The uses of exposure and risk in road safety studies

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Summary

This report explores the theoretical possibilities of defining exposure and risk, discusses the problems associated with the use of exposure and risk and gives examples of various safety studies in which use is made of exposure and risk indicators.

The report sets out with a definition of the three central terms used: accidents, exposure and risk. Each of the three terms is defined and definition problems and problems concerning accuracy of measurement and reporting are described. The conclusion reached is that there are general definitions of exposure and of risk, as used in the field of health prevention and risk analysis, but that in road safety practice, these terms should be defined within the context of the issue studied. For each application, the correct exposure measure should be used. This is sometimes impossible on account of the unavailability of the required information, or the necessity to collect it at great cost. Generally, the more aggregate the exposure measure, the more indirect the variables that are introduced, which casts shadows over the resulting risk calculations.

In the case of transport, the most widely used measure of exposure is the number of kilometres travelled for each travel mode. In some cases, useful additional insight is provided by taking into account the speed of travel, in which case exposure is expressed as the amount of time spent in the traffic system. One of the developments in recent years has been the installation of electronic and telecommunication equipment inside vehicles and along roads. Another development is the increasingly widespread use of mobile telephones. As a result it is becoming easier to collect up-to-date and reliable information on a variety of parameters that could be of importance in the calculation of vehicle exposure and risk. Additional information on the distribution of speeds, types of vehicles and following distances also seems to be a future possibility.

One of the contexts in which the term risk is used, is in comparing risks between different parts of the transport system, different transport modes or even different activities outside the field of transport. The desire is to have various activities exposed to equal risks, so as to establish a fair distribution of risks. After discussing the various problems and pitfalls in using this approach, it is concluded that the desire for equal risks in various segments of the transportation system is not practical. It is more useful to search for ways to make each segment of the transport system as safe as possible, keeping cost-effectiveness considerations into account.

Contents

1. Introduction

Many safety studies involve the use of the terms accidents, exposure and risk. One sometimes gets the impression that the use and definition of the terms exposure and risk differ from study to study and are chosen in an ad-hoc fashion. This report explores the theoretical possibilities of defining exposure and risk, discusses the problems associated with the use of exposure and risk and gives examples of various safety studies in which use is made of exposure and risk indicators. It will be shown that there is no general definition of exposure and of risk and that these terms should be defined within the context of the issue studied. The report also deals with many of the limitations connected with the use of exposure and points out the many pitfalls that lie on the path of the correct use of the term risk in safety studies.

The report sets out the generally used definitions of the terms exposure and risk in chapter two. This is followed by a chapter on the quantification of exposure on both an aggregate level and as applying to the study of road infrastructure. Chapter 4 presents some of the general issues associated with the use of risk and exposure, over-representation, the setting of national targets and risk versus effectiveness. Chapter 5 presents and discusses a variety of examples of safety studies that use risk definitions and some safety studies that were conducted without the use of risk as a denominator to evaluate safety effects. Chapter 6 discusses, in more detail, the relationship between accidents, exposure and risk as they are applied in studies that are concerned with the safety of road infrastructure, including the relationship between accidents and traffic volumes and the issue of risk as applied to the identification of hazardous locations. Chapter 7 presents the conclusions of the report.

2. Definitions of exposure and risk

Whereas the definition of a road accident is generally well-understood in road safety literature, the definitions of the concepts exposure and risk are much less well-defined. An accident is generally defined, in this context, as an event in which at least one motor-vehicle was involved, that occurred on a public road and which resulted in injury. This definition is used because in most countries computerised systems exist for the recording of such accidents. This is also the definition mostly used by police forces to record an accident. Other road accidents are registered in other databases or are unrecorded. National differences exist in the definitions of accidents that are recorded by the police, and in the definition of accidents with casualties that are to be entered into statistical databases and definitions of the various degrees of severity of injury. International data bases do not always account for such differences in definitions. The international accident data base IRTAD, maintained by the German Federal Road Research Institute (BASt), makes an effort to report on these differences and account for them where possible.

Although many shortcomings can be identified regarding this definition of an accident, at least we are talking about a recordable event which is to a certain degree exact. As to exposure and risk, on the other hand, we first have to agree on a definition and then it remains to be seen if the accepted notions are quantifiable and reasonably exact.

2.1. Definitions of exposure

In the context of this report, exposure is meant as exposure to risk. To what extent are certain segments of the population likely to be involved in an accident? The measure of exposure is generally defined as some form of the amount of travel, either by vehicle or on foot. Once the amount of travel is known for certain activities, or road users, and if we know the number of crashes that are associated with that activity or population, the associated risk can be calculated. Risk assessments can be used to improve transport safety and determine public health priorities. ….”The various ways of measuring the amount of travel are referred to collectively as ‘exposure data’ because they measure traveller’s exposure to the risk of death or injury.” (European Transport Safety Council (ETSC), 1999)

2.2. Definitions of risk

According to the Oxford Dictionary, risk is a “hazard, chance of bad consequences, loss etc., exposure to mischance”. Collins Dictionary describes risk as “a possibility that something unpleasant or undesirable might happen; something that you do which might have unpleasant or undesirable results.” In the field of road safety the concept of risk is used as a way to quantify the level of road safety relative to the amount of exposure, as opposed to the absolute level of safety as measured by the absolute number of accidents or casualties. The literature differentiates between various kinds of risk such as personal risk, societal risk, individual risk, group risk. Other differentiations can be added such as objective risk, subjective risk, voluntary risk and compulsory risk. A treatise on the various definitions of risk in the literature, their definitions, meanings and relevance is outside the scope of this document. For our purposes, risk will be used to mean the probability of an accident occurring. Such a definition was proposed in Hauer (1982).

One element which might usefully be added to the definition of risk as a probability is taking into account the severity of the outcome of an event. This distinction is proposed in Haight (1986). Most people would agree that, whereas the probability of death in one game of ‘Russian roulette’ (one-sixth) is considerably less than the probability of heads in the toss of a coin (one-half), Russian roulette is ‘riskier’ than coin-tossing. This distinction can be achieved when adding to the probability the concept of expected costs. When the cost of the outcome of each probability is multiplied by the probability of each event, risk can be defined as an expectation. Van Poortvliet (1999) quotes a definition of risk that takes both aspects into account, i.e both the probabilistic nature of risk and the severity of the consequences: “A combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.”

Reliability engineers use the term risk to express the probability of a well-defined, hazardous event occurring. In many industrial applications the consequences of such events can be estimated by using models that cover the chemical, physical and biological effects of such a hazardous event. Thus risk analysis typically yields a set of likelihoods, accident scenarios and consequences (Van Poortvliet, 1999). The quantitative approach makes it possible to calculate the expected losses during a given period of time, usually expressed in terms of fatalities, casualties and/or material damage. In the field of road safety a similar approach is generally used. This approach is generally preferred over the qualitative approach.

Popular perception associates risk with both the probability of a hazardous event for someone involved in a certain activity and with the severity of the outcome. If an accident occurs, problems generally arise when one tries to compare situations with both different probabilities and different consequences. Therefore, it is often preferable to talk about accident rates (or casualty rates) rather than risk. When comparing accident rates, it is assumed we are talking about situations with outcomes of similar severity, otherwise the situations should not be compared.

2.3. The size of the safety problem in terms of risk and exposure

Having defined risk and exposure, it is now possible to define safety and the size of the safety problem in those terms. *Figure 1* (Rumar,1999) defines the safety problem - I as a function of exposure, accident risk and injury risk:

$I = E \times A/E \times I/A$, where
I is the number of people injured,
E is exposure,
A/E is the probability of an accident (accident risk),
I/A is the probability of being injured in an accident (injury risk).

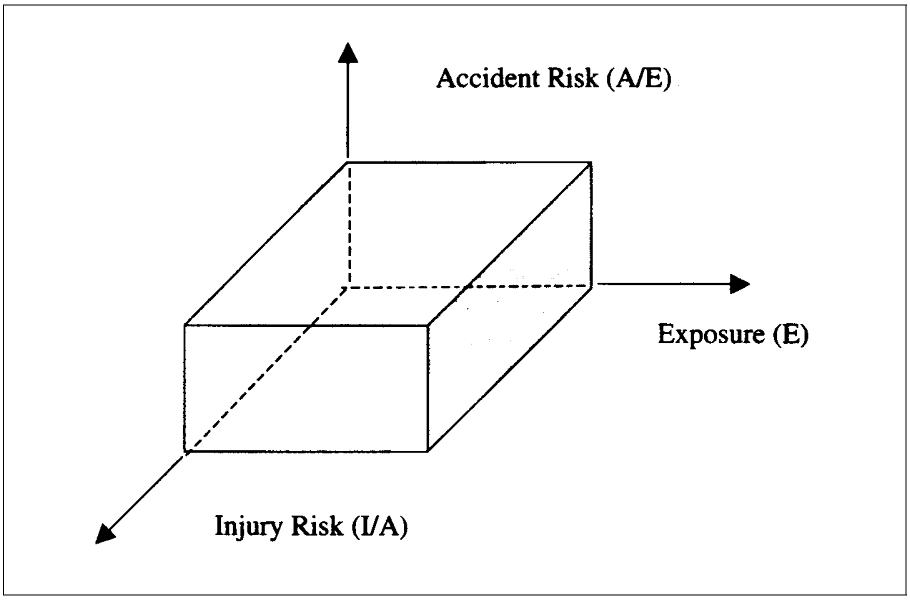

Figure 1. *The safety problem (human injury) illustrated by the volume of the box. From: Rumar (1999)*.

From this definition it becomes clear that countermeasures to improve road safety can come from activities along any one of the three axes. One can think of measures that reduce exposure, measures that reduce the risk of an accident and measures that reduce the risk of injury. It is also possible to take the time trend element into consideration. The absolute size of the safety problem, expressed in either the number of accidents or the number of casualties (SAFETY) of a certain severity results from multiplying the degree of risk, which has a trend with the exposure, which also has a trend element expressed as:

SAFETY (severity) = RISK (trend) x EXPOSURE (trend).

3. Quantifying exposure and risk

3.1. Exposure measurement

Exposure is generally expressed in a form related to the amount of travel. In most countries traffic data (volumes) are counted for traffic engineering purposes but few countries have systems of counting traffic volumes that enable comprehensive measurement of volumes on various parts of the road system, segregated by type of road user. Some countries have such systems for parts of the road system - motorways, main rural roads, major intersections, etc. Still other countries have only approximate estimates of the amount of travel, conducted on the basis of the known fuel consumption in the country.

Some countries conduct systematic counts at a series of counting sites, chosen to be nationally representative, covering all types of roads and different regions, and classifying counts according to type of vehicle and time of day. Such counts can be combined with detailed information about the road network to provide national and regional estimates of traffic volumes. Even in those countries, such estimates are generally not available on a per-city basis. Also in many cases local roads and minor roads are not included in the counting systems and the amount of travel on such roads cannot be estimated.

For the calculation of exposure by different groups of road users: car drivers, car passengers, public transport passengers, cyclists and pedestrians the information from traffic counts does not suffice. Additional information is generally obtained from national travel surveys, which are conducted in many countries with a frequency of between 5-10 years.

Data from different sources can be combined to calculate disaggregate exposure estimates for different population subgroups.

At this stage in the report, it can be said that for each application, the correct exposure measure should be used. This is sometimes impossible because the required information is not available, or has to be collected at great cost. Generally, the more aggregate the exposure measure, the more intervening variables are introduced that cast shadows over the resulting risk calculations.

3.2. Quantifying risk by hours of exposure

A number of authors have suggested that it is useful to calculate risk by hours of exposure to a certain activity (Evans, 1993; ETSC, 1999; Wesemann et al., 1998). In the case of transport, the most widely used measure of exposure is distance travelled, but it is obvious that even for transport the speed at which such travel is conducted might influence the risk. Speeds for various transport modes (walking, cycling, motorised transport) are widely different and therefore it has been suggested to normalise exposure (vehicle kms travelled) by multiplying by speed,

thereby obtaining a risk measure which is expressed as accidents or casualties per hour of exposure.
Collins (1990) provides details on accident fatality rates for various activities in transport and other fields of activity per passenger-hour and per passenger-km travelled (*Table 1*).

Transport and other activities	Fatalities per 100 million passenger-hours	Fatalities per 100 million passenger-km
Passenger travel by		
Bus or coach	1.4	0.06
Rail	6.0	0.1
Car	12.4	0.4
Water	16.0	0.8
Air	20.0	0.04
Foot	27.0	7.0
Pedal cycle	64.0	4.6
Two wheel motor vehicle	342.0	11.4
Employment		
All work	0.9	
Banking and financing	0.17	
Chemical industry	1.1	
Construction work	4.9	
All railway work	5.6	
Extraction of ores	13.0	
Being at home		
All ages	2.6	
People under 65	1.0	
People 65 and over	11.5	

Table 1. *Accidental fatality rates for transport and other activities. In Evans (1993), from Collins (1990).*

It can be seen that travel is a relatively high risk activity compared with such other activities as being at work (most kinds of work) and being at home. Large differences can be observed in the risk associated with the various travel modes, with bus and rail travel being relatively safe both in terms of vehicle kilometres travelled and hours exposed, air travel being relatively safe in terms of kilometres travelled but not in terms of hours of travel, due to the high speeds of travel. Travel by vulnerable road users, on foot, pedal cycle and motor-cycle being relatively unsafe both in terms of hours and kilometres of exposure.

Koornstra (in: ETSC,1999) also presents a risk comparison for various modes of travel aggregated for the whole of the European Union (*Table 2*).

Travel mode	10^8 person km		10^8 person hours	
	absolute	normalised	absolute	normalised
ROAD				
total	1.1	13.8	3.3	16.5
bus/coach	0.08	1	2	1
car	0.8	10	30	15
foot	7.5	93.8	30	15
cycle	6.3	78.8	90	45
mot.c/moped	16.0	200	500	250
TRAINS	0.04	0.5	2	1
FERRIES	0.33	4.2	10.5	5.3
PLANES	0.08	1.0	36.5	18.3

Table 2. *Fatality risks over distance and time for travel modes in the EU. Source: ETSC (1999). Normalised rates calculated and added by the authors.*

Taking bus and coach travel as a normative unity, it can be seen that risk expressed in terms of person-kilometres travelled is 10 times greater for cars and 100-200 times greater for the vulnerable modes (foot, cycle and motor-cycle/moped), with motor-cycles clearly being the most hazardous. Train and plane travel are also relatively safe. Looking at the same data with risk expressed in terms of person-hours of travel, the picture does not change a great deal. Travel by foot or bicycle becomes slightly less hazardous, because of the low speeds of these modes, whereas air travel becomes significantly more hazardous because of the high speeds of travel (hence the small number of hours per km of travel. Chapter 5 of the report will discuss the usefulness of making such comparisons in more detail.

