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On the Treatment of Flow in Traffic Safety Analysis

a non-parametric approach applied on
vulnerable road users

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With gratitude and joy,

Dalby, Good Friday 1996

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Summary

The treatment of flow in the area of traffic safety has a long tradition. The influence flow has on the number of accidents is, however, often considered so obvious that it tends to be trivial. In this thesis I can show that the relation between flow and accidents holds interesting information. Knowledge about such relations may be very useful for several purposes.

Traffic flow counts or other expressions of the traffic exposure are often only used to construct accident rates. Quite often the concept of accident rates is used synonymously with "risk". There is, however, a great risk '!' in mixing these two concepts. The word 'risk' is spontaneously interpreted as danger or hazard for someone involved in a certain activity. In common life, risk is used as a very broad concept including both the probabilities of an unwanted event, as well as the consequences of this event. The concept of accident rate is often used to avoid this "over-interpretation", but nevertheless also this concept needs to be treated with care.

Based on the way accident rates are used three main streams in the use of accident rates and exposure have been found. These three groups were derived from how different researchers used or interpreted their results. The three approaches are:

- The probability approach
- The effectiveness approach
- The standardization approach

The first approach is what is referred to when discussing accident rate in general. The other two approaches constitute a classification system based on the way in which the computed rates seemed to be interpreted.

In order to compare countermeasures, or conduct other types of traffic safety comparisons where the flow varies, it is vital to know the full shape of the relation between accidents and flow. Such relations are called Safety Performance Functions (SPF). If we focus on the situation for individual road users the equivalent Risk Performance Functions (RPF) may be used to increase the comparability. The traditional comparison of accident rates is equal to assuming the SPF is a straight line, and thus the RPF is a constant.

The main aim of this thesis is to develop a "transparent" system for estimating SPFs and RPFs. One step towards a transparent and, thus, interpretable treatment of accident and flow data is the development of a system for aggregating approaches in order to create aggregates with equal, or at least manageable, precision. The aggregation is based on relevant flow and is made in such a way that all aggregates represent the same number of the relevant road users.

In order to generate a non-parametric function, without built-in presumptions of the overall relationship between flow and accidents, moving averages line is used. A series of computer programs is developed in order to describe the accuracy of the resulting functions. Two computer intensive methods: simulation and bootstrap, are used. With both these methods, "exact" confidence intervals are produced.

Bootstrap is based on random selection, with replacement, from the original data observations. With this method several new data sets are constructed. The procedure is completed all the way throughout the analyses, over and over again, each time producing a bootstrap replicate of the end result. In order to estimate the confidence intervals the procedure has to be repeated about 1000 times.

Confidence intervals are then computed by a process of interpolation. The confidence intervals may only be produced in the range where there are several observations in the original data set. A special routine to handle this "edge problem" has also been developed.

The stability of and the power of the computation of confidence intervals is tested with the use of synthetic data sets produced by a random process. The 80% confidence intervals seems to be slightly "conservative" i.e. covering the true value in more than 80% of the cases.

The method developed was applied to a data set consisting of accident records, conflict observations and traffic flow counts for different road user categories from 95 non-signalized intersections in the cities of Malmö and Lund.

The result on bicycle and pedestrian safety is illustrated by the following Risk Performance Functions:

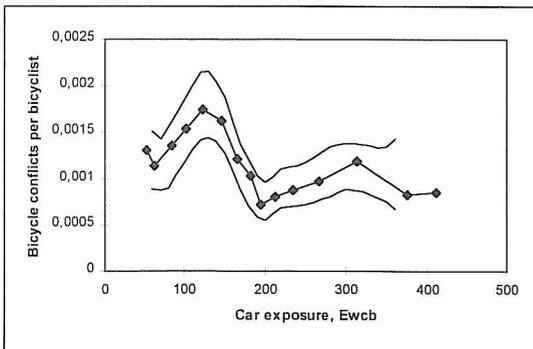


Figure 0.1 *Bicycle conflicts per bicyclist versus accumulated and weighted car flow (E_{wcb}). Moving average line (RPF) with an estimated 80% confidence interval*

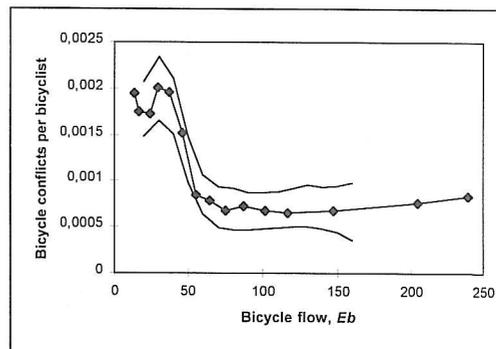


Figure 0.2 *Bicycle conflicts per bicyclist versus bicycle flow (E_b) Moving average line (RPF) with an estimated 80% confidence interval*

The results regarding bicycle safety are:

- the conflict rate for bicyclists is twice as large at locations with low bicycle flow compared to locations with higher flow
- the conflict rate for bicyclists seems to be high at locations within a limited range of car flow
- bicycle flow seems more significant than car flow for the conflict rates for individual bicyclists
- the conflict rate is generally higher for bicyclists approaching intersections from the minor street compared to those coming from the main street
- the difference in conflict rate between low and high bicycle flow is larger than differences due to the design variables tested: the width of the road and major or minor street

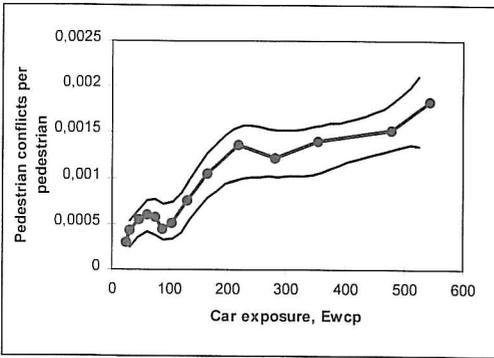


Figure 0.3 *Pedestrian conflicts per pedestrian versus car exposure (incoming cars per hour). Moving average line (RPF) with an estimated 80% confidence interval*

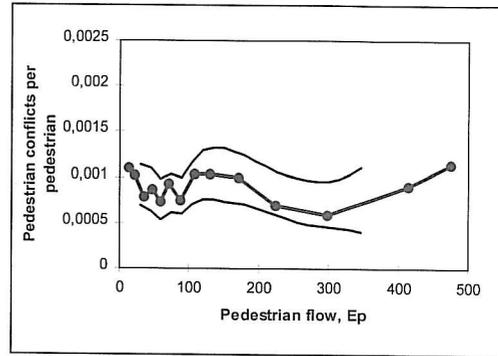


Figure 0.4 *Pedestrian conflicts per pedestrian versus pedestrian flow. Moving average line (RPF) with an estimated 80% confidence interval*

The results regarding pedestrian safety are:

- the conflict rate for pedestrians is largely unaffected by pedestrian flow
- car flow seems to be of great importance for the conflict rate for pedestrians
- the increase in conflict rate by increasing car flow seems to be a "step function" rather than a linear function

- zebra marking seems to increase the conflict rate for locations with low pedestrian flow, irrespective of car flow
- refuge seems to give a decrease in conflict rate which is larger than the increase "caused" by the zebra marking
- it has not, however, in this study, been possible to show that the width of the street or whether the street is a main street or minor street, has any significant impact on conflict rate for pedestrians

The empirical application has confirmed that:

- the method of aggregating and averaging gives a function with good visual interpretability
- the bootstrap method gives an accurate and useful description of the stability of the estimated non-parametric function
- the relationship between conflicts and flow is complex
- knowledge about such relations could improve traffic safety evaluations that include comparisons between groups of locations with different flow
- analyses of the non-parametric functions may be the base for suggesting active flow manipulation as a traffic safety measure
- information about the effect of flow on safety may be used to generate hypotheses about the processes underlying traffic safety problems

Thus, the question is not anymore whether flow contains valuable information for traffic safety analyses, but rather, if we are going to make use of that information in improving traffic safety.

1 Introduction

The fact that the amount of traffic affects traffic safety is so obvious that it tends to be considered trivial. In fact the amount of traffic, often called traffic *flow* or more general *exposure*, is often treated as a matter of routine. The relation between accidents and flow is, therefore, often assumed to be a simple (linear) relationship. One important message carried by this thesis is that there is all reason to assume that the relation is **not** that simple. One of my aims is consequently to highlight the need for more sophisticated analyses of the relationship.

The issue of the relation between flow and accidents is especially vital for *vulnerable road users* since we in their case need to consider both the amount of car traffic and the amount of vulnerable road users. The mix of road users with so different characteristics, implies more complex interactional patterns than if only one type of road user is involved. This in its turn implies more complex relationships between flows (cars and vulnerable road users) and accidents.

