then again declines, likely reflecting reduced walking. The increasing involvement of elderly people in pedestrian crashes may reflect the decreasing perceptual skills and agility.

These findings are interesting for policy makers who should promote bicycle use and walking as examples of sustainable means of transport. As long as the risk of these road users is high, these modes of transport may be less attractive than any other alternative.

7. CONCLUSIONS AND FURTHER RESEARCH

For many traffic safety researchers, the main problem is finding the right sources of data. The indicators needed for traffic safety analysis are exposure, risk and the number of victims or crashes. In many countries, these data are not always available in a format that is needed for specific modeling purposes. Especially exposure data is mostly not gathered with the objective of analyzing traffic safety.

In this study, we presented some examples of the use of travel survey data for the analysis of traffic safety. Starting from the classical decomposition of the number of victims in exposure and risk over time, we extended this approach to a decomposition for traffic safety by age and gender. Instead of trends in time, this analysis shows the impact of the main indicators of traffic safety for different ages of road users. From the classical decomposition, as well as from the decomposition based on travel survey data, interesting conclusions can be drawn. For each year, or for each age-gender combination, the number of victims can be explained as the result of exposure to risk and the risk itself. The models also show which factor is most determinant. Typically for age categories, it is possible to highlight the high-risk groups. Also, exposure measures based on travel surveys are mostly more detailed than the exposure measures based on traffic counts. They allow splitting up the analysis by socio-demographic characteristics like age and gender. As shown in the paper, they are better suited to point out the safety differences in the various modes of transport.

On the other hand, the approach has some limitations. First, the travel survey data are based on a sample of road users, who registered their travel behavior for a few days. Sampling errors may influence the results, and for some subcategories by age and gender, the number of respondents may be too low to allow valid extrapolations. Second, the sample of the travel survey is by no means in accordance with the observed crashes and victims. It is quite possible that there were no crashes registered among the road users in the travel survey sample. Instead, we can only match the extrapolated sample data of the travel surveys with the observed accident counts. It is then implicitly assumed that the exposure, calculated from the travel surveys, is also representative for the exposure that (partly) causes road crashes. Third, the availability of travel survey data determines the possibilities for analysis of the traffic safety situation. If trends in the number of victims are to be studied over a long period of time, we have to make sure that the travel survey is conducted on a regular basis. In Flanders, travel surveys are only available for 2 separate years, namely 1995 (Hajnal & Miermans, 1996) and 2000 (Zwerts & Nuyts, 2002), which excludes the possibility of a reliable evolutionary study. For Belgium, only one travel survey study is known (Hubert & Toint, 2002). Given the interesting conclusions that can be drawn on the basis of this kind of analysis, there is a clear incentive to extend the frequency of conducting travel surveys in Flanders, as it is done in other countries like the Netherlands.

Based on the results of this study, it looks interesting to further investigate some topics. Instead of only looking at age, gender and modal split, it might be interesting to take into account the reasons for travel or the transport mode choice. Also, the inclusion of different types of exposure and risk in an accident analysis will provide better insights in the accident generating process. An accident between a bicyclist and a car is influenced by both the exposure and the risk of the bicyclist and the car. For a tailor-made analysis of various kinds of crashes, this information may be of high value.

The use of travel survey data, which are typically mobility-related, can greatly improve the knowledge of the relationship between mobility and traffic safety. Given the importance of exposure in traffic safety studies, this does not come as a surprise. Therefore, this relationship should be further investigated. If mobility data are gathered on a regular basis, and directed towards traffic safety, these data can provide useful insights that would remain hidden if only less detailed information is used. For policy makers, this information can steer their campaigns, and determine what kind of transport mode should be made more safe and more attractive for specific groups of road users.

8. REFERENCES

Bijleveld, F.D. and Commandeur, J.J.F. (2004). The basic evaluation model. Paper presented at the ICTSA meeting, 27-28 May 2004, INRETS, Arceuil, France.

Cleveland, W.S., Devlin, S.J., and Grosse, E. (1988). Regression by Local Fitting, *Journal of Econometrics*, 37, 87-114.

Cleveland, W.S., and Grosse, E. (1991). Computational Methods for Local Regression, *Statistics and Computing*, 1, 47-62.

Cohen, R.A. (1999). An Introduction to PROC LOESS for Local Regression, In: *Proceedings of the 24th SAS Users Group International Conference*, April 11-14, Florida, USA.

COST329 (2004). *Models for traffic and safety development and interventions. final report*. Discussion Paper EUR 20913 – COST 329, Office for Official Publications of the European Communities, Luxembourg.

deLeur, P. and Sayed, T. (2002). Development of a Road Safety Risk Index, *Transportation Research Record*, Vol. 1784, pp. 33-42.

European Commission (2001). *White paper: European transport policy for 2010 : time to decide*, Brussels.

Evans, L. (2004). *Traffic Safety*, Science Serving Society.

Hajnal, I. and Miermans, W. (1996). *Onderzoek Verplaatsingsgedrag Vlaanderen. Analyseopdracht. Eindverslag*, Provinciale Hogeschool Limburg, Departement architectuur, Diepenbeek.

Hubert, J.-P. and Toint, Ph. (2002). *La mobilité quotidienne des Belges*, Presses Universitaires de Namur, Namur.

Hurvich, C.M., Simonoff, J.S., and Tsai, C.L. (1998). Smoothing Parameter Selection in Nonparametric Regression Using an Improved Akaike Information Criterion, *Journal of the Royal Statistical Society B*, 60, 271-293.

Mobiliteitsplan Vlaanderen (2001). Ministerie Vlaamse Gemeenschap, http://viwc.lin.vlaanderen.be/mobiliteit.

Oppe, S. (1989). Macroscopic models for traffic and traffic safety. *Accident Analysis and Prevention*, Vol. 21, pp. 225-232.

SAS Institute Inc. (2004). *SAS/STAT 9.1 User's Guide*. Cary, NC: SAS Institute Inc.

Staten-Generaal voor de Verkeersveiligheid (SGVV), Verslag van het Begeleidingscomité aan het Bestuurscomité (2001).

Toomath, J.B. and White, W.T. (1982). New Zealand Survey of Driver Exposure to Risk of Accidents, *Accident Analysis and Prevention*, Vol. 14, pp. 407-411.

Van den Bossche, F., Wets,G. and Brijs,T. (2005). The Role of Exposure in the Analysis of Road Accidents: A Belgian Case-study. Forthcoming in: *Transportation Research Record*, USA.

Verkeerstellingen 2002 (2003). Federale Overheidsdienst Mobiliteit en Vervoer, Directoraat-generaal Mobiliteit en Verkeersveiligheid, Directie Mobiliteit, Brussel.

Warshawsky-Livne, L. and Shinar, D. (2002). Effects of uncertainty, transmission type, driver age and gender on brake reaction and movement time, *Journal of Safety Research*, 33, pp. 117-128.

Wolfe, A.C. (1982). The concept of exposure to the risk of a road traffic accident and an overview of exposure data collection methods. *Accident Analysis and Prevention*, 14(5), pp. 337-340.

Zwerts, E. & Nuyts E. (2002). *Onderzoek Verplaatsingsgedrag Vlaanderen (januari 2000-januari 2001). Deel 3A: Analyse Personenvragenlijst*, Provinciale Hogeschool Limburg, Departement Architectuur.