Wesemann et al. (1998) suggested the use of risk per hour of exposure involved in various activities as a measure of comparison. Having collected data on accidents and fatalities at home, at work, in sports and in traffic from a variety of sources, it might be possible to calculate the risk of injury associated with these activities in terms of exposure in hours. However, for their study the detailed data needed to present such a comparison was not available. Instead, a much coarser comparison was conducted in terms of the number of individuals exposed to each activity (traffic and home). For the case of traffic accidents a calculation was presented comparing the risk of injury and fatality per distance and per hour of travel for various age groups, male and female (*Tables 3 and 4*).

Comparing results of risk in each age group per kilometre travelled and per hour exposed does not change the picture drastically. The two groups that have the higher risks, by both measures of exposure, are the young (15-24) and the old (65+). When looking at risk per hour of exposure, the risk of the young group increases and the risk of the old group decreases somewhat. This seems to indicate that the young are exposed to the risks at higher speeds.

Age	Male	Female	Total
Fatalities			
15-24	0.1520	0.0512	0.1055
25-39	0.0676	0.0297	0.0530
40-49	0.0478	0.0271	0.0403
50-59	0.0577	0.0359	0.0493
60-64	0.0821	0.0594	0.0725
65+	0.2445	0.1675	0.2059
Total	0.0884	0.0504	0.0730
Hospitalisations			
15-24	2.1633	1.2094	1.7232
25-39	0.8189	0.6016	0.7354
40-49	0.6037	0.6072	0.6050
50-59	0.7185	0.9057	0.7907
60-64	0.7948	1.2733	0.9965
65+	2.0844	2.5745	2.3300
Total	1.0559	1.0023	1.0342

Table 3. *Risk of fatality and hospitalisation per 10^7 traveller kilometres in the Netherlands, 1994-1996. From: Wesemann et al. (1998).*

Age	Male	Female	Total
Fatalities			
15-24	0.3462	0.1077	0.2313
25-39	0.2037	0.0620	0.1365
40-49	0.1366	0.0493	0.0951
50-59	0.1415	0.0603	0.1026
60-64	0.1549	0.0734	0.1120
65+	0.3395	0.1775	0.2474
Total	0.2210	0.0880	0.1553
Hospitalisations			
15-24	4.9201	2.5474	3.7801
25-39	2.4648	1.2577	1.8934
40-49	1.7259	1.1049	1.4310
50-59	1.7604	1.5216	1.6462
60-64	1.4965	1.5780	1.5393
65+	2.9030	2.7290	2.8040
Total	2.6389	1.7539	2.2021

Table 4. *Risk of fatality and hospitalisation per 10^6 hours of travel in the Netherlands, 1994-1996. From: Wesemann et al. (1998).*

3.3. The relevant measures of exposure and risk

In the context of risk calculations it is important to define and select the correct measure of exposure. The selection of what should serve as a 'correct' measure of exposure will depend mainly on the intended use. A large number of exposure variables can be selected, each suitable to a specific problem. In many cases, because of the lack of sufficiently detailed data, or the lack of accurate data, it is not possible to select the correct measure of exposure to suit a particular issue.

3.3.1. *Aggregate measures of exposure and risk*

In international comparisons and for trend studies on a national level, in many cases, the number of inhabitants or the number of vehicles is selected as the available exposure measure. Risk calculated as the number of fatalities divided by the number of inhabitants can be considered as a measure of mortality, i.e. what is the chance of death per population unit? The advantage of this risk measure is that it uses fairly reliable data which are generally widely available. It is therefore possible to conduct such international comparisons. The same cannot be said when attempting to calculate the risk of injury. Between countries large differences exist in the reporting procedures of road casualties. Various levels of under-reporting of accidents and casualties exist in different countries (Nilsson, 1997).
Defining risk as the number of fatalities (or casualties) per number of vehicles can be seen as a proxy to the risk of travel. In this context the number of vehicles is selected as a proxy to the number of vehicle-kilometres travelled which is a variable that is much more difficult to obtain reliably in many countries. Obviously, if a certain type of vehicle is considered, one should use only relevant accident figures for the type of vehicle under consideration.
One of the complications associated with this type of comparison is that the two risk measures- fatality per population unit and fatality per vehicle unit- behave very differently over time when comparing different countries. It should also be remembered that both measures are very comprehensive, not differentiating between different segments of the population (by age group, sex, urban or rural, etc.) and different types of vehicles. It is generally found that trends relating to the number of vehicles are a reasonable proxy to the number of vehicle kilometres travelled. In the literature, many studies exist reporting on risk comparisons conducted with these measures of exposure.
Such comparisons are useful in obtaining a very coarse picture of the safety situation, without contributing much to the understanding of the differences found between countries or changes over the years. For such an understanding risk calculations should be conducted on a much more detailed level.

Table 5 presents some examples of risk indicators on an aggregate level and their availability in international databases as well as the US database on fatal accidents (FARS).

	WHO	IRF	ECMT	IRTAD	EURO-STAT	FARS
Accidents/inhabitants				+		
Accidents/VehKm		+		+		
Accidents/VehKm I/O built-up areas				+		
Accidents/VehKm by road class				+		
Killed/inhabitants	+		+	+	+	+
Killed/inhabitants by age group	+			+	+	+
Killed/inhabitants by age group & sex	+				+	+
Killed/licensed drivers						+
Killed/million vehicles			+			+
Killed/million road users by road user type			+			
Killed/VehKm		+		+		+
Killed/VehKm I/O built-up areas				+		
Killed/VehKm by road class				+		
Injured/inhabitants				+	+	+
Injured/inhabitants by age group				+	+	+
Injured/inhabitants by age group & sex					+	+
Injured/ licensed drivers						+
Injured/million vehicles						+
Injured/Vehkm				+		
Injured/VehKm I/O built-up areas		+		+		
Injured/VehKm by road class				+		

Table 5. *Available risk indicators. From: DUMAS (1998).*

3.3.2. *Traffic volume as a measure of exposure*

Some form of traffic flow is generally taken as the measure of exposure when calculating risk on a certain part of the road network or for a certain type of vehicle. The most frequently used measure of exposure is the number of vehicle kilometres travelled. Details on the collection of data on vehicle kilometres travelled were given in *Section 3.1* of the report. A more detailed discussion on the relations between accidents and traffic volumes will be given in *Section 6.1* of the report. Risk levels on various parts of the road network or at various types of intersections are deduced from the ratio between accidents, casualties or fatalities and the relevant exposure measure related to traffic flow.

3.3.3. *Problems with quantifying exposure*

Most countries collect data on traffic volumes in a systematic way. These would almost certainly include traffic count data that are needed for decisions on building a new road, widening an existing one or re-designing an intersection. Some countries also have aggregated traffic counts for some parts of the road network (generally the major roads). A few countries have aggregated traffic counts which can be converted to reliable numbers of vehicle kilometres travelled, but these are subdivided for various parts of

the urban and non-urban network. When such traffic censuses are available, they can give us the necessary information on exposure, by type of road and type of vehicle, from which detailed risks can be calculated. In many other countries the alternative to a traffic census, is to measure fuel consumption on a national scale and to calculate the amount of travel on the basis of this measurement. Such calculations are open to many different error sources and generally lead to only rough estimates of the number of vehicle kilometres travelled. Such estimates can also not be subdivided into types of road. These are the major difficulties in obtaining exposure measures on a national scale. For more detailed studies, relating to a specific research question, it is generally required to collect special and dedicated exposure data. This is an expensive process and is not always feasible.
Further information can be obtained from travel surveys. Such surveys, conducted either at home or along the road, can supply further information on the number of trips people make, trip purposes, travel modes and details about the travellers. Some countries have such travel surveys and conduct them periodically every 5-10 years. Even in those countries, travel surveys generally only apply to the adult population and generally do not include trips on foot.

The lack of detailed and high quality exposure data is one of the reasons that in so many cases international comparisons are conducted on a per-capita or per-vehicle basis.

A recent report by the US Bureau of Transportation Statistics (BTS) discusses transportation data and risk measures (BTS, 2001). It states that:

> “More accurate, comprehensive and consistent measures of risk exposure could help our understanding of the relative importance of factors contributing to transportation crashes and improve our analysis of safety trends. Better exposure measures require data not only on the numbers of fatalities, injuries and accidents, but also data that indicate the overall level of transportation activity. Analyses of safety trends for non-motorised modes- bicycling and walking- suffer from the absence of exposure measures (such as hours of exposure to traffic). Moreover, bicyclists and walkers often take trips too short in length to be counted in national travel surveys. Furthermore, trips that begin and end at a residence, without an intermediate stop, are typically not counted, thus excluding much recreational bicycling and walking. Yet, more than 6,400 pedestrians and bicyclists died in 1995 in crashes involving motor-vehicles (15 per cent of all transportation fatalities)” “There is also a need for exposure information on specific populations (e.g children or elderly drivers). For example, inadequate exposure data on children under five years of age makes the evaluation of some transportation risks difficult. Moreover, better exposure measures and incident data are needed for evaluating risks associated with the transportation of hazardous materials….” (BTS, 2001).

3.3.4. *The possibilities with new information technology (IT)*

Traffic volumes
One of the developments in recent years is the installation of electronics and telecommunications inside vehicles and along the roads. The increasingly widespread use of mobile phones also presents many new possibilities. As a result it is becoming easier to collect up-to-date and reliable information on a variety of parameters that could be of importance in the calculation of vehicle exposure and risk. The amount of traffic flow can be determined by a number of IT technologies which are becoming cheaper each year. Above-ground vehicle detectors will in time become more prevalent and will become part of an ever-expanding system of traffic monitoring and control. Such systems are already well on their way along

motorways and will probably also be introduced on other types of roads and at intersections. Eventually it should be possible to develop a reliable system of traffic volume measurement on a road network-wide basis. Additional information on the distribution of speeds, types of vehicles and following distances also seems to be a future possibility.

Traffic conflicts
The study of traffic conflicts or critical situations has been carried out since the 1960's and is sometimes proposed as an intermediate estimator of risk. The argument provided is that at most locations the number of accidents is (fortunately) very small and subject to large chance variations. To be able to form an opinion on the level of safety of such a location, or the assessment of the effect of a safety improvement in a short period of time, it is important to have a method for the establishment of risk. The measurement of conflicts (which can be regarded as a proxy to accidents) is one practical method in this context. Flows can thus be related to conflicts, which are measured over a short period of several days, instead of being related to accidents, for which a number of years of data are needed. One of the drawbacks of the conflict methods (Brundell-Freij & Ekman, 1990) is that conflict measurement is a highly complicated and expensive method of data collection. With the advances in video observation, pattern recognition and automatic image processing it is becoming increasingly feasible to use automatic means of traffic observation to detect critical situations, such as conflicts or even accidents. These techniques are already being applied in systems of incidence detection on some motorways around the world.

3.3.5. *Traffic exposure at intersections*

On road sections, the number of vehicle kilometres is generally accepted as the relevant measure of exposure. At intersections, the correct measure of exposure is not that obvious, and has been the subject of many discussions.

It seems reasonable to suggest that some combination of the traffic flows on the intersecting roads is needed as the measure of exposure. The simplest combined measure is the sum of the daily traffic volumes. This is also a measure which is generally available, if traffic volumes are measured at all. But many other combinations are possible. The product of the daily flows, the sum of the products of the hourly flows, the sum of the products of the hourly flows- but subdivided into separate turning movements, etc. How does one decide on the correct measure of exposure, assuming that the right data can be made available. From logic, a multiplicative measure of flows seems more logical than an additive one. 999 Vehicles on one road interacting with one vehicle crossing on the other road would result in 1000 interactions according to the additive rule, as would 500 vehicles interacting with 500 crossing vehicles. According to the multiplicative rule, however, the first situation would result in 999 interactions, and the second one in 25,000 interactions, which seems a more reasonable result.

One way of establishing what is reasonable, is to calculate various indices of exposure and rank them for different intersections. The average number of accidents at those intersections could be recorded (over a period of some years) and also ranked. The measure of exposure that produced the highest correlation could be accepted for our purposes- being accident investigations (Mahalel & Hakkert,1976). The product of the daily crossing flows and the sum of the products of the hourly crossing flows have been used as exposure measures in many accident studies.

This topic becomes even more complicated when one has to consider the correct exposure measure at roundabouts and at signalised intersections, where for obvious reason the logic described above does not hold.

3.3.6. *Pedestrian exposure and risk*

In a way which is fairly similar to the discussion of risk and exposure at intersections one can consider the definition of risk to pedestrians. First one has to differentiate between pedestrians moving along the sidewalk (pavement) and pedestrians crossing the road. For pedestrians moving along the sidewalk a measure of exposure similar to vehicle kilometres on a road section - but in this case pedestrian kilometres - could be adopted. For pedestrians crossing the road, obviously the measure of exposure is linked to the number of pedestrians crossing the road. However it should also be some measure of the volume of vehicular traffic along the road. In this manner one obtains a measure of exposure which is the product of the traffic flow and the number of crossing pedestrians. Older & Grayson (1976) used PxV as a measure of exposure, P and V being the hourly numbers of pedestrians and vehicles on a certain road section. The risk was then defined by dividing the annual number of pedestrian accidents by the exposure. The reason accidents are counted annually and volumes hourly, is that the exposure has to be measured especially for such risk studies and is generally measured for a few hours only. Hakkert & Bar Ziv (1976) calculated various risk functions for pedestrians crossing under different road conditions- on zebra crossings, near zebra crossings, away from the crossing, at signalised crossings and near intersections. The proposed method seems to be reasonable for comparative purposes, i.e comparing the risk of crossing under different road conditions, but it remains to be proven that this technique by linking annual accident data with hourly volumes is robust enough. It also immediately becomes obvious that such calculations require special data collection efforts because the data needed are not generally available.