In spite of this and the fact that vulnerable road users represent a significant part of all killed and injured in traffic accidents, there are very few - if any - assessments of the safety of vulnerable road users which consider the influence of the amount of vulnerable road users. One reason is, of course, the lack of efficient techniques to count pedestrians and cyclists automatically. One other reason, though, is the vague interest for thorough analyses of vulnerable road users' safety, both by researchers and practitioners. One typical example is safety on zebra crossings for pedestrians. In spite of decades of large scale implementation of zebra crossings in Sweden, there was no proper evaluation of the safety effects. In my licentiate thesis I presented the first research study in Sweden on the safety effects of zebra crossings (Ekman, 1988). That study initiated my general interest for the safety of vulnerable road users and in particular for the relation between flows and accidents.

When our work in the area of exposure for vulnerable road users began, Karin Brundell-Freij and I were actually looking for the ultimate and "correct" measurement of exposure for vulnerable road users. We experienced, however, that such ultimate measurement of exposure could not be found and would only further burden the area of traffic safety analyses. Some new measurements of exposure were, however, constructed as described in (Brundell-Freij & Ekman, 1990). What we found was, that not only in the area of traffic safety analyses regarding vulnerable road users, but also elsewhere, the use of flow data was not as easy and straight forward as we and others had thought.

The main aim of this thesis is to provide a "transparent" system for treating the relation between accidents and flow. For this purpose I first start by looking at traffic safety analyses in general and the need for knowledge about the influence of flow (Chapter 2). In chapter 3 I discuss the use and misuse of accident rates

for treating the flow dependence of accidents in traffic safety analyses. This leads to a general discussion about accident and flow relations by introducing a *safety performance function* (chapter 4). The present safety situation for vulnerable road users is described by using general accident statistics in chapter 5. In chapter 6, I refer to the specific case study on pedestrian crossings mentioned above, where pedestrian accidents and the pedestrian flow is treated.

In chapter 7, I have developed the theoretical basis for describing the flow and safety relationship by a non-parametric function on safety and *risk performance functions*. A method to describe the stability of the resulting non-parametric function is developed, in chapter 8, by the use of computer intensive methods: simulation and statistical bootstrap.

The proposed method is then applied on a data set with data on bicycle and pedestrian conflicts and flow counts for the different road users. The result on bicycle safety is presented in chapter 9 and for pedestrians in chapter 10.

Finally I conclude by discussing the consequences of the developed safety and risk performance functions for traffic safety analysis, in chapter 11.

2 Traffic Safety Analysis

2.1 The need for traffic safety analysis

An activity such as traffic that results in hundreds of killed, thousands of injured and which affects all persons who sometimes experience fear, needs to be properly addressed. Traffic safety analysis is one of the vital tools for defeating the accident and security problem connected to traffic. I will not discuss the need for traffic safety analysis in great detail as it has been thoroughly investigated by Linderholm (1992) among others.

The general definition of the concept of traffic safety of an entity (location, person, etc.) is the expected number of accidents for that entity in a unit of time. (Hauer, 1992 (b)) It should actually be "traffic un-safety" .

Linderholm structures the traffic safety problem in the following hierarchical way according to the level on which actions could be taken:

- the structure of society
- the design of the traffic system
- the detailed system

Linderholm points out that actions often are taken on the lower level, "most solutions are sought on the lower level, in spite of the basic problem being one or two levels up". Despite what level we are working on, the need for proper evaluation tools is vital. Since traffic accident statistics, as well as most other measures of traffic safety, involve great uncertainty, the need for proper analysis is even more essential. Analyses concerning any of the three levels need consideration of flow aspects. In traffic safety evaluations of a detailed system, different flow levels are often considered as "disturbing factors" in the analyses. On the highest levels changes in flow are considered a mean to affect traffic safety and other negative consequences of traffic. In my opinion, even on the lowest level, flow could be regarded as a "tool" for traffic safety work.

The traffic safety handbook produced by TØI (1989) suggests three ways of improving the traffic safety situation:

- reduce the amount of traffic (exposure)
- reduce the probability of an accident to occur (reduce accident risk)
- reduce the consequences of a collision

While recognising the importance of the third item, this report will only deal with the two first items. Reduction of the consequences of accidents is an issue with great diversity. It includes producing safer vehicles, building a more "forgiving"

traffic environment (lamp posts etc.) as well as for example persuading bicyclists to wear helmets. The area of traffic planning and engineering, however, deals primarily with the first two levels. Measures influencing these two levels in the structure given by TØI, are often called *active safety* countermeasures in contrast to those influencing the third item which are called *passive safety* measures.

One way of introducing flow implications - among others - is suggested by Thulin and Nilsson (1994). They present the accident situation in a three-dimensional process where the accident problem is defined as follows:

$$E(F) = \frac{\text{Number of Fatalities}}{\text{Number of injured}} * \frac{\text{Number of injured}}{\text{Million kmtravelled}} * \text{Million kmtravelled}$$

where $E(F)$ is the expected number of fatalities due to road accidents. On an individual level it is quite obvious that the number of fatalities is not linearly related to the distance travelled, as implied by the equation proposed by Thulin and Nilsson. On an aggregated level, however, the equation gives a good opportunity to describe the difference between road user groups in terms of the varying mix of the three different dimensions. One interesting result from this analysis is that elderly car drivers have a high value of the first rate which describes the vulnerability of the road users (number of fatalities per injured person), 0,06 compared to 0,03 for the middle-aged. On the second rate (number of injured per distance travelled) the elderly also have a high value, 0,32 compared to 0,08 for the middle-aged. However, since the distance travelled is much lower, 940 compared to 13.785 for the middle-aged, the number of fatalities among the elderly is not that extremely high (24 compared to 42 for the middle-aged drivers).

Almost all traffic safety work includes some kind of comparison between groups of road users, locations, time of the day, year, etc. This comparison is the main subject of this work, and most of the questions raised in connection with comparisons are rather complicated. The aim of this work has been to contribute with some tools and the theoretical framework for comparisons where flow varies between the entities compared.

2.2 The general need for comparability

In the area of traffic safety, you encounter several theoretical and practical problems when making the analyses. Most of those problems are related to the variation and covariation of several important factors between locations and over time. Furthermore, from an analytic point of view accidents are too rare events, in order to "produce" enough data so that proper analyses can be conducted. Data are also seldom perfectly adapted to a specific study aim.

The safety evaluation of a countermeasure can be designed according to different experimental design strategies, TØI (1989) gives the following options:

- statistical experiments
- before and after studies with control group
- before and after studies without control group
- with-and-without comparisons
- statistical covariation studies

All of these design strategies have advantages as well as disadvantages and are suited to answer slightly different questions. Statistical experiments are, however, considered the best method by most researchers in most cases. Properly controlled statistical experiments are, however, quite rare in the area of traffic safety for several reasons. The most important one is that it seems very difficult to be able to conduct a proper random sampling procedure in our area of science. For political, ethical and economical reasons it is often impossible to conduct random selection of objects to treat or not to treat.

No matter which study design is used there will always be a crucial moment of comparison. In many cases the comparison is not as easy as one first assumed. In most comparison situations the amount of traffic plays a vital role, since the amount of traffic rarely is the same in the entities to be compared. Traffic flow, or more generally speaking the exposure, plays an important role in most traffic safety comparisons.

2.3 The role of flow in traffic safety analysis

In section 2.1 I claimed that on an individual level it is quite obvious that the number of injuries is not linearly related to the distance travelled. If you are travelling a lot the experience is likely to increase. If a person rarely appears in the traffic environment his behaviour can be expected to be rather different from that of the average person.

The safety implications of this may vary a lot. While an increased experience leads to a generally increased ability of making correct predictions regarding safety related events, there is, at the same time, a risk that the increased experience is automating the behaviour to such an extent that the preparedness for safe actions is reduced. ("I have been travelling here thousands of times, and I have experienced nothing that could cause an accident").

In contrast the inexperienced road user might make incorrect predictions. On the other hand he is (most often at least) well aware of the fact that he is inexperienced and, therefore, also tries to compensate for that by acting more cautiously. I do not want to discuss psychological theories more in detail. It is not necessary.

I just want to point to the fact that there are obviously quite strong safety implications on an individual level due to variations in experience. The aggregated result of this, i.e. the sum of accidents in a defined system is, of course, also strongly related to the experiences obtained by the individual road users. The amount of traffic is then strongly influencing the evolution of experience. The amount of traffic is not only a "physical" factor, (i.e. the more road users there are the more likely it is to collide with one), but also an important factor in shaping the expectations of road users.