Another way of looking at pedestrian injury rates is proposed by Roberts, Norton & Taua (1996). In their study the number of streets crossed per child per day was selected as measure of exposure. Data from 2873 completed questionnaires were classified by number of cars in the family and by socio-economic background. It was found that children from poor families and children from families without a car crossed a considerably greater number of street, compared with families with one car and even more so, compared with children from families with two cars. The values ranged between 7.4 street crossings per day to 1.7 crossings. As has been discussed above, it seems that this exposure measure is not perfect, not taking into account the pedestrian and vehicular volumes at each crossing, but it certainly provides for a better indication of risk than just calculating the number of accidents per child.

3.4. **The use of fN diagrams**

The results of calculations on risk, especially in high-risk technologies, are often expressed in fN diagrams, which show the expected frequency f of an event that has at least N fatalities as a function of this number of fatalities. *Figure 2* shows calculated fN curves for a number of high-risk technologies. This, in principle, enables a comparison of risks for society as a whole.

The graph starts with events with ten or more fatalities per year. Aviation appears highest on the curve with ten events with ten fatalities or more per year in the US. Rail transport comes lower down the scale with one event per two years (0.5). Lower still appear various types of transport of hazardous materials (LPG, chlorine, LNG). Except for rail transport, the order of the curves does not change when taking events with greater numbers of fatalities.

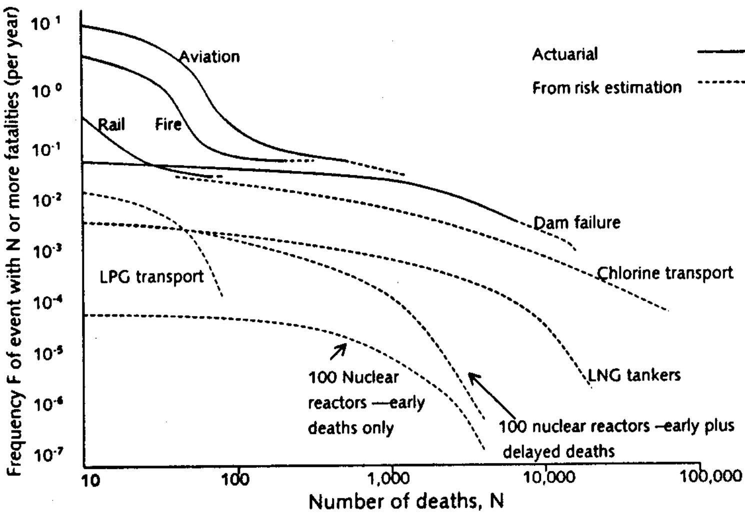

Figure 2. *Calculated fN curves for high risks in the US. In: Van Poortvliet (1999) from Cappola and Hall (1981)*.

For the various transport modes (road, rail, civil aviation and merchant shipping) the graph from Evans (1994) is illuminating. *Figure 3* presents data for Great Britain for the years 1963-1992.

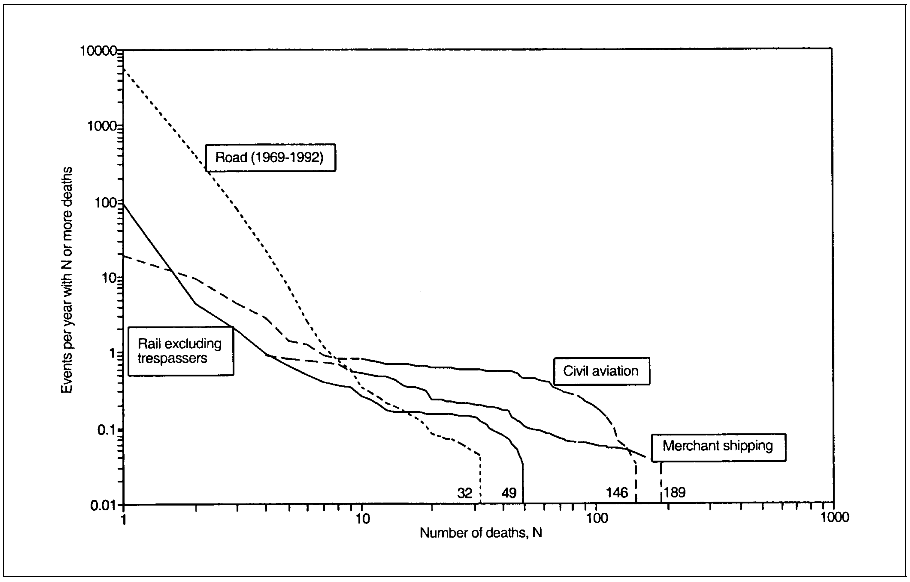

Figure 3. *fN-curves for British transport accidents: 1963-1992. From Evans (1994)*.

The total number of casualties and fatalities accumulated through the occurrences of a large number of events with only one or two fatalities is much higher for road transport than for the other modes of transport.

Because of the distribution of the number of fatalities per event in road transport in particular, the use of fN curves is not that helpful. The large majority of fatal road accidents incur one fatality or two. Events with many fatalities are rare and almost invariably capture the media's and politicians' attention with the result that actions are considered and taken which would not have occurred, had the same number of fatalities been spread over a large number of events. This points to a lack of rationality in terms of decision-making on the basis of cost-benefit considerations. In the other transport modes the frequency of events with small numbers of fatalities is much lower. Only rail industry has a considerable number of events with one death or more (around one hundred), compared with over five thousand in road transport. The number of large scale disasters with tens to hundreds of fatalities is reversed for the different modes. Merchant shipping had an event with 189 fatalities once in a hundred years, civil aviation had an event with 146 fatalities once in a hundred years. The corresponding figure for rail was 49, and for road transport 32.

4. Some issues associated with the use of exposure and risk

4.1. The desire to assess risk levels and to strive for equal risks

According to a recent ETSC report it is important to collect exposure data for risk assessments that can be used to improve transport safety. ETSC defines the following ways to conduct such assessments:

- "monitoring casualty trends and evaluating policies which have been introduced to improve safety, in order to provide a sound basis for developing new policies
- comparing the levels of risk of different types of travel (for example by transport environment or transport mode)
- setting priorities, that is identifying those transport situations with high levels of risk in order to formulate policies and concentrate resources to reduce risk levels, especially for high severity crashes (ETSC,1999*).*"

The safety policy for each mode of transport should be similar: research, develop and apply cost-effective countermeasures that have the potential to reduce crash risk and/or severity.

A basic assumption is that it is desirable to strive for equal risk to various categories of road users, including the vulnerable road user, in order to achieve equal risk on various categories of roads. Unequal risks on different categories of roads and for different categories of road users do, however, exist and it is almost impossible to envisage that such risks can be made equal at reasonable economic costs. Similarly, equal risks in various parts of the country, municipalities, regions, and provinces are almost certainly unachievable at reasonable economic costs. Even the calculation of such risks is almost impossible because of the lack of reliable and detailed exposure data on the provincial and municipal levels.
If good data is not available, one resorts to the usual levels of aggregation- national, provincial or municipal- per inhabitant, per kilometre of road, etc.

At the regional and municipal levels there is also the problem of interpretation. Some authorities have high levels of risk but have done a lot of work on road safety, others have done little. What is the correct measure of risk? At a high level of safety, the additional effort required to achieve more safety is much greater (more costly) than at lower levels of safety, and so positive results are more difficult to achieve. A further complication arises from the fact that equal levels of risk are unrealistic if conditions are not equal. Large municipalities generally also have higher population densities and have more congestion than smaller towns. As a result they will experience lower numbers of fatalities and seriously injured victims per capita. Similarly, provinces or regions that are highly urbanised will have higher population densities and experience lower levels of fatalities and serious injuries. This issue will be discussed in further detail in *Section 4.6* which considers the cost-benefit considerations of safety measures and in *section 6.1* which discusses accident rates and traffic flows.

In this context one should ask whether it is correct to strive for equal risk or for highest benefit-cost returns on safety improvements. Striving for equal risks on various parts of the road network or equal risks to various groups of road users sounds politically correct, but is, in all likelihood, impossible to achieve at reasonable economic costs. Urban roads will have fewer fatalities per kilometre travelled than rural roads, because of the lower speeds of travel. Motorways will have fewer fatalities per vehicle kilometre travelled than other types of rural roads, because of the level of segregation between different modes of transport (no slow vehicles) and the segregation of movements (no at-grade intersections). It would be more fruitful to try and find ways in which each category of road and road user is made safer by applying cost-effective countermeasures.

More generally, and along similar lines of thought, when dealing with risk comparisons between different activities- is it really worthwhile to strive for equal risk levels for citizens in a variety of occupations? Is it reasonable to expect a factory worker to be exposed to the same level of risk as the bank employee? Looking at the risk and exposure data collected in Evans (1993), this clearly does not seem to be the case. In banking and financial employment there are 0.17 fatalities per hundred-million hours of work, compared with a rate of 4.9 in construction work and 13.0 in mining. In transport modes (under certain rough assumptions of travel speed) the risk of a fatality per hundred-million passenger hours is 1.4 in a bus or coach, 12.4 in a car, 27.0 on foot and 342.0 on a motor-cycle. There is no realistic way in which it will be possible to achieve equal risks for these modes. This concept is considered ‘unfair’ by some. Others on the other hand do not think there is any unfairness (Ekman, 1996). No person who considers riding a motor-cycle would be doing so under the assumption that it will be as safe as riding a bus, or as safe as travelling in a car. What could be asked however, in such circumstances, is what safety measures could be taken that would improve the level of safety of motor-cyclists and would still be considered cost-effective. Some of these measures would also apply to other types of road users. An example of such a measure is making car fronts safer, which would lead to lesser injury severity when crashes with motor-cyclists and other road users occur.

4.2. Over-representation and risk

Much of the work on risk in safety studies seems to stem from accepted and established procedures taken from the field of epidemiology as practiced in medical and health related studies. From epidemiology a logic is adopted which seems to be the basis for the use of exposure and the calculation of risk (Hauer, 1995a). It is the search for over-representation in various populations under study that lies at the basis of this approach. Searching for over-representation seems to suggest the following line of thought and action:

> [deviation-from-normal] leads to [clue-to-cause] leads to [clue-to-remedy]

Many classical epidemiological-medical studies have successfully taken this approach and in some cases led to major achievements.

One underlying requirement in this chain of thought is a further assumption which is the *“presumption-of-sameness-except-for-the-suspected-cause”* (Hauer,1995a; Ekman, 1996). In medical studies, this might well be a legitimate assumption in many cases. Hauer (1995a) presents the example of John Snow, who established in 1854 that people who live in the same districts, but whose water is supplied by different companies, had vastly different incidences of cholera, many years before the discovery of the vibrio of cholera. From this Snow could infer what the cause of the cholera epidemic was and what the remedy might be.

In transportation safety studies, the presumption of sameness hardly ever holds good. In the comparison of accident and fatality rates for different modes of transport (air travel vs. road travel), rates for different modes of road transport (lorries, cars, motor-cycles, etc.) it is definitely wrong to assume sameness. By itself, over-representation in accidents or fatalities has no discernable logical link to funding, programming, decision or action. The decision-making process should be concerned about establishing the relevant facts, adopt a set of proven countermeasures and base the decision on the cost effectiveness of the preferred solution.

A subject that has received a lot of attention in recent years is the issue of older drivers and their ‘over-representation’ in accidents or their higher-than-average risk (Hauer,1995a). The motivation behind this seems to be related to the fact that in many countries society is ageing, and that, therefore, something should be done about this over-representation. Indeed, when the rate is calculated ‘per mile driven’, drivers in the 75+ group have trice the rate of drivers in the 35-40-year-old age group. Yet, when looking at the numbers, 1486 drivers who were 75-80 years old died in the US in 1986, whereas 3203 drivers in the 30-35-year-old age group died in the same year. This indicates that in terms of absolute numbers, the focus should be on the 30-35-year-old group. It seems perfectly clear that the quest for countermeasures should be driven by improving the safety record for the older driver. This could be done by adapting the highway infrastructure to better suit the older driver, or by other means that could be implemented in a cost-effective manner. The knowledge about the higher involvement rate does not help us further in this matter.

4.3. Doing without information on risk and exposure - an example

The following study on the effect of seat belts can serve as an example that demonstrates that it is not always necessary to use exposure data and calculate risks to measure the effect of a safety measure. Yet, the example also shows that omission of exposure data may result in inexplicable outcomes or mistaken conclusions.
In 1983 a law requiring the use of safety belts in cars came into force in Great Britain. Subsequently, Professors Harvey and Durbin from the London School of Economics were asked to evaluate the safety effect of this law. Their results are described in Harvey & Durbin (1986). The authors looked at a time series of fatal and seriously injured car drivers and passengers over a period of fifteen years starting in 1969 and continuing till December 1984, two years after the introduction of the law (*Figure 4*).