The importance of flow on safety is clearly demonstrated by researchers. Pasanen (1993), for instance, studied pedestrian accidents by video recording a busy urban intersection in Helsinki. He showed that none of the accidents he recorded on video included pedestrians being hit by a car driving in a platoon. All the accidents involved so called "free cars". It is quite natural that pedestrians do not enter the street while a platoon is moving in front of them. If the platoon, on the other hand, is at standstill it encourages many pedestrians to cross. Thus the presence of crossing opportunities is likely to affect the traffic safety situation for pedestrians. Platooning is, of course, related to the amount of flow but not in a simple way, especially if there are signalized intersections in the surrounding.

Theories about behavioural adaptation play an important role today, when discussing traffic safety. In an OECD-report (1990) it was stated that *"behavioural adaptation exists, and does have an effect on the safety benefits achieved through road safety programmes. Results indicate that, generally, behavioural adaptation does not eliminate the safety gains obtained, but it does reduce the effectiveness of road safety programmes in a number of cases."*

The concept "behavioural adaptation" is used for the disturbing factor, that unintended road user behaviour modifications is to planned traffic safety improvements. This could for example be caused by increased speed from drivers that feel safe. Behavioural adaptation may, however, well be seen as a part of normal, but complex, interaction between a road user and the vehicle, road and other road users.

One factor that influences the behavioural adaptation is the "social norms" described in a model by Fishbein and Ajzen(1975). For instance, the behaviour of a pedestrian is dependent on the presence of other pedestrians, forming an informal group. A typical example of this is when we, as pedestrians hesitate to act in a risky manner, by for example, avoiding to cross in a short gap, when there are children around.

Another factor that influences behavioural adaptation is the expectation of the driver. An example of the effect of low expectation is given by Draskóczy (1988). She looked at bus drivers' expectations on trains at railway crossings.

Table 2-1 *Speed of buses at different railway crossings (Draskóczy, 1988).*

Type of crossing	Crossing	Number of trains per day	Mean of minimum speed of approaching busses
Without active protection	a	20	21.0 km/h
- " -	b	20	27.5 km/h
Protected by flashing lights	c	52	23.3 km/h
- " -	d	200	16.0 km/h
- " -	e	200	18.2 km/h
- " -	f ¹	106	7.8 km/h

From, Table 2-1 we can see that bus drivers' increased expectation of a danger at the locations with more trains, result in lower speed. Speed is, by the way, known as the key factor in balancing the behavioural adaptation.

The examples I have presented indicate clearly that the relationship between flow and safety can be expected to be rather complex. Despite this, traditional traffic safety research has concentrated on accident rates, thus obscuring the complex relationship. This is further elaborated in the next chapter. The same also holds for practical implementation. In the Swedish handbook for assessing the effects of road and street investments, accident rate is the key variable (Vägverket, 1989). The new approach in 1989 was that accident rates could be calculated for each stretch of road, based on the accident rate computed from the accident statistics and on the expected value for this specific road environment. Thus, different expected accident rates are presented for all sorts of road environments. This assumes that accident rates differ significantly due to different road layout, but, not, however, due to the influence of other road users. Which could according to above well be the case, due to platooning effects, road users' expectations, informal groups, or any other flow related phenomena.

¹ Crossing "f" was a special case, as a severe accident with many fatalities had occurred there some years before. This fact caused drivers to behave extra cautiously.

3 The Use of Accident Rates

3.1 The definition of accident rate and risk

It seems to be rather obvious that there is a general demand for accident rates. Since the amount of traffic varies and thereby the general expectation on the traffic safety outcome the need for tools for better comparison is evident. The risk concept is often used without much thought and is vaguely defined. The general definition of accident rate, as for example used by TØI (1989), is:

$$\textit{Accident Rate} = \frac{\textit{Number of accidents}}{\textit{Exposure}}$$

Exposure as used in the denominator is normally some kind of measure of the amount of traffic that has resulted in the accidents. The choice of measure of exposure is quite often made somewhat arbitrarily depending on the available statistics. Several studies have looked into the selection of suitable measures of exposure (e.g. Nilsson et al, 1978,1980,1983, Haight, 1986, Brundell-Freij & Ekman 1990)

Quite often accident rates are used synonymously with risk. There is, however, a great risk '!' in mixing these two concepts. The word 'risk' is spontaneously interpreted as danger or hazard for someone involved in a certain activity. In common life, risk is used as a very broad concept including both the probabilities of an unwanted event, as well as the consequences of this event. A risky situation could be a situation with high probability or a situation with fear of severe consequences. Situations with both high probability and severe consequences, are of course also considered risky. A bigger problem arises when we try to compare situations with both different probabilities and different consequences if an accident would occur. This is the reason why I prefer to talk about accident rates rather than risk. This assumes that the outcome is somewhat similar for the situations compared. At least the concept of accident rates does not imply that it is trivial to compare situations with different severity.

My experience is, however, that even if the researchers do a strict and proper definition of the used concepts and terminology the receiver of the research result might still interpret the accident rate as risk. To be honest, even researchers (including myself) often over-evaluate the result and handle accident rates as if they were equivalent to the common concept of risk.

It is quite common that the interpretations of the results do not correspond to the definition made. This was discussed in a previous study of which I was co-author (Brundell-Freij & Ekman 1990) and was further elaborated by Hauer (1995). It was made clear that although one often tries to explain contra-intuitive differ-

ences between accident rates by "disturbing factors", those differences may well be a natural consequence of the way the rates were defined.

3.2 The myth of accident rates as obvious clarifying tools

Quite often when accident rates are used, the reason for it is that it should be more fair or clarifying than to just look at the number of accidents and the exposure. I will show later that there is no theoretical reason to believe that accident rates should be used for the purpose of standardization. What then can accident rates be used for?

In practice there are normally two common motives for using accident rates:

- 1) to identify over-representation with the aim to correct for unfairness
- 2) to identify over-representation, with the hope of finding a clue to causal factors

3.2.1 *To adjust for unfairness*

The first motive, to identify over-representation in order to correct for "unfair levels of risk", sounds at first as a legitimate purpose. The idea of unfairness is quite difficult to handle especially for an engineer such as myself. I think it is important to be able to present objective facts rather than doctrines about moral issues. Furthermore I have some difficulties in understanding how high accident rates always would indicate situations that are more important to do something about than others. Accident rates are not more objective facts than plain numbers are since the choice of the comparison denominator involves a choice of analysing approach.

If one studies the accident situation for motorbike drivers and compare them with drivers of private cars, I do not think that the higher accident rate for motorbike-drivers gives much information in the debate of unfairness of the situation for the MC-drivers. In my opinion the unfairness would be much better discussed if one could discuss accident causation or the legitimacy of the purpose of the trip (which I know is virtually impossible).

Is it really self-evident that we should consider it natural that all activities have the same level of risk? If one chooses between climbing in steep rocks or strolling in a park it is natural that we accept higher risk for the mountaineer. If a pedestrian walks on the pavement or runs across a motorway we do not expect similar level of risk.

I do not expect the accident rates to be the same for a protected and an unprotected road user. If the higher accident rate should be the proof of a safety problem it does not only limit the search for a cure to the problem. When the high accident rate for motorbikes is seen as the indication of a safety problem then it is often regarded as if the cure is to be found among that road user group.

What if the most effective cure to the safety problem is to be found among other road users or the traffic environment, rather than among the group with high accident rate? Or if we look at the situation for the driver of a motorbike, do we have to use the proof of high accident rates to realise that sitting on a steel horse, with enormous motor-power and speeding capability and with hardly any protection in case of an accident, is dangerous and needs further attention?

But if the sub-groups were expected to be similar, for instance, two different makes of motorbikes, could it then be of some help to use accident rates in the search for cure?

3.2.2 Finding a clue to causal factors

The second motive, to use accident rates to find causal factors behind accident occurrence also sounds appealing at first. The idea of using accident rates to find clues about the cure of the safety problem is probably inherited from the *epidemiological paradigm*. The epidemiological paradigm has been discussed by Hauer, (1995) and could be described as the following logical chain:

$\{deviation-from-normal\} \Rightarrow \{clue-to-cause\} \Rightarrow \{clue-to-cure\}$

Looking at the traffic safety problem as a health problem might be a good idea but there are some major assumptions that we have to bear in mind when using the epidemiological paradigm.

Behind this idea is the belief that we have two groups that differ only in the studied background variables. An example from medicine could be that two groups with different water supply are compared. One group becomes sick and the other does not catch the disease, or more appropriate, the rate² of disease differs between the groups (since the groups happened to be of different size). Then it might be wise to investigate the water quality in order to find a clue for the disease. The *deviation-from-normal* is then that one group has a higher probability of catching the disease than the other. *Clue-to-cause* is then, that there might be something wrong with the water. The obvious *clue-to-cure* should then be to clean or avoid the contaminated water.