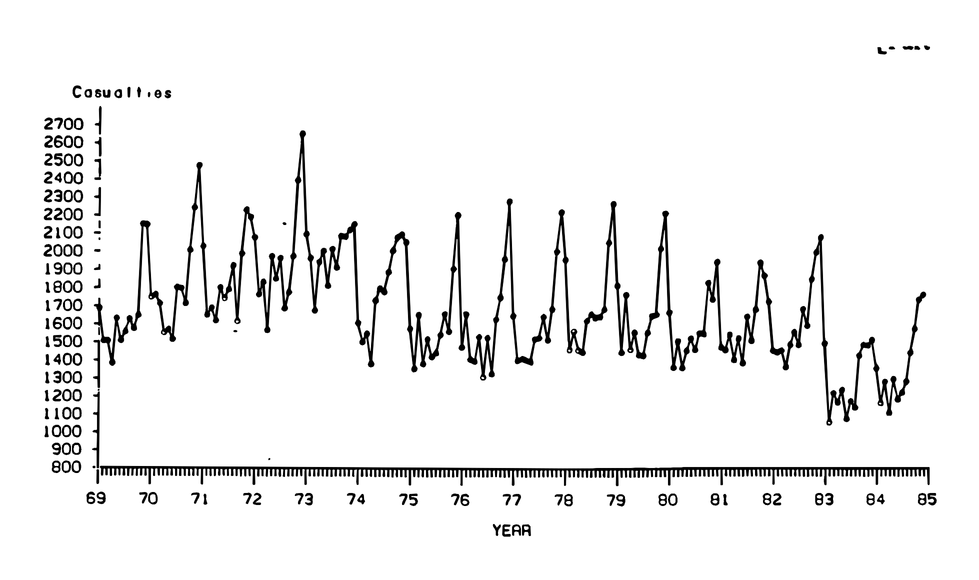

Figure 4. *Car drivers killed and seriously injured in the UK, 1969-1984. From: Harvey and Durbin (1986)*

Car passengers were further split into front seat passengers who were directly affected by the law and rear seat passengers. Applying statistical structural time-series models the authors were able to model the series for the before period and estimate the effect of the law by comparing the actual fatality and serious injury figures with their estimate of what those figures would have been without the introduction of the law. Their estimate of the effect was a significant reduction of 23 per cent in the numbers killed and seriously injuries for car drivers and 30 per cent for front seat passengers. For rear seat passengers, however, a small increase of 3 per cent was found. For the number of persons killed similar large reductions in the number of fatalities were found for car drivers and front seat passengers, but the number of rear seat passengers killed increased by 27 per cent. The authors could not find a satisfactory explanation for this increase. One explanation put forward was that there was the possibility that after the introduction of the law, which did not affect rear seat passengers, a certain number of passengers transferred from the front seat to the rear seat.
It is exactly this type of question and outcome that could have been answered in detail, if at the time a series of exposure measurements had been in place counting, over time, the number of passengers in front seats and in the rear of cars.

Risk can serve as the basis for the selection of research and action themes which should then be justified on the basis of cost-benefit considerations. Decision-making can be carried out on the basis of comparative risk levels, on the basis of accident and injury data (without risk) and according to cost-benefit considerations. Each method has advantages and disadvantages and should be selected according to the circumstances. Decision-making on the basis of the numbers of accidents, injuries or fatalies focuses on the size of the problem and prevents us from focusing our efforts on a segment of road safety that might look bad from the point-of-view of risk but which might not be very significant in terms of the quantities involved. Decision-making on the basis of risk tends to lead to actions that are considered fair in terms of the road users involved. If a segment of road, or a certain type of road, or a group of road users has a risk that is higher than the risk for another group or higher than average, this is considered unfair and decision-makers are urged to adopt policies that would lead to an absolute and relative decrease in risk for that group. In practise, such decisions are not reasonable, not possible and almost certainly not economical. Motor-cycle riders have higher risks than car occupants, pedestrians have higher risks of dying from an injury than car occupants, regional and local roads have higher levels of risk than motor-ways and so on. The final decision should generally be based on cost-effectiveness considerations because, in the field of road safety, like in any other field, the amount of expenditure is limited and investments should be allocated to those fields that produce the highest accident, casualty and fatality reduction that can be achieved per unit of money invested.

4.4. National safety levels and targets

National road safety targets are generally set in terms of numbers of accidents, casualties and fatalities, or percentage reductions to be achieved. This has been the case in The United Kingdom, The Netherlands, Sweden, Australia and many other countries. There are several reasons for this approach. First, in terms of the impact on the population, it is the absolute numbers that count. Focusing on risk might show a reduction in risk which might be the result of an increase in exposure being greater than the increase in accidents or fatalities. This would thus not lead to an absolute reduction in the number of casualties or fatalities. Targets based on risk levels are also undesirable because of the fact that risk levels in general tend to decrease over time because of the whole range of road safety activities and because of inherent changes in the traffic volumes and composition. Once having set targets in terms of numbers, it is however possible to use risk levels to check for changes in certain areas, regions or municipalities. If the number of casualties or fatalities in a region is increasing faster than average, it is worth looking at the exposure and risk to study the differences before reaching conclusions.

When dealing with trend analyses of road safety phenomena, it might be possible to work with the rough accident and injury data for short-term prognosis. On the basis of past trends, when dealing with before-after evaluations, it is generally possible to apply time series models and inter-vention-type models to predict the short-term effect of a countermeasure using accident and casualty data. In the case of long-term projections, 5-10 years onwards, it is generally necessary to first estimate the underlying trend in exposure data before making a prognosis.

4.5. What is an acceptable level of risk?

In a general way, the question of what is an acceptable level of risk in road traffic is virtually impossible to answer. Any limit other than zero risk is arbitrary and disputable. Zero risk, however, may be a valid ambition in theory, but hardly possible, if at all, to realise in practice. Furthermore, when talking about the acceptable level of risk a distinction must be made between various types of risk, for example individual risk versus societal risk and voluntary risk versus compulsory risk. What risk level is acceptable for an individual road user when he or she makes a particular trip with a particular transport mode? What is the acceptable risk level for society as a whole, in other words how many accidents or casualties per year per unit of exposure are we as a society willing to accept at public roads? And is it reasonable to accept higher risks when these are taken on a voluntary basis (e.g. a recreational bicycle tour) than when taken on a compulsory basis (e.g. for professional drivers or home-work travel). Some of these questions are answered by society, through actions that government and local agencies take on the programs and budgets devoted to road safety. There are no absolute and correct levels, as becomes obvious when looking at the actions taken in different countries, which result in them having different levels of risk and safety. At the individual level there are also no correct and absolute answers. Individual risk varies from person to person, from task to task and can even vary for the same person depending on mood, time-pressure and whether the risk is voluntary or compulsory.

An interesting issue related to risk and acceptability considerations is raised by Erskine (1996). Erskine makes the distinction between risks to those who have access to cars and those who do not have access. He points out that, although risks associated with the use of cars, in terms of both the number of casualties and fatalities per vehicle- km travelled, have been decreasing considerably over the years, it is the parts of the population that do not have access to cars, i.e. the poor, the young, the old and women (i.e the non-driving population) that are adversely affected by the increased exposure to motorised travel. In order to come to more socially responsible decisions, the needs of these separate populations should be taken into account.

Along a slightly different line of thought, one could also make the distinction between risks involved as a passenger or driver of a certain type of vehicle, and the risks associated with the use of such a vehicle to other road-users. In this way, lorries are a very safe means of transport to their occupants, because very few fatalities occur to drivers and passengers of lorries, both in absolute numbers and expressed as fatalities per vehicle-km travelled, but they are involved in a proportion of fatal accidents which is considerably larger than their share in vehicle kilometres driven. The same is the case for buses. Cars are also becoming safer and safer for their occupants, because most technological innovation and development has been applied to improve the safety of the occupant: US and European safety regulations, seat belts, air bags, etc. Thus the risk of being injured or killed per vehicle-km travelled continually decreases. However, the issue of injuries and fatalities caused by these vehicle to the vulnerable road-user are only now being addressed and still there are few technological developments that are effective.

Similarly, relevant for the transport of dangerous goods in particular, one could make a distinction between the accident or injury risk for road users and the risk for third parties, for example for those living in the area and being exposed to toxic chemicals following a road accident with a dangerous goods truck. In the Netherlands this distinction is made in the external safety report which is required for the dangerous goods transport industry. As an indicative value, the third party risk in this type of industry should not exceed 10^{-4} for events resulting in 10 victims and 10^{-6} for events resulting in 100 victims per year per kilometer route (RIVM, 1998).

4.6. Risk versus effectiveness

So far the issue of the economic costs associated with countermeasures that aim to change levels of risk and thereby the number of casualties or fatalities in the transport system has not been dealt with in this report. Risk-benefit assessment has been applied in such diverse fields as medicine, public health and environmental protection. The methods used in these fields might also be applied to the field of motor-vehicle safety (Thompson, Graham & Zellner, 2001). Risk-benefit analyses can be categorised according to the situation and may include cases where:
- neither risks nor benefits can be readily quantified;
- risks can be quantified, but benefits cannot readily be quantified (or vice versa);
- risks and benefits are quantified in very different terms or units;
- risks and benefits are quantified in similar terms.

It is this last category which has been focal in medical and pharmaceutical research and which is of great interest to the transport safety field, especially when considering the introduction of road safety devices or other countermeasures. Thompson, Graham & Zellner (2001) discuss a number of quantitative approaches to deal with this issue.

One approach (QALY) calculates the quality-adjusted life years associated with a certain safety measure. QALYs combine information on duration of life and health-related quality of life into a numerical index. This technique is widely used in the medical field to assess new drugs or medical interventions and could be applied in the road safety field as well.

A slightly different technique, called DALY is promoted by the World Bank and the World Health Association (WHO). DALY also combines information on duration of life and quality of life into a numerical index that can be aggregated across people. The DALY approach evaluates health states in terms of a single dimension, degree of disability, whereas QALY addresses a wide range of dimensions of quality of life.
A third approach which has been suggested calculates the Normalised Injury-Fatality Costs (NIC). It is a research-based tool which assumes that all health-state values and preferences are reflected in the actual lifetime costs of medical treatment, ancillary costs (which include costs of permanent partial incapacity) and fatality costs to society. NIC intentionally neglects so-called 'pain and suffering' costs, as these were believed to be subject to enormous variations.

Despontin, Verbeke & Brucker (1997) suggest that decision-makers should approach the issue of road safety countermeasure evaluation in a two-dimensional way as illustrated in *Table 6*.

Factor contributing to accidents / safety characteristics	Road user	Vehicle	Road
Exposure	- Separation of different road user categories - Changes in number of trips-	- Regulation of vehicle traffic	- Regional planning of traffic control - Road improvements reducing travel distances
Risk	- Improvement of education, information and road user behaviour in relation to traffic rules	- Crash avoidance measures: vehicle speed regulations - Vehicle equipment (studded tires, running lights in daytime, etc.)	- Improvements on roads, streets or traffic network - Speed reduction signs - Road/street maintenance
Accident consequence	- Individual protection equipment (seat belts, helmets) - First aid education	- Improved crash tolerance	- 'Soft' road side design - Alarm telephones

Table 6. *A classification of road safety measures. In: Despontin, Verbeke & Brucker (1997) from OECD (1981).*

Safety measures are classified on the basis of two criteria. The first criterion is related to 'factors contributing to accidents'- the road user, the vehicle and the road. The other criterion relates to the safety characteristic changed, namely exposure, risk or accident consequence. The final decision on which safety countermeasure should be preferred should in each case be taken on a cost-benefit basis.

Elvik (1997) also thinks that cost-benefit analysis will become increasingly important in the field of road safety decision-making. One reason is the limited financial resources that will be available for road safety. Funds should therefore be applied as efficiently as possible. Another reason is that more and more often a choice will have to be made between competing objectives, which could be environmental or based on mobility, energy or safety. Converting conflicting objectives to an economic yardstick is one way of treating problematic decisions.

One underlying dilemma has not been adequately resolved. On the one hand, in terms of accident or fatality risk, the transport system becomes safer as the years go by. In almost all countries for which reliable statistics are available, risks have been decreasing over time. At the same time, exposure, measured in vehicle kilometres travelled has continued to increase in most countries. The result is that in many cases the absolute number of accidents, and in some cases the number of fatalities have continued to increase. As to effectiveness it could be said that the transport system has become more efficient in terms of the number of accidents or fatalities it produces for each unit of exposure, however, in overall terms of safety, the system has become less safe by producing more casualties, or fatalities in some countries, as a result of the increased exposure. To produce further safety improvements it should therefore be attempted to reduce levels of exposure by modes of transport that have high risks associated with them and convert some of that exposure to modes that have lower risks. Even that approach should be regarded with caution as the following two examples will demonstrate.

The first example is taken from Evans, Frick & Schwing (1989). It is often stated that the most dangerous part of a trip by plane is the trip to the airport. Evans, Frick & Schwing show this not to be the case. When comparing air travel with road travel, the risks look very much worse for road travel. Death rates per billion miles travelled are 0.6 by air, compared to 24 by road. But, there are three reasons why such a comparison is inappropriate. First, the airline rate is 'passenger fatalities per passenger mile', whereas the road rate is 'all fatalities (including occupants, pedestrians, motorcyclists, etc.) per vehicle mile'. Second, road travel that competes with air travel is mostly done on rural freeways, which are among the safest part of the road network. Third, driver and vehicle characteristics vary over a wide range of risks. In their study, Evans, Frick & Schwing make a number of assumptions and show that a 40-year-old, belted, alcohol-free driver of a car which is 700 pounds heavier than average is slightly less likely to be killed in a 600-mile-trip on the rural interstate freeway system than in a regularly scheduled airline trip of the same length. For 300 mile trips, the driving risk is about half that of flying.

In discussing costs and benefits associated with road safety measures two approaches are possible and are in widespread use. The first approach evaluates all the costs associated with the introduction of a certain safety measure and compares these with the benefits achieved from the reduced number of accidents, casualties or fatalities expressed in monetary values. The second approach does not convert the reductions in accidents and casualties into monetary values, but compares the numbers of accidents saved with the costs involved. This is the cost-effectiveness approach.
In cost-benefit calculations different values are adopted for accidents, casualties of varying degrees of severity and for fatalities in different countries. Even the theoretical methods adopted in the different countries are not the same. Some are adopting the gross loss of output approach, some the net loss of output approach and some adopt the approach considered more advanced and correct, the willingness-to-pay approach. This approach is considered by some to be un-ethical and therefore to be avoided. It is however wrong to assume that by taking the cost-effectiveness approach such issues can be avoided. If one safety scheme prevents a certain number of casualties of varying degrees of severity and another scheme prevents a different mix of severities at a different cost, the decision still has to be made how to weigh these different mixes. The monetary conversion adopts one particular mix.

5. Some examples of the use of risk calculations in a number of road safety applications

Having established that there is no universal treatment of exposure and risk in safety studies and evaluations, it is illuminating to present some examples of the way in which exposure and risk should be used in a number of applications. The first examples are taken from the safety literature. These are followed by a number of examples taken from a number of studies conducted by researchers at SWOV.

5.1. The involvement of lorries in fatal accidents

It is well known and documented that lorries are involved in a considerable percentage of fatal accidents in most countries. In Sweden, in 1992, out of the total number of fatalities- 759 in the year 1992, 132 fatalities (of which seven lorry occupants) occurred in collisions with lorries and another seven fatalities occurred in single vehicle lorry accidents (*Table 7*).