If we once again look at the situation for motor-cycle-drivers and want to compare it to private car drivers we have the following numbers available:

² Number of sick persons per inhabitants in the group

Table 3-1 Some examples of Swedish statistics 1992

	Private cars	Motor-cycles
Number of fatalities per year (1992)	485	33
Distance travelled per year (times one thousand million)	93	0,4
Rate of fatal injury	5,2	82,5

What we see then are some very different figures. All of the figures are in fact different. Most of the persons killed have been passengers or drivers of private cars.

Since the distance travelled is so much larger for the car drivers than for motorcyclists the rate is much higher for motorbikes than for private cars. If we have a choice in how to transport ourselves, or give recommendations to others for that matter, we would probably recommend the private car. For this to be reasonable this assumes, however, that the groups are similar. In this case it is somewhat difficult since we know that the group of persons driving motorcycles differ in many ways from the car-group, e.g. age, experience, and purpose of trip. We have no reason to believe that the "normal" accident rate should be the same for two groups that are so basically different. Apart from the difference in background variables we are comparing a protected and one vulnerable road user group.

If we want to use these figures to find the most effective safety measure the choice is even more difficult. Now the perspective is more from a society point-of-view. If we are able to reduce the number of accidents in the car group with 7 per cent (which might be hard but not unrealistic) we have to find a safety solution that reduces the motorbike accidents with 100 per cent in order to save the same number of persons. I am not certain that it is easier to achieve a total elimination of motorbike accidents than it is to reduce the number of accidents with cars with 7 per cent. This means that even though the difference in accident rates is huge this is not an obvious indication that it is easier to solve the safety problems highlighted by a high accident rate.

The main conclusion drawn from this is that there seems to be no general or universal way of using the concept of accident rate. In the study mentioned earlier (Brundell-Freij & Ekman, 1990) we saw, however, three main streams in the use of accident rates and exposure. These three groups were derived from how different researchers used or interpreted their results. The three approaches are:

- The probability approach
- The effectiveness approach
- The standardization approach

The first approach is what is referred to when discussing accident rate in general. The other two approaches constitutes a classification system based on the way in which the computed rates seemed to be interpreted.

3.3 The probability approach

The professional use of accident rates or risk often originates from concept models that can be interpreted from statistical theory in the following way:

Let us define a population, finite or infinite, of possible experiments, (i.e., a pedestrian crossing at a specific location). Each experiment connects to one of two possible outcomes, accident or non-accident. The accident rate for the pedestrians should then indicate the probability of an accident. The definition of the rate is consequently, the share of the population connected to the outcome ‘accident’ out of the total population of events, accidents or non-accidents.

If we deal with an infinite population (i.e., all pedestrians that might have used this crossing device given the circumstances) we can, of course, not compute the probability explicitly. Even if the population is limited, the computation of the probability of a certain outcome is in most cases very resource-consuming and often practically impossible.

This is where the statistical concepts of sample and estimates come in. We then have to bear in mind that the probability and then the risk or accident rates interpreted as probability, assumes an explicit or implicit definition of a population over which the probability is computed. The probability that I will get involved in an accident tomorrow is not defined in terms of population and outcome. Therefore the probability could neither be computed nor estimated. The probability that a person of my age, with my level of experience, social class, etc., becomes involved in an accident a specific day this year might, however, be estimated (with some effort and inaccuracy, of course).

A proper computation according to this approach requires an interpretable population over which the probability of a certain outcome is computed. This population could be defined in many different ways. The important restriction is that exposure needs to be a measure of the size of the population.

This highlights the important theoretical concept of “true underlying accident rate”. This concept assumes that there is some kind of statistical probability of an accident to occur. This concept can then handle the problem expressed in the following question; How is it possible that it seems 100 per cent safe to be in the

traffic system at all times except when some odd circumstances lead to a terrible accident? Has the system been absolutely safe for 5 years and then all of a sudden the risk was at an extreme peak during 20 seconds of this year? (Brundell-Freij, 1994). According to the probability approach the answer to the latter question is NO. The accident is rather a digitalization of the underlying probability, *true underlying accident rate* (Hauer, 1992(b)). As in most problems where statistical theory is applicable, the understanding does not come from detailed studies of single events but rather from looking at the problem from some distance.

The classic tool to exemplify probability is the die. When using the statistical approach, we have to throw the die many times in order to calculate the probability density function, and thus investigate the skewness of the die. Another approach could be to measure the small piece of wood carefully. Measuring the centre of gravity, the shape of each corner and the length, width and height of the cube might give other kinds of proof or answer to the question of skewness. In order to judge if the die is skew or not it might be a good idea to follow this engineering approach. If the different sides of the die are not similar it is a fair assumption to say that the die is skew. How this skewness effects the probability of achieving six eyes on the die might, however, not be so easy to say. It is for me quite interesting that the die has been the most common illustration of the statistical phenomena random event. It is interesting since we have rather simple and well-established alternative models that could be applied, as for example Newton's classic mechanical theories. The main problem with these models is that even if the principles are known and simple, the need for accuracy is enormous in order to predict the outcome, and an infinite change in the start-value has significant impact on the end result. The word *underlying* in "true underlying accident rate" refers to the idea that there is some long term probability which we only experience with the resulting, digital outcome in terms of the accident really occurring. The word *true* indicates that this rate is a more true description of the level of safety than the observed outcome in terms of historical accident rate.

It is important to stress that there is a fundamental difference between the intuitive concept of risk which is connected to a certain activity, during a certain moment of time, and the statistical concept of probability, which is defined over a population. Nevertheless accident rates computed and interpreted according to the probability approach seems to offer a both handy and useful tool for many safety analyses.

3.4 The effectiveness approach

Another way of looking at the problems of accidents in traffic is derived from economy: according to this theory, one has to compare the costs in traffic (for

example accidents or hospital costs) with the effect or benefits of traffic. This turns out to be a matter of effectiveness. If two systems generate the same number of accidents but "produce" different amounts of traffic, the system that "produces" most transportation is supposed to be the most effective.

According to economic theory one usually distinguishes between two different methods of evaluation. The first is the cost benefit analysis where the costs are subtracted from the benefits. The other is the cost-effect analysis where the cost is compared (divided) with the benefit. In cost-effect analyses the cost and the effect do not necessarily have to be measured on the same scale. In Sweden different types of accident reducing measures have been prioritized according to their effectiveness: cost per saved life (Mattson et al, 1991).

If we use exposure as a measure of the output or benefit of the traffic system, and accidents are regarded as the cost of obtaining that output, the ratio would correspond to the economic term cost-effect ratio (c/e).

Lots of efforts and research have been put in to the estimation of relevant accident costs. Not much has been done to compute the general welfare generated by transportation. Questions like 'is it better if I drive 60 kilometres to the office than if I reach it in 30 kilometres?' have not been properly addressed. If we, for example, notice an increase in the amount of kilometres travelled to meet friends, one could interpret this in two different ways. One interpretation could be that people met more friends and thereby increased the welfare. Another interpretation could be that the friends now live further away and thereby one has to travel further to meet each friend. In the later situation the effect is none or decreased welfare.

Do we increase the effectiveness of the system if we add some extra safe metres to each trip? This could be achieved by encouraging all drivers to make an extra loop on the parking lot before and after the trip. This could also, and more seriously, be achieved by planning our residential areas in line with the concept of separation. This normally leads to a traffic system where the car traffic is led around the area in order to create a protected area in the middle. With this the same transport task is achieved with a longer trip.

Added to this comes the situation when the trip in itself is considered a benefit. To some, recreation trips might be relevant. Actually, according to the original idea of cost effectiveness, recreation trips fit best into the concept of effectiveness.

Therefore the effectiveness approach seems not to be justified unless the definition of both the costs and the benefits can be done satisfactorily. It is, however, important to state that this approach does not have much in common with the popular interpretation of risk. One advantage is that it allows a very broad definition of the traffic safety problem. Not only monetary effectiveness ap-

proaches could fit into this category, but also such concepts as the use of time or not renewable resources. The accident problem has by some researchers (Gunnarsson, 1974, Hauer, 1992(a)) been regarded as a loss of time where the accidents represent the lost time living as a healthy person. This could then be compared with the time 'gained' with an effective transport system, for example higher speed.

3.5 The standardization approach

From an analytic point of view the accident rates are introduced in order to increase the comparability. This striving towards increased comparability has often led to a desire to standardize the levels of safety with respect to traffic flow. It has been considered almost self evident that it is unfair to compare the level of safety at two locations without adjusting for the traffic flow.

The question might be, e.g., whether there is a safety effect of a certain detail in the intersection design. Our data are the number of accidents in several intersections with and without the studied intersection design. The problem is then that the intersections naturally have different amount of traffic. Since we know that the amount of traffic influences the safety outcome, it is natural to try to compensate or standardize for the influence of traffic flow. This is in principle not different from the fact that the intersections might vary in other aspects as well, such as surrounding environment, the level of speed and the mix of road users entering the intersection. To prove the safety effect of a single factor we must either have a well-established knowledge on the expected safety effect from all the other varying factors and how these effects interact (this type of knowledge is rare) or be careful in choosing our studied items to ensure equality or at least randomness in factors other than the studied (which is normally impossible).

As stated above we know or believe that the expected number of accidents, $E(A)$ is related to a number of system characteristics such as speed levels, traffic flows, road user types, details in design, etc.

This could be formally expressed as:

$E(A) = F(\text{flows, speed, distribution of road users, design etc...})$

If the function F could be expressed as

$F = G(\text{flows}) * H(\text{speed, distribution of road users, design etc..}),$

and H thus is independent of flow, then the quotient

$$H = \frac{E(A)}{G(\text{flows})}$$

would express the value of H for each system.

If the form of G is equal for the systems studied, under these restrictions,

$$R = \frac{E(A)}{G(\text{flows})}$$

the system with the lowest value of R also gives the smallest expected number of accidents, if traffic flows were equal in all systems (no matter of flows), and other characteristics in each system were kept constant.

R would, under the given restrictions, and with exposure measured by $G(\text{flows})$, be a tool to choose the safest solution (system) for any combination of traffic flows. This is the theoretical basis for the common interpretation of accident rate or risk that we call the standardization approach. There are, however, some major arguments why the restrictions above could not be neglected.

The restrictions could be put under three headings;

- Multiplicativity
- Conformity
- Constancy

3.5.1 Multiplicativity

The assumption is that the function F could be expressed as the product of two separate functions, with one being only dependent of flow. The basis for this description has to be that the flow takes care of the probability of an accident to occur and that all the other factors (collected in the function H) only influence the outcome of a possible accident. This means that all the other factors must be independent of flow. This strongly contradicts more modern theories on accident causation. In the modern theories about accident causation, accidents are more often described as a complex breakdown in the interaction between road users, vehicle and environment rather than the result of a single fault by one factor or one road user. Furthermore it is easy to imagine that there are several types of possible accidents even in a restricted system. Each type then has a specific probability of occurring and thereby a specific H -value. F above should then be expressed as:

$$F = G_1(\text{flows}) * H_1(\text{speed,..}) + G_2(\text{flows}) * H_2(\text{speed,..}) + ..$$

and then there will be no denominator to compute H from $E(A)$. Thus, the multiplicativity will not hold. We could then conclude that theoretical derivation of the "number of possible accidents" could not result in a measure of exposure to use for standardization purposes.

Of course the assumption of multiplicativity could hold even if the theory of possible accidents and probability does not. In that case the form of G would have to be estimated empirically.

3.5.2 *Conformity*

If we now have been able to determine the form of G empirically for one system, do we have reason to believe that this form is the same for all systems?

It is, in principle, clear that one cannot assume that all systems are the same. In some designs of an intersection, for example, the number of left-turners does have a large effect on the number of accidents, while in other systems (where left turning is separated in time or space) there is no such influence at all. There might obviously be great difficulties in comparing the influence of traffic flow between signalized systems and non-signalized systems.

It is quite clear, that even if the assumption of multiplicativity may hold or maybe assumed to hold at least approximately in some cases, this will seldom be the case with the assumption of equality between G s.

3.5.3 *Constancy*

If we have tested the assumptions above and computed the H s for the systems to compare, could we then be sure that the system with the smallest H would also give the best safety, the lowest expected number of accidents, under any circumstances? This assumes that for any specific value of flow the value of G will be equal for all systems studied under the external circumstances, while all other characteristics will remain constant, as they were, when studied. If the form of G is derived from an empirical study it should rather be to say that all other factors show the same relation to flow as they did when studied.

Since flow is determined from a series of human decisions (whether to make a trip or not, choice of mode, route choice and time of departure etc.) it will be strongly influenced by the qualities of the traffic system. The incoming flow will most certainly be affected by the qualities of the system, just as the incoming flow will affect the qualities of the system, at least in the long run. We also know that many of the properties determining the value of H (e.g., speed) is closely related to flow, and thus the value of H will not be independent of flow.

My conclusion is that it is theoretically impossible to standardize with respect to traffic flow. Furthermore it often hides one of the most powerful tools to affect traffic safety, namely the flow. This could be further illustrated by applying the same approach on speed. Since we know that there is a strong relationship between speed and safety, one could in a similar way argue that one should standardize for the speed before comparing the safety effect of the countermeasures. Is it interesting to know the safety effect of a hump if it had not reduced

the vehicle speed? Standardizing for the effect of speed would discredit all measures that reduce the number of accidents by reducing the speed of (in my opinion this is true for quite a few of the available countermeasures) since this effect would be neutralized. If we want to evaluate the traffic safety effect when introducing a subway system in a town: Would it then be interesting to look at the road and estimate the number of accidents that would occur if the vehicle traffic was not reduced?

4 A General View on the Relation Between Flow and Safety

In the area of traffic safety work, the use of accident rates is, thus, by tradition almost sacred. Most often accident rates are used without even thinking of it as a model choice situation. One major reason could be that it seems obvious that an increase in flow leads to an increase in the number of accidents. If we have a system without road users it is obvious that it cannot produce any traffic accidents. And if the number of road users increases this will then obviously lead to increased probability for an accident to occur.

One is, however, jumping to conclusions if one from these elementary findings assumes that the relationship is linear. But the common way of using accident rates with the standardization approach actually assumes a linearity between accidents and flow, although the assumption of linearity between accident and exposure often is implicit.

Let us start from the beginning. Let us assume two different systems with differences both in accident history and the level of exposure. These two systems could be two different locations or the same location at two different moments of time, but they could also represent two different modes of transport. If we plot our two systems and call the first system A and the other B the graph could look like this:

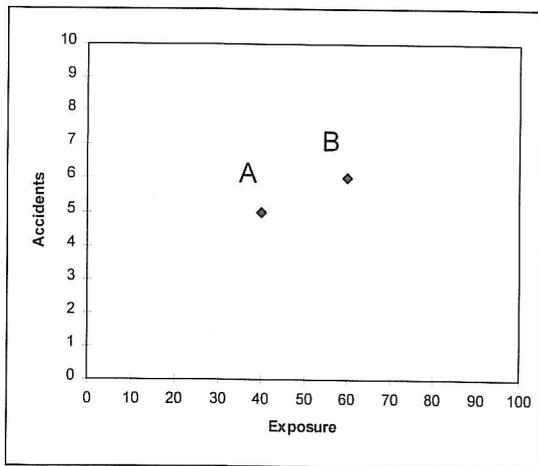


Figure 4.1 Two systems with different levels of exposure and level of accidents

At a first view we may conclude that system B has created more accidents than system A. Does that then tell us which system is the best? Yes, it does, if we with *best* mean the system that creates the lowest number of accidents. But what we are trained to do almost instinctively, is to look at the exposure. Then we realize that system B also has a much higher level of exposure. With exposure, in this example, we assume some measure of flow or amount of travel that corresponds to the accidents. In other words measures of exposure, that may create accident rates interpretable according to the probability approach. We may then compare these two accident rates. What is done in that case, could be illustrated with two straight lines that connect A with the origin and B with the origin respectively. The accident rates are then represented by the slope of these lines.

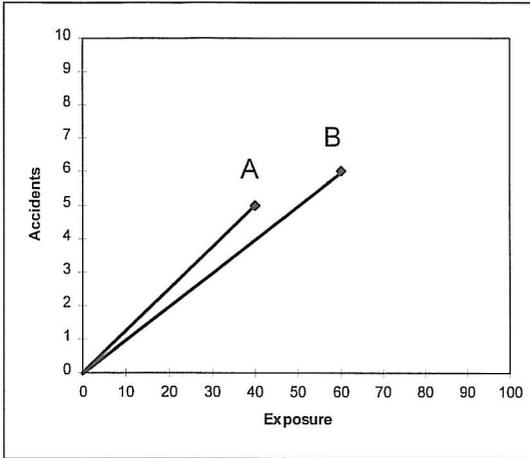


Figure 4.2 Two system connected with a "slope line"

The normal interpretation of this is then that the steepest slope, the highest accident rate, is the most dangerous one. Let us now assume that we happen to know the accident rates for several observations of the same, or at least similar systems at different positions on the exposure-axis. If we connect these observations we might well get the situation represented in the next figure.