Killed as	Killed in single accident	In collision with										
		Pass. car	Lorry	Bus	MC	Mop./ cycle	Tractor	Animal	Train	Tram	Other	Sum
Car occupant	195	133	80	16	1		3	14	14	10		466
Lorry occupant	7	2	7				1					17
Bus occupant	2	0	0									2
Motor cyclist	19	10	1					3				33
Mopedist	2	7	7		1							17
Bicyclist	9	41	20	3	1	2						76
Pedestrian	0	92	17	7	2	3	5			4	8	138
Tractor	1								3			4
Others	5	1										6
All killed	240	286	132	26	5	5	9	17	17	14	8	759

Table 7. *Fatalities related to vehicles or road users and accident types in Sweden, 1992. From Nilsson, 1997).*

From the absolute numbers it would seem that, on the one hand, lorries are a very safe mode to their occupants, with only 14 fatalities per year, compared with 466 killed car occupants, 138 killed pedestrians or 76 killed cyclists. On the other hand 132 fatalities in collisions with lorries is 17% of the total number of fatalities and is a much higher proportion than the number of lorries in the total vehicle population. This seems to lead to a number of possible conclusions.

- It is likely that lorries drive a much greater distance per year compared with other types of vehicles.
- It is likely that because of their greater mass, once an accident occurs, the outcome will be more severe and the injured person is most likely to be in the other vehicle or to be a vulnerable road user.
- It is possible that lorry drivers are bad drivers and are therefore involved in a higher proportion of collisions than their share in the vehicle park.

Without additional information on the exposure background of lorries and other types of vehicles it is not possible to come to the correct conclusions. Even with the correct exposure information for the various types of vehicles it is very difficult to obtain reliable exposure information for the vulnerable road users, the pedestrians and the cyclists, and even when that is available, from travel surveys or other means, it generally applies only to the adult population and not to children.

One additional complication manifests itself in the calculation of involvement rates (risks) of lorries. This issue was recently treated by Hauer (2001). Hauer’s conclusion is that, for the rates to be calculated correctly, if vehicle exposure is used in the denominator, then the count of vehicles involved in accidents must be in the numerator (and not the number of accidents in which such vehicles are involved). Similarly, if driver exposure is in the denominator then the count of drivers of a certain category in accidents should be in the numerator and not the number of accidents involving that category of driver.

A second issue discussed by Hauer (2001) is the question of over-representation. His question is- if some type of entity is found over-represented in reported accidents of specific severity, may one conclude that entities of this type are in fact more likely to be involved in accidents? His answer is 'no'. If one is dealing with reported accidents of a specific severity, as one almost invariably is, then the over-representation may be caused by a mix of three factors: the probability to be in an accident per unit exposure, the probability of the accidents to be reported and the probability of the accident to be of the specified severity. Without knowing these three probabilities it is not possible to come to the right conclusions. This issue applies to both lorries and vulnerable road users in particular. It applies to lorries, because on account of their greater mass they are more involved in accidents with higher severity and are therefore likely to be over-reported in registered accidents. To calculate the accident risk of lorries, looking at the registered accidents will result in over-representation, which might not be the case if 'accidents with material damage only' had also been taken into account. The issue also applies to the vulnerable road user, especially the bicycle, for which it is known that accidents are greatly under-reported and are therefore not found in the general accident statistics in their representative share.

A recent report by Lyman and Braver (2001) also addresses the issue of large truck safety by analysing various crash involvement rates. The study examined different measures of truck crash fatality risk, to better understand how two main indicators – the public health aspect of large truck crashes and the risk per unit of travel - have changed over a period of 25 years. The study looked at large truck occupant fatalities (trucks over 10,000 pounds), and passenger vehicle occupant fatalities and calculated their rates per 100,000 members of the population, per 10,000 licensed drivers, per 10,000 registered trucks and per 100 million vehicle miles of travel (VMT) for each year over the period 1975-1999. Results show that in 1999, large truck crashes resulted in 3,916 occupant deaths in passenger vehicles and 747 in large trucks. Passenger vehicle occupant deaths in large truck crashes per 100,000 members of the population have increased somewhat since 1975 (1.28 in 1975, 1.44 in 1999). There has been a considerable decrease in occupant deaths per truck VMT since 1975, but the percentage reduction has been greater for occupants of large trucks (67%)

than for occupants of passenger vehicles (43%). However, truck drivers are at an elevated risk of dying relative to their numbers in the workforce. Large truck involvements in fatal crashes per truck VMT decreased by 68% for single-vehicle crashes and by 43% for multiple-vehicle crashes. In contrast, passenger vehicle involvements in fatal crashes (including those that did not involve a large truck) per passenger VMT have decreased less (33% for single-vehicle crashes, 23% for multiple-vehicle crashes).

Both arguments brought forward by safety groups and by the trucking industry are correct in their assertions. Large truck involvement in fatal crashes has dropped substantially when measured per unit of travel, but the public health burden of large truck crashes, as measured by death per 100,000 members of the population, has not improved over time because of the large increase in truck mileage. Countermeasures are needed to better protect both passenger vehicle occupants in collisions with large trucks and the occupants of large trucks.

5.2. Drivers involved in accidents while under the influence of alcohol

One of the important topics in road safety and road safety countermeasures is the subject of driving under the influence of alcohol (DUI). Work on this subject began many years ago and has always been high on the agenda of decision-makers and the police. A major mile-stone in this field was the study of Borkenstein et al (1964). The study became known in the technical literature on the subject as the Grand Rapids study. Borkenstein collected information on alcohol levels of drivers involved in accidents and similar information on drivers in the population at large (not involved in accidents). Borkenstein's study involved about 5000 accident-involved drivers and a similar number of drivers as control group. From this information Borkenstein developed a risk function which describes the over-involvement of drinking drivers in accidents as a function of their blood-alcohol level (*Figure 5*). Without collecting the information on the general driving population, which serves as the exposure measure, it would be impossible to determine the over-involvement.

From the curve it can be seen that at alcohol levels of between 0.5 till 0.79 promille the chance of an accident increases significantly by 35% compared with the zero alcohol level. At 0.8 to 0.99 promille the chances have increased by a factor two, and above that the risk of involvement continues to increase exponentially. A subsequent study, conducted along similar lines in Germany (Kruger, Kazenwadel & Vollrath, 1995) produced similar results. At all levels of alcohol consumption accident-involved drivers were over-represented. The degree of over-involvement was even somewhat higher than in the original Borkenstein study.

Having collected accident data and exposure data on such a large scale the Borkenstein study was regarded as authoritative and provided the foundation on which many countries established their blood alcohol limits. A few countries, including the Netherlands, adopted a 50 g/100 l limit, more countries adopted an 80 g/100 l limit and the US initially adopted a limit of 100 g/100 l (Mathijssen and Twisk, 2001). Countries in the East-European block still maintain a zero-tolerance limit, as does Iceland. The Scandinavian countries maintain a 20 g/100 l limit.

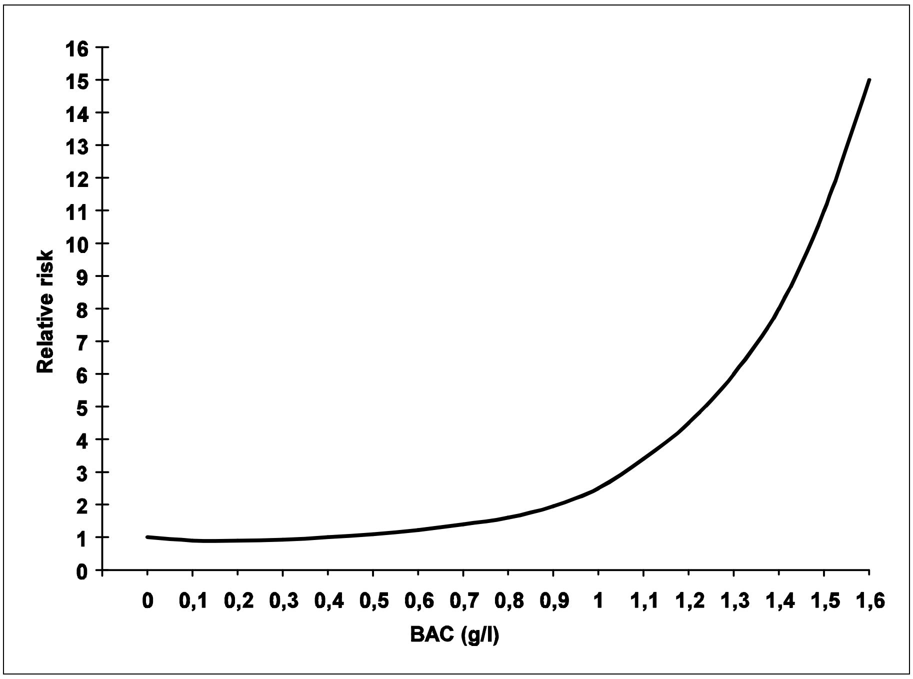

Figure 5. *The relationship between Blood Alcohol Concentration (BAC) and accident risk. From: Mathijssen & Twisk (2001) after Borkenstein et al., 1964.*

One initial by-product of the original Borkenstein study was that an under-involvement in accidents seemed to occur at low levels of alcohol consumption, between 10 g/100 l and 40 g/100 l. This phenomenon became known as the Grand Rapids Dip (Hurst, Harte & Frith, 1994). Subsequent re-analysis of the original data by Hurst and others has shown that this dip was a result of the statistical composition of the samples and when this is taken into account correctly, the dip does not exist.

The use of exposure data in this example was crucial in determining the effect of alcohol in accident-involved accidents. Without the exposure data it would not have been possible to measure the extent of over-involvement and decision-makers would not have had the scientific basis on which to adopt countermeasures, which in this case were the alcohol limits. Through the adoption of this course of action the number of drivers who continue to drive while under the influence has decreased considerably in most countries.

A similar approach is now essential in determining the correct course of action regarding regulations on the use of drugs and medication. Without extensive surveys on the use of these substances by the driving population at large, in comparison to the driving population involved in accidents, it will not be possible to come to scientifically based regulations. Without the scientific basis, it will be difficult to persuade the public and the decision-makers to follow the right course of action.

5.3. The effect of speed on the risk of accident involvement

Another issue which is of major importance in road safety research is the effect of speed on the risk of being involved in an accident. Because of the extensiveness of this topic it will not be treated in detail, but some points which bear upon the issue of risk will be discussed. Speed is not generally mentioned as a major contributor to accidents, when looking at the possible causes of accidents detailed in accident reports filled out by the police who arrive at the scene of an accident. This absence is sometimes taken to mean that speed is not a major contributing factor to accidents. The reason that speed is not mentioned in such reports is that it is almost impossible to determine the speed of a vehicle involved in a crash without an in-depth investigation, which is not normally conducted by the police. As a result police officers tend to stick to the manoeuvres and actions, prior to the accident, that they can prove and report; such actions as not giving way, changing lanes, not stopping for a stop sign etc.

Research has shown, however, that speed is indeed a major contributory factor in accidents and should be dealt with as a topic of great importance. But speed in itself is not all that needs to be known in order to investigate the subject. Of importance are also the speed in relation to the speed of other vehicles using the road,this is generally called the speed differential and was described in detail by Solomon (1964). Another factor of major importance is the variation in speed (speed variance), which was described in detail by Finch et al. (1994). Both these variables indicate that, in order to study the importance of speed on accident involvement, one has to have further details on the speed of the traffic at large and not just of speeds of vehicles involved in crashes. The information on traffic speed should be regarded as a measure of exposure.

Finch et al. (1994) reviewed data from a variety of sources that seems to indicate that the relationship between accident involvement rate and deviation from the mean traffic speed is U-shaped. Taylor, Lynam & Baruya (2000) referring to studies of Maycock et al. (1998) and Quimby et al. (1999) report different results. The increase in risk at higher speeds than average was established but the increase at lower speeds than average could not be determined. In this case the relevant exposure measure is the speed of vehicles travelling along a stretch of road. Not only the mean speed of such vehicles is of importance but also the speed variance. Once such information is known it becomes easier to determine the accident potential of such a road or to consider the possible effects of countermeasures that are contemplated.

It seems that speed and speed distribution are significant factors in establishing the risk of an accident and in determining the severity of such an accident. The implication of this for accident and risk studies is, that speed information should be taken into account. As in many cases speed information is not available, great care should be taken when calculating and comparing risks on various parts of the road and transport system. It seems wise to avoid comparing risks between parts of the transport system that have very different speed distributions or between modes with widely different speeds, as much as possible.

5.4. A preliminary study to explore directions for elaborating on risks

In 1998 the Dutch Ministry of Transport decided to reinforce its road safety policy by promoting the use of risk indicators. Roszbach (1998) prepared a report which was intended as a preliminary study on the subject exploring possible directions for the quantification of risks. Roszbach dealt with the definitions of exposure and risk, compared various types of risk and discussed problems associated with the quantification of risk in various applications. Roszbach points out that, in terms of policy setting, working with risk indices on a provincial and municipal level can be counterproductive. It might be better to work with absolute numbers of accidents, casualties and fatalities. Increased mobility leads to more vehicle kilometres (increased exposure). Accident rates (risks) decrease with increased exposure and as a result those provinces and municipalities with larger increases in mobility might be rewarded for improved performance. Another point made by Roszbach, as indeed also made in the present report, is that exposure data should reflect the problem being studied. The report also points out that for the assessment of infrastrucure safety it is better to work with accident rates as a measure of traffic volumes. In this report this has been termed Safety Performance Functions (SPF). This approach is to be preferred over working with average accident rates per type of road section and intersection (index numbers). Roszbach suggests a step-by-step approach to safety decision-making:

- Determining that something has to be done. On this level it is often possible to work with the raw accident and casualty data;
- Determining where something should be done. In some cases exposure data will already be required at this level;
- Determining what should be done. At this level we generally need comparative and normalised data.