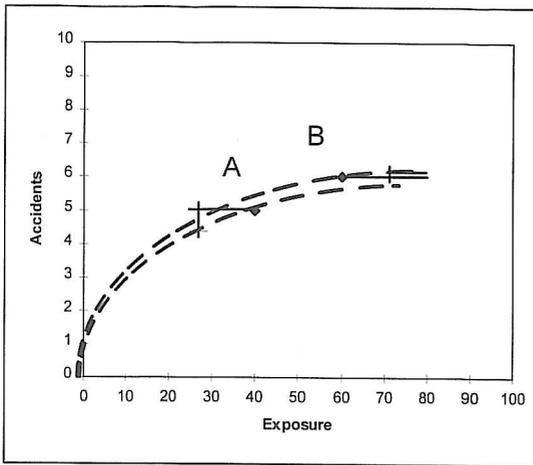


Figure 4.3 Two systems with hypothetical Safety Performance Functions

Here we can observe that for every given value of exposure, system A results in more accidents. This would, contrary to the previous interpretation, mean that A is better (safer than B).

If we, however, want to transfer people from one system to another, a given decrease in exposure in A transferred to B would result in a much smaller increase in accidents in B than the reduction of accidents in system A. So here we should recommend a transfer of flow from A to B even if B always creates higher accident rates at the same level of flow. Once again accident rates are only interesting if the aim of the comparison is relevant.

So if we want to compare countermeasures, or if we want to suggest transferring people from one mode of transport to the other, we have to know the full shape of the relation between accidents and exposure. An early discussion of the problem mentioned above is mentioned in (Mahalel, 1986). This function was first called the Safety Performance Function (SPF) in (Hauer, 1995).

If we consider our two systems A and B as two different types of intersection design it is easy to imagine that the shapes of the Safety Performance Functions could at least theoretically look like they do in the next figure.

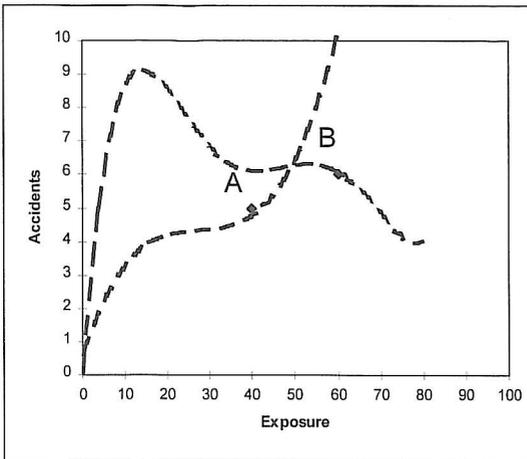


Figure 4.4 Two systems with Safety Performance Functions that cross each other

In this figure we cannot say which system is the safest without knowing the levels of exposure in the systems we want to compare. From a practitioner's point of view it is easy to find examples that fit to such curves.

One type of layout might be excellent for a limited range of flow but the same layout is not expected to work under other flow conditions. A four-way stop intersection might work quite well as long as the flow does not exceed the limit where the informal interaction still can take place. It is also quite clear that if we take modern theories about behavioural adaptation into account Wilde (1994) a single road user's behaviour could not be expected to be the same if he or she were alone on the road as the behaviour is in a saturated situation.

Most modelling work has used flow as one major explanatory variable. The most used model structure is the exponential $E(A) = k * exposure^y$ (Kulmala, 1995). One advantage with this approach is that it fulfils some basic ideas about traffic and traffic safety: It starts in the origin, zero flow creates no accidents. Furthermore is it monotonically increasing with increasing flow, as long as y is positive. One major problem with this approach is that the last assumption is not completely supported by basic traffic theory, nor modern behaviour adaptation theories. The results from estimations based on empirical data is often that y is slightly less than 1. This means that accidents increase by increasing exposure less than a linear approach would have given.

The safety performance function could be investigated empirically, and should, in my opinion, be investigated without any preassumption of functional form. Methods for such investigations are presented in chapter 7. Safety performance

functions offer, in contrast to accident rates, a general tool for the treatment of flow in different kinds of traffic safety analyses.

5 Traffic Safety for Vulnerable Road Users

5.1 Definition of Vulnerable road users

All road users could actually be called vulnerable since all humans are vulnerable in one way or another. Normally we, however, exclude persons sitting inside some kind of a frame, from the group "Vulnerable Road Users". With vulnerable road users we thus usually mean pedestrians and two-wheelers.

There is, however, a great difference between the situation for different vulnerable road users. The vulnerability is mainly depending on two factors. The first is the severity of the hazardous events and the second the presence or absence of protection against these events. The degree of injury severity in a situation is strongly dependent on the road users' own speed or other interfering road users' speed. A distinct increase in the probability of getting killed in a collision is at hand when the collision speed exceeds 30 km/h (Pasanen, 1992). A human being is relatively capable to handle hazardous situations as long as he walks around in a normal, "non-traffic-environment". Then the protection God has provided us with, a hard head and the ability to put out one's hands to break the fall, is then sufficient. However, if the speed increases, this protection is not sufficient to hinder severe consequences of an accident.

Moped riders and motorcyclists are extremely vulnerable once something happens to them even if no other road user interferes with them, and even if they wear helmets and other personal protection. Bicyclists are next in line with much lower speeds compared with moped and motorbike riders. Bicyclists may, however, still reach dangerously high speeds. The level of personal protection is radically lower for bicyclists. The use of helmets is at the moment only about 5% for the adults. The use of helmets vary a lot geographically and age-wise. As an example 35% of the younger children use a bicycle helmet in Sweden. (Vägverket et al, 1994).

Pedestrians are obviously the most vulnerable road users at least when it comes to vulnerability towards motor vehicles. Pedestrians do not normally use any kind of personal protection to prevent injuries. We would - for various reasons - consider it rather strange to suggest helmets on pedestrians even if a helmet would help if a pedestrian hits the ground after being hit by a car. Single accidents of pedestrians are still not considered as traffic accidents officially, and therefore not included in police accident statistics. Lately a shift in thinking has occurred. It is now more commonly accepted that this kind of accidents must be considered. Especially single pedestrian accidents involving elderly should not

be neglected as they are quite frequent and costly. As maintenance of the footpaths has to be taken from the same budget as other road maintenance, it is important to start to include these accidents in traffic safety planning.

Apparently vulnerable road users could be defined as "a group of road users that are lacking adequate protection while appearing in the traffic environment". The terms 'Vulnerable Road Users' and 'Unprotected Road Users' are normally used synonymously in our discipline. Unprotected refers rather to the presence or absence of protection while vulnerable deals with the fragile nature of the road user. An old person is more vulnerable than a young person even if both are equally unprotected. When I refer to pedestrians and bicyclists in this thesis I call them "Vulnerable Road Users" (VRU) partly because I am used to do so and partly because I think these road users are naturally vulnerable rather than a group that not yet has adequate protection devices.

5.2 General description of the magnitude of the safety problem

The magnitude of the safety problem for vulnerable road users is remarkable. Of all persons killed in traffic in Sweden vulnerable road users stand for 36 per cent (SCB, 1993). Out of all police reported injury accidents, accidents involving motor vehicles and vulnerable road users stand for 32% (Table 5-1).

Table 5-1 The number of police-reported injury accidents, in Sweden 1992, by accident type. (From SCB, 1993)

Accident type	Number	%
Motor vehicle - single	3545	23%
Motor vehicle - Motor vehicle	6229	40%
Motor vehicle - Vulnerable road user	4952	32%
Other	873	4%
Total	15599	100%

Since this work deals especially with vulnerable road users the most important arena is the urban area. In Sweden "urban area" is defined rather broadly, more in line with the term "built-up area". It does not only include the city centre but all the areas that are not rural. Big arterials and ring roads are normally also included in the definition of urban areas (From SCB, 1993). The definition does not perfectly suit the study of pedestrians and bicyclists since they do not use arterials very much. We, however, find most of the accidents involving pedestrians and bicyclist within the urban areas as is defined in the general statistics.

Table 5-2 *The number of police-reported injury accidents, in urban areas in Sweden 1992, by accident type. (From SCB, 1993)*

Accident Type	Number	%
Motor vehicle - single	966	11%
Motor vehicle-Motor vehicle	3528	39%
Motor vehicle - Vulnerable road user	4315	48%
Other	181	2%
Total	8990	100%

Comparing at the persons killed or injured (Table 5-3 and Table 5-4) we can observe the vulnerability of the unprotected road users.

Table 5-3 *The number of police-reported killed or injured persons, in urban areas in Sweden 1992. (From SCB, 1993)*

	Number of killed or injured persons	%
Car, driver or passenger	6116	54%
MC, driver or passenger	526	5%
Moped, driver or passenger	678	6%
Bicyclist driver or passenger	2499	22%
Pedestrians	1470	13%
Other and unknown	61	1%
Total	11350	100%

Table 5-4 *The number of police-reported killed persons, in urban areas in Sweden 1992. (From SCB, 1993)*

	Number of killed persons	%
Car, driver or passenger	82	33%
MC, driver or passenger	14	6%
Moped, driver or passenger	8	3%
Bicyclist, driver or passenger	48	19%
Pedestrians	90	36%
Other and unknown	6	2%
Total	248	100%

In urban areas about 45 per cent of the police-reported killed or injured persons are vulnerable road users. Among the killed persons the number is as high as 65 per cent. This highlights the vulnerability of pedestrians and two-wheelers.

Table 5-5 The number of **hospital-registered** killed or injured persons, in the city of Lund in Sweden (1988-10--1989-09). (From Berntman - 1991)

Accident Type,	Number of persons killed or injured	%
Car, driver or passenger	67	27%
MC, driver or passenger	15	6%
Moped riders, driver or passenger	7	3%
Bicyclists, driver or passenger	113	46%
Pedestrians	40	16%
Other	4	2%
Total	246	100%

If we take accidents reported to the hospitals (Table 5-5) into account, the picture is changing dramatically in two ways. Firstly, the number of injury accidents involving pedestrians and bicyclist seems to be a much bigger problem when we look at the hospital data compared to police reported accidents. Secondly it especially applies to bicyclists. According to hospital data the biggest safety problem seems to be for the bicyclists since 46 per cent of all killed or injured persons in Lund are bicyclists.

Under reporting of accidents with vulnerable road users is a big problem not only in police accident statistics but also in accidents reported by hospitals. Accidents involving vulnerable road users are more under reported than accidents involving only motor vehicles. There are many reasons for this. One is that the police do not necessarily get involved since an accident involving vulnerable road users does not normally lead to demolished cars hindering the rest of the traffic. Another reason is that pedestrians and bicyclists do not consider all traffic related accidents as being "traffic accidents". A common remark from a person involved in an accident is "- this was not a traffic accident, I just fell off the bike and broke my arm". The most troublesome part of this is that if we use biased accident statistics we might draw the wrong conclusions. These problems turn then from just being an "academic problem" to a matter of setting priorities.

Many people have intuitively a strong concern for vulnerable road users. One reason could be that all of us act as vulnerable road users every now and then. Even the most dedicated car driver has to act as a pedestrian sometimes.

Vulnerable road users are a rather non-homogeneous group (Gunnarsson, 1995). In the empirical part, only pedestrians and bicyclists will be dealt with. When it comes to bicyclists, the safety problem is quite evident now when we know more about the accidents reported to the hospitals. The bicycle is also the mode of transport that could solve many of the increasing environmental problems foreseen in future urban areas. The main drawback with encouraging more

bicycle traffic is, however, the safety problem. One hypothesis I want to formulate is: We know that a marginal increase in bicycle flow, by transferring people from cars to bicycle, will lead to an increase in the total number of injured persons. While true for a marginal change it is probably not true for major changes in mode choice. One reason for this is that bicyclists do not hurt other road users to the extent that cars do. Another reason is that the total amount of travel might decrease if it is done by muscular power rather than by oil. It might also be that for individual bicyclists the probability of getting involved in an accident might vary according to the amount of bicycle traffic.

Pedestrians move around in the traffic environment often with completely different objectives than other road users. Pedestrians strolling around in a town normally do not consider themselves as road users, transporting themselves from A to B. One general problem, or challenge, is the complex nature of pedestrian and bicycle transport. Both pedestrians and bicyclists are much harder to describe as one homogeneous group when appearing in traffic compared to for example car drivers. The vulnerable road users consist of the widest possible range of age groups, experience, knowledge and skill. This is one reason for why I am treating pedestrians and bicyclists separately in my further analyses. (Chapters 9 and 10).

6 Pedestrian Crossings in Sweden, a Case Study

As an example of the use of accident rates I will refer to a study that I presented in 1988 (Ekman 1988). This report was, however, only published in Swedish, and therefore a short summary of the method and the result will follow below. In some ways, that study is the beginning of the present work.

In order to test the safety effect of a standard zebra crossing, a comparative study was carried out with data collected from five cities in southern Sweden. Since the zebra crossings are the most commonly used traffic safety countermeasures in Sweden, it is quite natural to look for the safety benefits of such a countermeasure. The vast majority of intersections in the central parts of Swedish urban areas have been equipped with marked zebra crossings.

It has been considered almost self-evident to most people that it is safer to cross the road at a zebra crossing. The well-known fact that most of the accidents where pedestrians have been hit by a car in urban areas happen at either a zebra crossing or at a signalized intersection has not changed the opinions about the zebra crossing. It was considered obvious that this was due to the high exposure at zebra crossings and signalized intersections respectively. No one had, however, up to that point, measured the exposure of pedestrians in Sweden.

6.1 The method

The study was designed to ensure comparison with previous British studies by Jacobs and Wilsson (1967). In that study only a few streets were examined but in my study, data were collected from a lot of streets in the five cities. In line with the British study the street was divided into segments that could be considered comparable. For the division into zones see appendix A

In addition to the zones defined in the British study some zones were added in order to make it possible to compare the zebra crossing, including the area just surrounding the zebra marking, to approaches with no zebra marking or signalized facilities. The reason for this was that the previous studies pointed out that there was a big difference in accident rates between the zebra marking and the area just beside the zebra marking. This had been used as an indication of the safety benefits of the zebra crossing. My hypothesis was rather that the high accident rate beside the zebra marking should be looked upon as a "negative side effect" of the zebra marking.

Accident data was collected from the following cities in southern Sweden.

Table 6-1 Cities where the data was gathered from

City	Inhabitants in the urban areas of the city in 1980
Göteborg	457000
Malmö	227000
Lund	55000
Landskrona	27000
Eslöv	14000

Data on police reported injury accidents where pedestrians had been hit by a vehicle was collected from 1979 to 1984. The length of the period was a compromise between a reasonably large data set on one hand and on the other hand avoiding too large changes in the traffic situation during the time period.

Each accident was classified in line with the zone system, which means that only accidents that involved both crossing pedestrians and cars were considered. Accordingly, the number of crossing pedestrians was counted at all streets. In order to cover all the selected streets the counting was carried out with a sample technique. All the counting was carried out by manual observers. In total 56700 kilometres of street were covered. For each individual zone the number of crossing pedestrians was counted twice during a short time (two times 6 minutes). In order to avoid "peak" traffic period the counting of crossing pedestrians was carried out during 09.00 to 12.00 and 13.00 to 16.00. An analysis of the accident occurrence gave at hand that it was appropriate to count the traffic during off-peak-time, since the accidents seemed to be dispersed during the day with some concentration to the afternoon.

The accident rate was defined in accordance with the probability approach. The aim was to see if it was safer for those pedestrian crossing the street at a zebra crossing compared to those crossing at other similar locations. The accident rate was then

$$R = \frac{\text{the number of police reported accidents during 6 years}}{\text{the number of crossing pedestrians during 12 minutes}} * 1000$$

The multiplication with 1000, in the computation of R , was made to get manageable numbers.

6.2 Result

The main result was that crossing at intersections where there is zebra marking seems to result in **higher** risk for an individual pedestrian than crossing at other

intersections. It was also shown that signalised intersections seem not to generally provide a safe crossing situation for pedestrians. For children and "elderly" there seems, however, to be an indication that the signal could slightly improve the situation.