5.5. Predictions of traffic safety in 2010 in the Netherlands

A report by Commandeur & Koornstra (2001) analyses road safety developments in the Netherlands during the period 1948-1998 at a nationally aggregated level. The purpose was to find models that could describe developments of mobility (exposure) and fatality and casualty risk as accurately and as simply as possible. Having developed fairly accurate models, prognoses were made of future developments in mobility, casualty risk, number of road fatalities and hospitalisations up to the year 2010. The models developed presented a fairly accurate presentation of the trends in past years. Yearly deviations from observed mobility and risk were studied. It was found that there is a relation between the deviations for mobility and fatal risk figures. It appears that mobility deviations show a strong, negative trend relation with the risk deviations ten to eleven years later. The models developed seemed to provide a strong basis for the prognoses of mobilty, casualties and fatalities produced in the report. One of the drawbacks of these models is related to the relationship between mobility and risk deviations. It seems to be that they are very country-specific and have to be carefully calibrated on local data. Negative trend correlations in different countries varied between four and twenty years and in some countries the correlations were positive instead of negative (Commandeur, 2002).

5.6. The involvement of elderly drivers in accidents

One of the issues which has received attention in recent years is the involvement of elderly drivers in crashes. This interest is partly the result of various misconceptions about elderly drivers, and partly of the growing number of the elderly in the driving population in motorised societies. It seems therefore relevant to have a clear picture on this issue, based on data and research findings. A recent SWOV report by Davidse (2000) dealt with this issue. The report consists of three main parts. First, an analysis is conducted of the present situation in the Netherlands, based on crash data, population data and travel distance data. Secondly, a prognosis is made of future trends and implications and finally an inventory and evaluation of measures to possibly lower the risks for elderly drivers are presented. The present report will deal only with the first part of the study. Davidse calculated the risks, the number of casualties and the accident involvement of elderly car drivers and compared them with various other age groups. The elderly were defined as being 65 years old and older,and were sub-divided into two groups: aged 65-74 and aged 75 and older. Other age groups were 18-24, 25-29, 30-39, 40-49, 50-59 and 60-64 years old. Rates were defined as car driver casualties, or fatalities or accidents per thousand million (billion) vehicle kilometres travelled. In most rates, a U-shaped curve was established of risk against age groups, with increased rates for the young and old drivers. The main conclusions drawn by Davidse were that:

- The 75-year-olds and older had the highest chance of being killed in a road accident (death risk). The 18-24 year olds came second.
  The 75-year-olds and older came second in victim risk (the chance of being killed or injured, regardless of the severity). The 18-24 years old had the highest victim risk.
- The death risk of those 75-year-olds and older is high because they are (physically) more vulnerable than other age groups. On the other hand, however, the death risk of the (male) 18-24 years old is high because they are more often involved in accidents than other age groups. The elderly car driver will, therefore, profit from an improvement of secondary safety more than other car drivers.
- A reduction of the number of accidents involving elderly car drivers (primary safety) can be achieved by designing measures that are specifically aimed at the types of accidents in which the elderly more often appear to be the 'guilty party'. These are especially accidents resulting from not giving the right of way and accidents involving left-turns at intersections.

A recent study by Li, Braver & Chen (2001) came to very similar conclusions. Using national US data systems, the role of fragility (susceptibility to injury) versus excessive crash involvement in the increased fatality risk of older drivers per vehicle mile of travel (VMT) was estimated. For each age and gender group, deaths per driver involved in a crash (a marker of fragility) and drivers involved in crashes per VMT (a marker of excessive crash involvement) were computed. Compared with drivers aged 30-59, those younger than 20 and those aged 75 or older both had much higher driver death rates per VMT. The highest death rates per mile driven, 13-fold increases, were observed among drivers aged 80 or older, who also had the highest death rates per crash. Among older drivers, marked excesses in crash involvement did not begin until age 75, but explained no more than about 30-45% of the elevated risk in this group of drivers; excessive crashes explained the risk among drivers aged 60-74 to a lesser extent. In contrast, crash overinvolvement was a major factor contributing to the high risk of death among drivers younger than 20, accounting for more than 95% of their elevated death rates per VMT. These findings suggest that measures to improve the protection of older vehicle occupants in crashes will be more effective than measures directed towards reducing the involvement of older drivers in crashes.

The above two studies demonstrate the usefulness of rates in the analysis of a problem. By focussing separately on the crash involvement rates and the fatality rates per vehicle kilometre for drivers of different age groups, the correct countermeasure approach could be identified. Some of these results could have been identified by just working with the fatality and casualty numbers, by calculating the number of fatalities per hundred crashes for each age group, but this would not have taken into account the relative amounts of travel for each age group.

5.7. The involvement of young drivers in accidents

One example of the necessity to work with both the accident numbers and risk rates is demonstrated in Twisk (2000). In the Netherlands, in the period between 1985 and 1997 the number of young drivers involved in serious accidents dropped considerably. The number of drivers in the age group 20-24 involved in serious accidents decreased from 2829 in 1985 to 1502 in 1997, a decrease of 47%. The number of drivers in the age group 18-19 decreased from 682 in 1985 to 343 in 1997, a decrease of 50%. The number of accident-involved drivers in other age groups decreased by a much smaller percentage: from 9082 in 1985 to 8050 in 1997, a decrease of less than 12%. *Figure 6* shows the absolute number of young drivers involved in serious accidents for 18-19 and 20-24 year old male and female drivers. *Figure 7* shows the number of vehicle kilometres driven by these groups and *Figure 8* shows the accident risk developments.

It immediately becomes clear that the large reduction in the number of young drivers involved in serious crashes is the result of reduced exposure. In the report by Twisk the reduction in mileage is further traced to demographic and other changes that occurred over the period concerned, which had a major effect on the age group studied. An economic recession affected the number of licensed young drivers, and free public transport travel passes were issued to young students.

The study demonstrates the need to work in an ad-hoc fashion, on both the raw casualty data and on exposure and risk rates to come to a comprehensive investigation of a certain phenomenon.

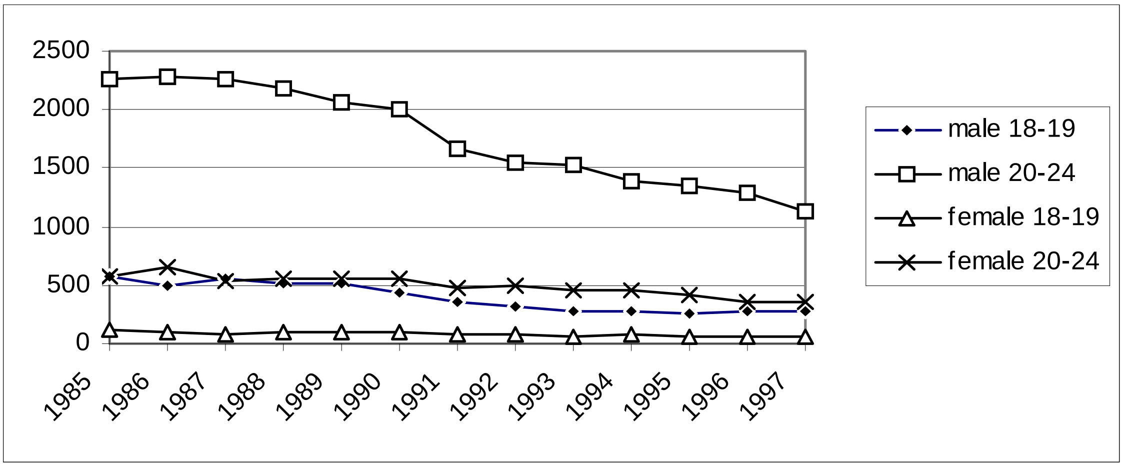

Figure 6: *Absolute number of young drivers involved in serious accidents by age group, sex and year in the Netherlands. From: Twisk, 2000.*

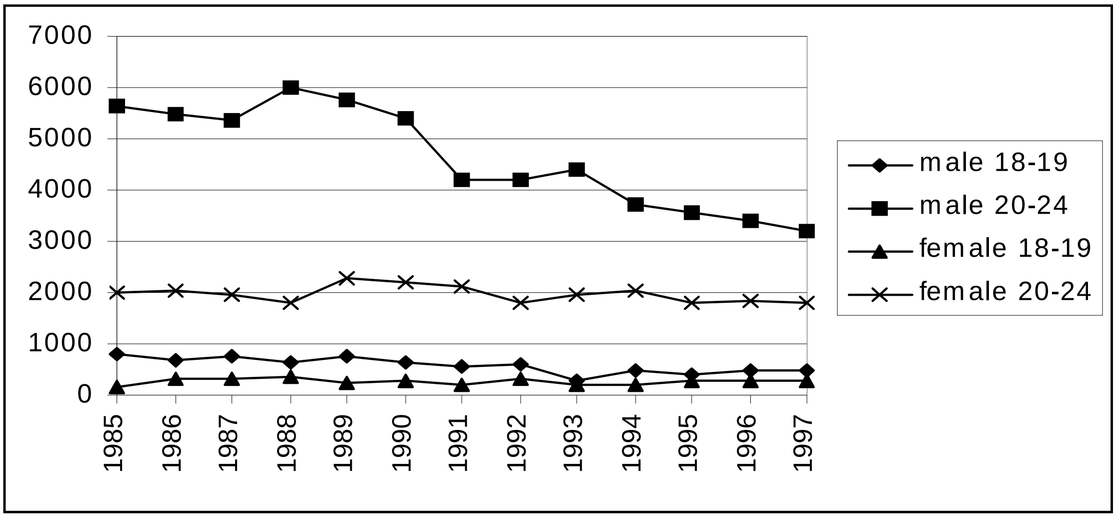

Figure 7: *Mileage (kms) by age group, sex and year in the Netherlands. From: Twisk, 2000.*

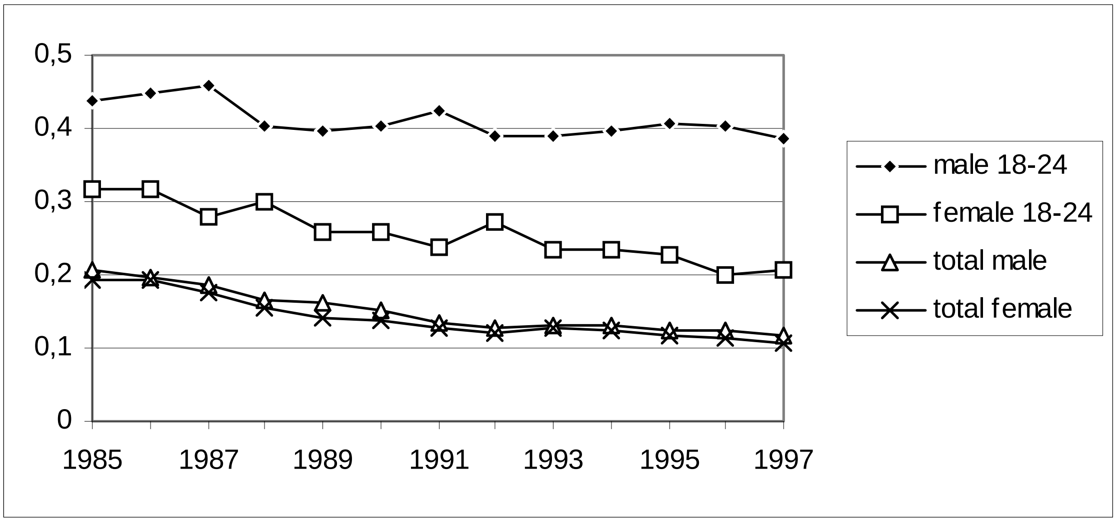

Figure 8. *Accident risk of young drivers versus total driver group by sex and year in the Netherlands. From: Twisk, 2000.*

5.8. Road safety in the Netherlands up to 1999

Van Schagen (2000) published a report which describes the extent and nature of road safety in the Netherlands over a period of 15 years and which served as the basis for prognoses on the developments in road safety to be expected in the future (the year 2010). Trends, backgrounds and explanations of the data were presented. A number of developments which are known to have a strong relation with safety, were studied in detail. These included certain driver behaviours-speeding, drinking-and-driving and the use of seat belts. Developments in certain driver groups were also analysed separately: moped riders, lorries, older car drivers and cyclists. It was possible to reach conclusions about the prognoses after making separate prognoses about the trends in vehicle kilometres and the casualty and fatality rates. Having established the development in exposure and in casualty rates, it became possible to predict the future number of casualties and fatalities in the year 2010. On the basis of these predictions conclusions were reached on the possibility of reaching the strategic targets the government had set for that year.

6. A more detailed discussion on risk and exposure in the context of infrastructure

6.1. The relationship between accidents and traffic volumes

One of the main reasons for defining and using exposure in studies related to infrastructure is to equalise for differences in intensity of use, so as to make comparisons meaningful. The unit of study might be a number of road sections or a number of intersections. Accident rate (Ar) is thus defined as:

$$Ar = \frac{\text{Expected number of accidents over a certain period of time}}{\text{Amount of exposure over a period of time}}$$

The number of accidents is related to the exposure and generally increases with an increase in exposure. The shape of the curve that relates the two entities is nowadays termed a 'safety performance function' (Hauer, 1995a; Ekman, 1996; Persaud et al, 1999). It has by now been well- established that for road sections the shape of the safety performance function (SPF) is not a linear one. *Figure 9* gives an example of a hypothetical SPF for a road. Accidents vary according to the amount of exposure in a non-linear way. In this context the exposure is generally expressed as traffic volume (AADT) or as vehicle kilometres travelled. When discussing intersection safety the relevant measure of exposure would be the number of vehicles entering the intersection, or some measure thereof. In that case too, the relationship is normally not linear.

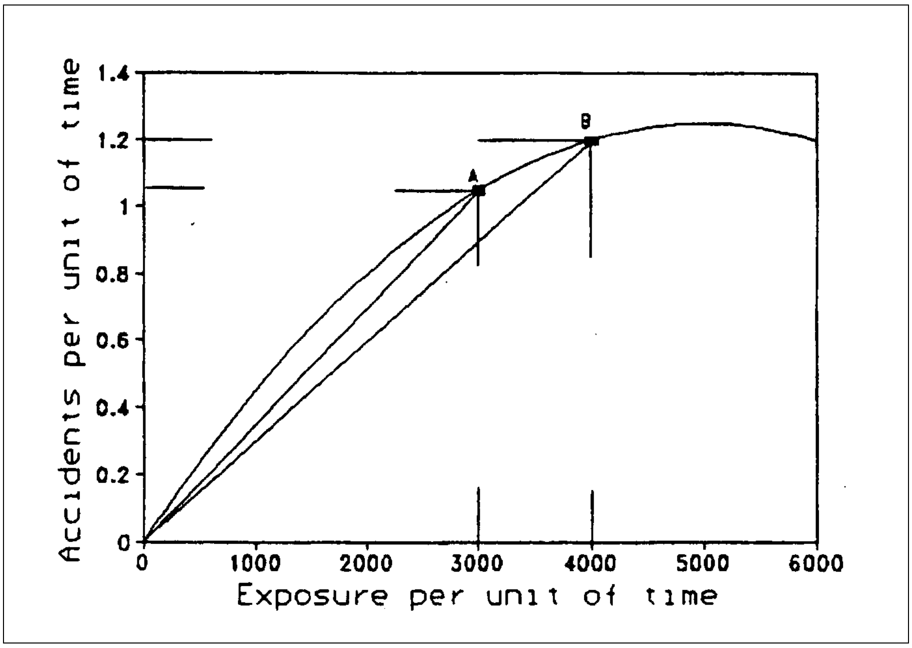

Figure 9. *Safety performance function and accident rates. From: Hauer (1995a).*

It can thus be stated that division by exposure does the job of equalising only if the SPF is a straight line(through the origin). If the SPF is non-linear, the accident rate is of limited use, or incorrect. For the passing motorist a lower rate would still mean that per travel unit the chance of an accident is lower, hence we could talk of a lower risk. From the point of view of those who wish to consider the effect of a road safety intervention (a change to a road section or intersection) it would be impossible to relate the change in the accident rate to the intervention. One would first have to know the shape of the SPF before one could make an intelligent statement. A drop in accident rate does not necessarily mean that the intervention improved safety. The rate of accidents or fatalities per million vehicle kilometres travelled (million VKT), which is a widely used index of comparison, generally decreases over time for a variety of reasons. Vehicle kilometres travelled are generally defined as the distance travelled per vehicle multiplied by the number of vehicles. Each additional vehicle-km causes a smaller increase in the number of accidents. The decreasing slopes of curves OA and OB (see *Figure 10*) represent this fact. The ratio of accidents per vehicle-km is given by the angle a. The meaning of an improvement in safety is that, for each amount of travel, the resulting number of accidents is reduced. Therefore, curve OB describes an improvement over curve OA. For each amount of travel, the resulting number of accidents is smaller. It can be seen from *Figure 10* that the change in accident rate by itself does not indicate a change in safety. Point C, having a smaller slope than D (a<b) is worse than D from the overall safety point of view, but the fact that the accident rate is lower means that for a passing motorist the risk is lower.

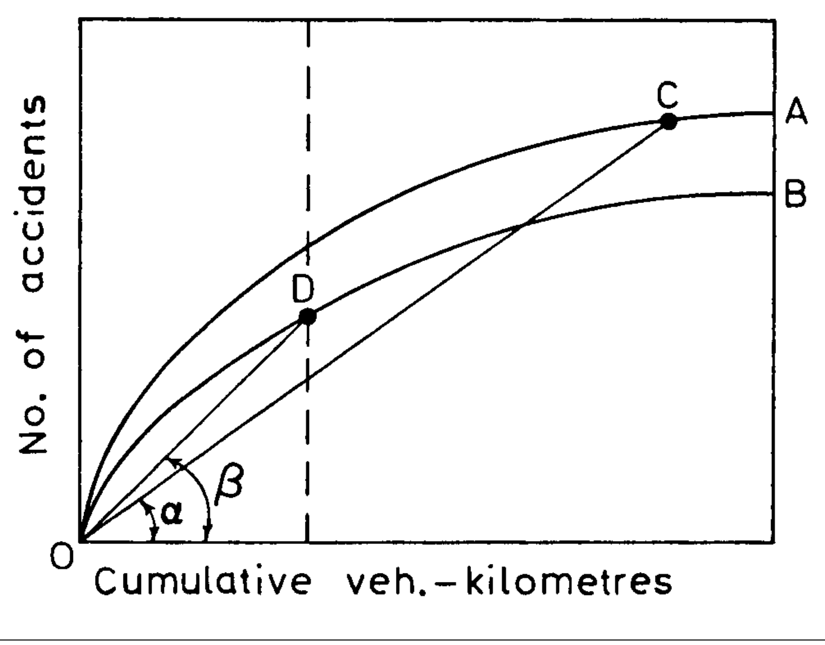

Figure 10. *The relationship between number of accidents and cumulative vehicle kilometres travelled. From: Hakkert, Livneh & Mahalel, 1976.*

Similarly, when taking this line of argument to other fields of safety intervention it can also be concluded that there is little ground for assuming that the number of aviation fatalities is linearly related to the number of flighthours, or that the number of truck accidents is proportional to truck-miles travelled or to ton-miles carried.

The next part of this section will present findings from some studies that indicate the non-linearity of the relationship between accidents and traffic flow.

6.1.1. *Safety Performance Functions (SPF)*

The detailed relationships between accidents and traffic volumes have been discussed extensively in the literature and during the past 5-10 years have become known as Safety performance Functions (SPF) in the North-American literature (Hauer, 1995a; Persaud et al.1999). A safety performance function (SPF) is the relationship between the traffic volume (AADT) on a highway and the safety of that highway, defined as the number of accidents (defined per unit of time and highway length). SPFs have been calibrated for a number of locations, mainly on rural highways, both two-lane rural roads and freeways.

Persaud et al. (1999) present a number of SPFs developed as part of their work on rural roads in Ontario, Canada. For a set of 197 rural four-legged signalised intersections in Ontario, during the years 1988-1993, the SPF was estimated as:

No. of accidents/year = 0.0005334 x (total entering AADT) exp 0.8776

For two-lane paved rural highways in Ontario, during the years 1988-1993, a set of 28,000 0.5 km long sections was selected. Only accidents with injury were included in the study. The SPF developed was:

No. of injury accidents/year = 0.000637 x (section length) x [exp(-0.08215)
X (total road width)] x (AADT) exp 0.8993

It can be seen that for both the intersection and road section models the exponents for traffic volume were 0.8776 and 0.8993, indicating a non-linear relationship between accidents and traffic volume.

For 4-lane freeways in Canada, Persaud et al. (1999) calibrated the following SPF for injury accidents:

Injury accidents = (Section length) (0.0000537) (AADT) exp (1.01786)

In this case it is shown that the relationship is almost linear.

6.1.2. *The relation between aggregate number of collisions and distance travelled*

Smeed (1974) studied the relationship between the aggregate number of collisions between certain types of vehicles and the distance travelled by these vehicles. He calculated and plotted the product of the distances travelled by vehicles of certain categories (cars, lorries, motor-cycles, pedal-cycles) against the number of two-vehicle accidents of those categories. He concludes that “it seems that we must, to a large extent, give up the hypothesis that the number of two-vehicle accidents is generally proportional to the product of the distances travelled by the types of vehicles involved.”

As, however, traffic volumes vary greatly during different parts of the day, it might be possible to look for a relationship by clustering accidents and traffic volumes into groups with similar traffic volumes. The number of non-pedestrian single vehicle accidents was plotted against the estimated distances travelled by the vehicles in these hours. The numbers of two-vehicle accidents of various categories in the various hours was plotted against the functions of the distances travelled in these hours. It was found that, to a considerable extent, the number of single vehicle accidents involving any type of vehicle during any daylight hour was found to be proportional to the distance travelled by vehicles of that type during those hours. The number of collisions between any two categories of vehicles during any daylight hour was found to be proportional to the product of the distances travelled by each type of vehicle during that hour. Significant discrepancies were found, however, between the expected number of accidents and the actual numbers, indicating that other factors, not taken into consideration, might also have an influence. It could also be the case that significant errors exist in the estimation of distances travelled for each type of vehicle.

In terms of safety studies related to infrastructure it seems advisable to develop and take account of Safety Performance Functions before making comparisons. The development and use of these SPFs is becoming widespread in many countries and the errors introduced by not accounting for differences in traffic volumes seem no longer warranted.

6.2. Hazardous locations

The subject of hazardous locations plays a central role in safety management of road infrastructure. At each level of administration responsible for the construction and maintenance of roads - municipalities, provincial and central government - a certain number of locations (road sections and intersections) can be identified that have a ‘higher than expected’ number of accidents. Once identified, countermeasures can be proposed for such locations and the locations can be improved. Many models exist in the literature that deal with the identification of such locations, generally termed black-spots or hazardous locations. Intrinsic to all the more advanced methods is that they incorporate a procedure for the estimation of the number of accidents that should be expected at a location of the type under consideration. Hauer (1995b) provides a review of many of the models that have been proposed in the past (see also Mahalel, Hakkert & Prashker, 1982). The first task at hand is always to devise a method that will identify a limited number of locations (sections and/or intersections) for further consideration, to be chosen from the many thousands of such locations a road authority has under its jurisdiction.

The final aim of this procedure should be the engineering treatment of a number of locations that will bring about a reduction in the number of accidents at the lowest costs possible. The locations do not therefore have to be hazardous or have a considerable concentration of accidents in order to qualify. In that sense the terms ‘hazardous location’ or ‘black-spot’ are not neutral words and Hauer suggested the cumbersome term “sites with promise” (Hauer, 1995b). The more recently proposed procedures for identifying sites for safety investigation are based on the Experimental Bayes (EB) technique. This essentially aims to smooth out the random fluctuation in accident data by specifying the safety of a site as an estimate of its long-term mean (m) instead of its short-term accident count (Persaud, B., Lyon, C. & Nguyen, T. (1999). The latter propose an improvement to the established methods by basing the selection of sites not only on the knowledge of the long-term mean but also on the calculated number of 'treatable' accidents.

There are a number of selection principles to choose a limited number of locations for further consideration out of a long list of locations. Basically the selection principle can be the number of accidents or the accident rate, being the number of accidents divided by the exposure. Variations on these two principles are also possible. Therefore, the methods proposed in the literature can be divided into selection according to the highest number of accidents or selection according to the highest rate. Again, some methods suggest a combination of the two. In deciding which is the better method, it is important to ask what the purpose of the process is. Hauer(1995b) cites three possible motives:

- Motive 1.
  Economic efficiency: identify sites at which remedial action would prove cost-effective.
- Motive 2.
  Professional and institutional responsibility: recognise and rectify sites that are deficient either because of how they were built or because they have deteriorated while in use.
- Motive 3.
  Fairness: identify sites that pose an unacceptably high hazard to the user.

For motives 1 and 2 the selection should be based on the number of accidents or the changes in the number of accidents. For motive 3 the selection should be based on the accident rate. The list resulting from a selection on the basis of motive 3, i.e. risk to the road user, will generally result in a list which includes locations with a small number of accidents and low volumes of traffic, because these are the sites that have high accident rates. Such sites will generally have low rates of return and are not to be recommended on the basis of cost-benefit considerations.

Table 8, taken from Hauer (1995b), describes five different selection criteria of which the first three are based on efficiency and rely on the number of accidents, and the last two assign priority on the basis of fairness and selection according to accident rate.

To conclude this discussion of methods for the identification of hazardous locations it has been shown that methods based on the number of accidents would generally provide a more cost-effective approach, resulting in the higher number of accidents being saved per invested unit of money. Methods based on selection according to accident rate, seem to introduce a measure of fairness into the system, but on the whole will not result in a cost-effective allocation of budgets and will not result in achieving a significant reduction in accidents. If the methods are to be made more reactive to a deterioration in the safety situation, methods have been suggested which are a variation on the accident number method.

Selection criteria		Consideration	Rank by	Comment	
A	EFFICIENCY	Measures that reduce the probability and/or severity of accidents (eg. illumination, slope reduction)	F (best done by target accid.)	These are usually high-exposure sites and tend to be near the top of the list year after year. Once they are ‘identified’ and examined, one can decide whether a safety improvement is appropriate. Sites of this kind may not need to be monitored and repeatedly identified.	
B		Deficiency since site opened to traffic (or since reconstruction) that can perhaps be cheaply rectified	$\Delta F/\sigma_F$ (Total accid.)	Such sites should be identified as soon as possible. The entire accident history (since opening or reconstruction) seems relevant to identification. However, once a site is shown to be normal, continued monitoring seems pointless.	RESPONSIBILITY
C		Deterioration of safety while in use that perhaps can easily be rectified	Size of jump in F	In this case periodic monitoring of all sites is required. It may turn out that jumps in F are statistically difficult to spot. It seems sensible to monitor for deterioration by means other than accident occurrence.	
D	FAIRNESS TO USER	It is not acceptable to have sites where the risk to road users is too large	R	These are often low-exposure sites. At such sites, a high R may be a natural consequence of lower design standards. It will take a long time to have enough accidents to estimate R reliably. Use of accumulated accidents may be necessary. Once such sites are labelled 'normal' further monitoring may not be required.	
E		It is not acceptable to have sites where the risk to a road user is considerably larger than at sites of similar class	$\Delta R/\sigma_R$	For the reason listed above ΔR is also difficult to estimate reliably and use of the accumulated accident history and clues other than accidents are important. Once such sites are labelled ‘normal’ further monitoring may not be required.	

Table 8. *Motives, considerations and ranking criteria. From: Hauer, 1995b.*

7. Summary and conclusions

The report sets out with a definition of the three central terms used: accidents, exposure and risk. Each of the three terms is defined and problems of definition, accuracy of measurement and reporting are described.

The conclusion reached is that there are general definitions of exposure and risk as used in the health prevention and risk analysis fields, but that in road safety practice these terms should be defined within the context of the issue studied. In the context of this report, exposure is meant as exposure to risk. To what extent are certain segments of the population, or certain types of vehicles likely to be involved in an accident? The measure of exposure is generally defined as some form of the amount of travel, either by vehicle or on foot. In the report, risk is used to mean the probability of an accident occurring, weighted in some way by the severity of the accident outcome. In many cases it would be better, and more neutral, to refer to rates and not to risks.

As was discussed in the report, for each application, the correct exposure measure should be used. This is sometimes impossible because the required information is not available, or has to be collected at great cost. Generally, the more aggregate the exposure measure, the more indirect variables are introduced, which casts shadows over the resulting risk calculations.

In the case of transport, the most widely used measure of exposure is the amount of travel for each travel mode. In some cases, useful additional insight is provided by taking into account the speed of travel, in which case exposure is expressed as the amount of time spent in the traffic system. Due to the very different conditions and circumstances, it is considered to be of little use to extend this comparison of risk per unit of time to other activities beyond the field of transport. Within the field of transport, transport modes can usefully be compared, up to a certain point, by risk per unit of travel or per unit of time. Taking bus and coach travel as a normative unity, it was shown that risk expressed in terms of person kilometres travelled is 10 times greater for cars and 100-200 times greater for the vulnerable modes (foot, bicycle and motor-cycle), with motor-cycles clearly being the most hazardous. Train and plane travel are also relatively safe. Looking at the same data, with risk expressed in terms of person hours of travel, does not change the picture greatly. Travel by foot and travel by bicycle become slightly less hazardous, because of the low speeds of these modes, whereas air travel becomes significantly more hazardous because of the high speeds (hence the small number of hours per kilometre).

The lack of detailed and high quality exposure data is one of the reasons that in many cases international comparisons are conducted on a per capita or per vehicle basis, and deal mostly with fatalities because of the inaccuracy of injury reporting. One of the developments in recent years is the installation of electronics and telecommunications inside vehicles and along roads. The increasingly widespread use of mobile phones also presents many new possibilities. As a result it is becoming easier to collect up-to-date and reliable information on a variety of parameters that could be of importance in the calculation of vehicle exposure and risk. Additional information on the distribution of speeds, types of vehicles and following distances also seems to be a future possibility.

On road sections, the number of vehicle kilometres is generally accepted as the relevant measure of exposure. At intersections, the correct measure of exposure is not that obvious, and has been the subject of many discussions. The product of the daily crossing flows and the sum of the products of the hourly crossing flows have been used as exposure measures in many accident studies. The definition of risk to pedestrians can be discussed in a way which is fairly similar to the discussion of risk and exposure at intersections. In this manner one obtains a measure of exposure which is the product of the traffic flow and the crossing number of pedestrians. The risk is then defined by dividing the annual number of pedestrian accidents by the exposure.

One of the contexts in which risk is used, is in comparing risks between different parts of the transport system, different transport modes or even different activities outside the field of transport. The desire is to make various activities exposed to equal risks, so as to make risk distribution ‘fair’. After discussing the various problems and pitfalls with this approach, it is concluded that the desire for equal risks in various segments of the transportation system is not practical. It is more useful to search for ways to make each segment of the transport system as safe as possible, keeping cost-effectiveness considerations into account.

The report also describes studies in which useful safety evaluations were conducted without having to resort to risk and exposure measures. On a more general level, risk can serve as the basis for the selection of research and action themes, which should then be justified on the basis of cost-benefit considerations. Decision-making can be carried out on the basis of comparative risk levels, on the basis of accident and injury data (without risk) and according to cost-benefit considerations. Each method has advantages and disadvantages and should be selected according to the circumstances. Decision-making on the basis of the number of accidents, injuries or fatalities focuses on the size of the problem, and prevents us from focussing our efforts on a segment of road safety that might look bad from the point of view of risk, but which might not be not very significant in terms of the quantities involved. Decision-making on the basis of risk tends to lead to actions that are considered fair in terms of the road users involved. It has been demonstrated in the report that this is actually not practical or reasonable. The final decision should generally be based on cost-effectiveness considerations because, in the field of road safety, like in any other field, the amount of expenditure is limited and investments should be allocated to those fields that produce the highest accident, casualty and fatality reductions that can be achieved per unit of money invested.

In the context of national levels of safety and the setting of road safety targets, it was shown that targets are generally set in numbers of casualties and fatalities. This seems preferable over setting targets regarding risks, which can become intertwined with changes in exposure (mobility), which will affect the risk. When comparing risks and safety between different transport modes, different regions of a country or different countries, however, it seems that comparisons will have to be made on the basis of accidents and fatalities per vehicle kilometre travelled and in some cases, per passenger hour. In other cases a risk per passenger trip may be more meaningful.

In chapter five, the report describes a number of studies from the major fields of road safety research and activity which deal with the issue of risk. The fields covered include the subject of the involvement of lorries in fatal accidents; driving under the influence of alcohol; the influence of speed in crashes and crash severity; risk used in assessing national safety levels; accident, injury and fatality trends; target setting; and elderly and young drivers.

Chapter six discusses the relationship between accidents and traffic volumes in more detail. This is an issue of central importance when dealing with safety of the road infrastructure and has to be understood before making risk calculations. It was demonstrated that this relationship has to be determined first, in the form of a ‘safety performance function (SPF)’, before risks on various network sections can be compared. Many studies have demonstrated that the relationship between accidents and traffic volumes is not a linear one, which complicates matters greatly. When considering safety in the context of road infrastructure, there is a need to take information on traffic volumes into account. The report has documented that gross comparisons per vehicle kilometre travelled will lead to errors. Nowadays, enough information is available to develop safety performance functions (SPFs) for various segments of the road system to make meaningful comparisons. SPFs for intersections and for pedestrian and bicycle travel should also be developed.

The report concludes with the issue of hazardous locations and establishes that locations had better be identified on the basis of the expected number of accidents, based on models developed for similar locations, rather than on the basis of accident rates (risks).

References

Borkenstein, R.F., Crowther, R.F., Shumate, R.P., Ziel, W.B. & Zylman, R. (1964). *The role of the drinking driver in traffic accidents.* Research Report. Department of Police Administration, Indiana University, Bloomington, Indiana, USA.

Brundell-Freij, K. & Ekman, L. (1990). *Safety and exposure- aspects of the relationship with special attention to vulnerable road users*. Research report. Dept. of Traffic Planning and Engineering, University of Lund, Sweden.

BTS (2001). *Transportation data and risk measures.* Bureau of Transportation Statistics, www.bts.org, USA

Commandeur, J.J.F. & Koornstra, M.J. (2001*). Prognoses voor de verkeersveiligheid in 2010* (Predictions of road safety in 2010). SWOV report R-2001-9. SWOV, Leidschendam, the Netherlands

Commandeur, J.J.F. (2002, in preparation) *Algemene en periodieke trends in de ontwikkeling van de verkeersveiligheid in acht ontwikkelde landen* (General and periodical trends in road safety development in eight developed countries). SWOV, Leidschendam, the Netherlands.

Davidse, R.J. (2000). *Ouderen achter het stuur* (The elderly at the wheel). SWOV report D-2000-5. SWOV, Leidschendam, the Netherlands.

Despontin, M., Verbeke, A. & Brucker, K. de (1997*). The economic evaluation of road safety in the European Union*. In: Proceedings of the European Seminar on Cost-Effectiveness of Road Safety Work and Measures. November 1997, Luxembourg.

DUMAS (1998) *Accident Investigation; final report Work Package 4*. Prepared by DENCO (GR), University of Brescia (I), INRETS (F), TRL (UK), AUTh (GR). Developing Urban Management And Safety (DUMAS).

Ekman, L. (1996). *On the treatment of flow in traffic safety analysis*. Bulletin 136, Institute of Traffic Studies, Technical University of Lund, Sweden

Elvik, R. (1997). *Cost-benefit analysis of road safety measures is more important and relevant than ever before*. In: Proceedings of the European Seminar on Cost-Effectiveness of Road Safety Work and Measures. November 1997, Luxembourg.

Erskine, A. (1996). *The burden of risk: who dies because of cars?* Social Policy and Administration, 30(2), 143-157.

ETSC (1999). *Exposure data for travel risk assessment: current practice and future needs in the EU*. European Transport Safety Council, Brussels, Belgium

Evans, A. (1993). *Older road users - the role of government and the professions*. In: Proceedings of road safety conference. AA Foundation for Road Safety Research, London.

Evans, A.W. (1994). *Multiple-fatality transport accidents 1946-1992.* In: Department of Transport (ed.) Transport Statistics Great Britain 1994, pp. 17-29. HMSO.

Evans, L., Frick, M.C. & Schwing, R.C. (1989). *Is it safer to fly or drive? –A problem in risk communication.* General Motors Research report, General Motors Research Laboratories, Michigan, USA.

Finch, D.J., Kompfner, P., Lockwood, C.R. & Maycock, G. (1994*). Speed, speed limits and accidents*. Project Report 58, S211G/RB, Transport Research Laboratory, Crowthorne, Great Britain

Haight, F.A. (1986). *Risk, especially risk of traffic accident.* Accident Analysis and Prevention, 18, pp. 359-366.

Harvey, A.C. & Durbin, J. (1986). *The effects of seat belt legislation on British road casualties: a case study in structural time series modelling.* Journal of the Royal Statistical Society, 149, pp.187-227.

Hauer, E. (1982). *Traffic conflicts and exposure.* Accident Analysis and Prevention, 14, pp. 359-364.

Hauer, E. (1995a). *On exposure and accident rate.* Traffic Engineering + Control, 36(3), pp.134-138.

Hauer, E. (1995b). *Identification of sites with promise*. TRB Record 1542. Transportation Research Board, Washington DC, USA.

Hauer, E. (2001). *Computing and interpreting accident rates for vehicle types or driver groups*. TRB meeting paper, TRB annual meeting, Washington DC, January 2001, USA

Hakkert, A.S. & Bar-Ziv, J. (1976*). Accident risk and delays at mid-block pedestrian crossings*. International Forum Series (Vol. 2): Traffic, transportation and urban planning. George Godwin Publishers, London, pp. 165-174.

Hakkert, A.S., Livneh, M. & Mahalel, D. (1976). *Levels of Safety in Accident Studies - A Safety Technology Index.* In: Proceedings of the 8th Australian Road Research Conference, August 1976, Session 27, pp. 1-6.

Hurst, P.M., Harte, D. & Frith, W.J. (1994). *The Grand Rapids Dip Revisited.* Accident Analysis and Prevention, 26, pp. 647-654.

Kruger, H.P., Kazenwadel, J. & Vollrath, M. (1995*). Grand Rapids Effects revisited: Accidents, Alcohol and Risk*. In: Proceedings of the 13th International Conference on Alcohol, Drugs and Traffic Safety, ICADTS.

Li, G., Braver, E.R. & Chen, L.H. (2001). *Exploring the high driver death rates per vehicle-mile of travel in older drivers: fragility versus excessive crash involvement.* IIHS research report. The Insurance Institute for Highway Safety, Arlington, USA

Lyman, S. & Braver, E.R. (2001). *Occupant deaths in large truck crashes in the United States: 25 years of experience.* IIHS research report. The Insurance Institute for Highway Safety, Arlington, USA.

Mahalel, D. & Hakkert, A.S. (1976). *Estimating the number of accidents at intersections from a knowledge of the traffic flows on the approaches.* Journal of Accident Analysis and Prevention, Volume 10, no. 1, pp 69-79.

Mahalel, D., Hakkert, A.S. & Prashker, J.N. (1982). *A system for the allocation of safety resources on a road network.* Accident Analysis & Prevention, 14 (1), pp. 45-56.

Mathijssen, M.P.M. & Twisk, D.A.M. (2001). *Opname en afbraak van alcohol in het menselijk lichaam. (Demonstration of the metabolism of alcohol in the human body).* R-2001-19. SWOV, Leidschendam.

Nilsson, G. (1997*). Methods and necessity of exposure data in relation to accidents and injury statistics*. IRTAD Special report. Swedish Road and Transport Research Institute, Linkoping, Sweden

Older, S.J. & Grayson, G.B. (1976*). An international comparison of pedestrian risk in four cities.* In: Proceedings of the International Conference on Pedestrian Safety. Michlol, Technion, Haifa, Israel

Persaud, B. et al. (1999*). Applying the science of highway safety to effect highway improvements- a multi-disciplinary approach*. In: Proceedings of the Canadian Multi-disciplinary Road Safety Conference XI, Quebec, Canada, April 1999.

Persaud, B., Lyon, C. & Nguyen, T. (1999). *Empirical Bayes procedure for ranking sites for safety investigation by potential for safety improvement*. TRB record 1665, Transportation Research Board, Washington DC, USA.

Poortvliet, A. van (1999). *Risks, disasters and management - A comparative study of three passenger transport systems*. Ph.D. thesis, Technical University Delft, the Netherlands.

RIVM (1998) *Milieubalans 1998*. From: http://www.milieubalans.rivm.nl

Roberts, I., Norton, R. & Taua, B. (1996). *Child pedestrian exposure rates: the importance of exposure to risk relating to socioeconomic and ethnic differences in Auckland, New Zealand.* Journal of Epidemiol.Community Health, *50*, pp. 162-165.

Roszbach, R. (1998). *Risicobenaderingen in wegverkeer*. (Risk approximations in road traffic). SWOV report R-98-13. SWOV, Leidschendam, the Netherlands.

Rumar, K. (1999). *Road safety and benchmarking*. In: Proceedings of the Paris Conference on Transport Benchmarking. November 1999, Paris, France.

Schagen, I.N.L.G. van (2000). *De verkeersonveiligheid in Nederland tot en met 1999*. (Road safety in the Netherlands up to 1999). SWOV report D-2000-15. SWOV, Leidschendam, the Netherlands.

Smeed, R.J. (1974). *The frequency of road accidents.* Zeitschrift für Verkehrssicherheit, 20(2), pp. 95-108.

Solomon, D. (1964*). Accidents on main rural highways related to speed, driver and vehicle.* Bureau of Public Roads, Dept. of Commerce, USA.

Taylor, M.C., Lynam, D.A. & Baruya, A. (2000) *The effects of drivers' speed on the frequency of road accidents*. TRL report 421. Transport Research Laboratory, Crowthorne (UK).

Thompson, K.M., Graham, J.D. & Zellner, J.W. (2001*). Risk-benefit analysis methods for vehicle safety devices*. In: Proceedings of the 17th International Conference on the Enhanced Safety of Vehicles, June 2001, the Netherlands.

Twisk, D.A.M. (2000). *Why did the accident involvement of young (male) drivers drop by about 50 percent?* In: Proceedings of the 10th seminar on behavioural research in road safety. Esher, Surrey, 3-5 April 2000, pp. 109-117.

Wesemann, P., Bos, J.M.J., Hertog, P.C. den, Adriaanse, M.C. & Blankendaal, A.C.M. (1998). *Onveiligheid van wonen, verkeer, arbeid en sport*. (Safety in the sectors and social activities: domestic, traffic, industry and sport). SWOV report R-98-70, SWOV, Leidschendam, the Netherlands