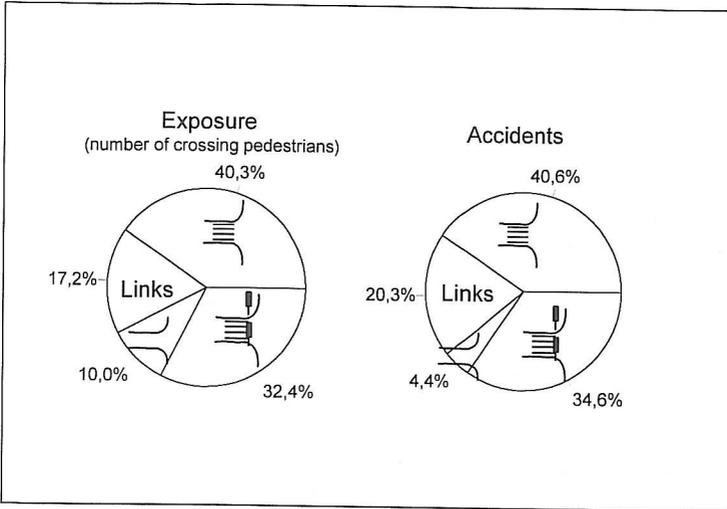


Figure 6.1 The distribution of exposure and accidents

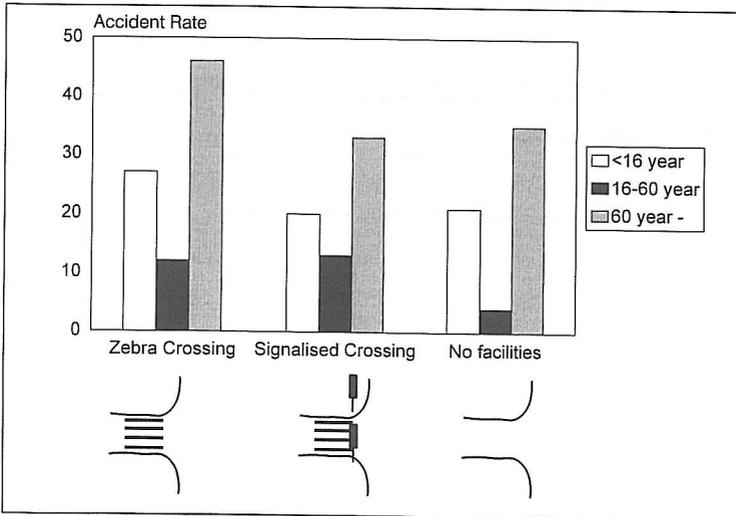


Figure 6.2 Accident rates for the three crossing types by age groups

When the "weak groups"(children and elderly) were excluded, it became obvious that the high accident rates for zebra crossings could not be caused by "high number of weak road-users", see Figure 6.2.

The results were not only checked for "age effect" but also for car flow. The crossing point studied was along long streets with most of the types of zones covered in order to control for car-flow. If a street with remarkably high car flow was picked, this would then affect all the zones. As a double check, car flow was compared and no major difference was found between the types of zones. Signalised intersections and intersections with no facilities were even found to have slightly higher car flow than those locations with zebra crossings.

The general explanation to these remarkable results was that pedestrians experience a false feeling of safety when "protected" by zebra marking or signalization. Another way of expressing it could be that pedestrians cross more carefully when no help is provided. This study does not cover the mobility gains, if there are any, from zebra crossings or signalization.

Three main conclusions could be drawn from this study:

- The safety potential in signalised intersections is not fully achieved
- Behaviour adaptation or behaviour modification is the key to safety improvements or failure.
- The safety potential is great at both zebra crossings and at signalised intersections, since two thirds of all pedestrians cross at these locations.

6.3 Discussion of the result and the use of accident rates

When looking at the study now afterwards I realize that I and others have used the results to highlight different questions related to zebras:

- Should one avoid crossing the streets at zebras?
- Should we remove zebra markings?
- Should we recommend a "massive transfer" of pedestrians from zebras to other crossing locations?

As for the first question the main result from this study seems quite clear, namely that the probability of an "un-informed pedestrian" to be involved in an accident is higher for all age groups if he or she crosses the street at an intersection with zebra crossings. The addition, "un-informed", is due to the hypothesis that it should have to do with a false feeling of safety. If you know about these results there should be no ground for relying on any protection by the zebra crossing and thereby no false feeling of safety either. And thereby there is no reason to expect

higher accident rate for the informed pedestrians. The answer to the first question thus would be "yes, do not cross at zebras" if one continues to act as uninformed.

What is not so clear is the answer to the second question: Does this study tell us enough about the safety effect of installing or removing zebras? It may be reasonable to make the assumption, based on the results, that zebra crossings are not a very good safety device. However, such a conclusion would be based on the epidemiological paradigm as described in section 3.2.2 and thus on the assumption that zebras and other locations are similar apart from the zebra marking. As other background variables will remain if the zebra marking is removed, differences in such background variables will continue to cause differences in accident rates. The demand for similarity is the reason why some researchers are basically sceptical towards cross sectional studies (Hauer, 1992 (a)). Already in the project report this issue was discussed: are zebras systematically installed at dangerous locations?

Looking at the third question it may seem plausible that all factors will be kept constant if we move pedestrians away from the zebras and that the accident rate at each location will remain the same. However, one important background variable will change, namely the magnitude of the pedestrian flow.

Unless we know that accident rate is independent of pedestrian flow or the relation between them it is hard to tell if this result tells us anything about the safety effect of moving pedestrians. In other words, we need to know the shape of the Safety Performance Function.

In chapter 10 I will, however, show that accident rates tend not to increase with increasing pedestrian flow. There is thus no reason to believe that high pedestrian flow would normally lead to high accident rate.

The main implication from the study will still be that there is a safety problem at zebra crossings in Sweden. This result is only valid for Swedish circumstances since at least the behaviour at zebra crossings is strongly dependent on local habits and regulations.

Until the zebra crossing more directly influences the car-driver-to-pedestrian interaction there is no reason to expect any positive safety effect of installing zebra crossings in Sweden.

This study exemplifies a common problem: a situation where all relevant comparisons will cover large differences in flow and we thus require knowledge about the Safety Performance Functions in order to make the conclusions.

7 Determining Safety Performance Functions

7.1 An empirical approach

As has been argued in the previous chapters there seems to be no reason to assume that accidents should have a linear relation to exposure, regardless of how we define exposure. The relation between accidents and exposure need to be described in a way where the insight about the complexity of the system is used, even if we never fully can describe the process. My hypothesis is that there exists a *safety performance function*, at least for a subpopulation of systems, that describes the relation between accidents and flow. This function needs to be derived out of empirical data. This might then give us useful information about the complex systems themselves and about possible traffic safety measures, but might also be a tool when engineering measures are evaluated.

7.2 The database

In order to construct Safety Performance Functions, I have used an old database consisting of information about 95 intersections, mainly in the city of Malmö. The most disaggregated elements of the database are the approaches to intersections. For each intersection, the following data about all approaches is available:

- Accident history for 7 years
- Conflict data from two days of observation
- Car flow³ for each direction (left, right and straight on)
- Bicycle flow³ for each direction (left, right and straight on)
- Pedestrian flow³ (crossing the approach)

This database was originally created for a study aiming at validating the Swedish Traffic Conflict Technique (Svensson, 1990). In order to get somewhat comparable locations, signalized intersections were excluded.

7.2.1 Conflict and accident database

Data on police reported injury accidents were collected from 1976 to 1982 (in total 7 years). Since they were collected to correspond to the conflict studies and

³ all counting was done manually

the counting, only accidents during day time are represented (from 9.00 am to 6.00 pm).

In each of the 95 intersections two days of conflict studies were carried out during 1981 and 1982. One day conflict studies covered 6 hours of observation spread over the time from 9.00 am to 5.00 pm. The observers were specially trained according to the Swedish Traffic Conflict Technique (see section 7.3.1). Only serious conflicts have been used in the study.

Table 7-1 The conflict and accident database

Situation	Number of serious conflicts	Number of accidents ⁴
Car - Bicycle	193	43
Car - Pedestrian	177	46
Total	370	89

7.2.2 The flow database

During one of the two days when the conflict studies were carried out, traffic was manually counted by one observer. Cars and pedal cyclists were counted for each turning movement (left, right and straight on) for each approach. The category "Car" includes passenger cars, lorries, buses, tractors and motor cycles. Crossing pedestrians were also counted.

The counting was carried out during the six time periods per day, when the conflict observation was carried out. The data from the whole day was aggregated and transformed to average hourly flow.

Pedestrians crossing the approach were counted for each crossing direction. In this study the two directions were added together in order to obtain the number of persons crossing each approach.

The bicyclists were counted for each turning movement. The number of entering bicyclists was obtained by adding up the bicyclists for the three directions.

In order to create exposure values that represent "conflicting exposure", car flow, bicycle flow and pedestrian flow was computed slightly differently in the two situations of comparison.

In order to use the flow data in the best way, new variables were constructed. These variables are called "accumulated car-exposure". The idea behind this flow measure is just to count the number of cars that the bicyclists and pedestrians respectively could be exposed to, and thereby possibly may come in conflict with.

⁴ Police reported injury accidents

7.2.3 Accumulated car exposure for bicyclists

For each of the three movements of the bicycle entering at approach A, the total number of cars that may come in conflict with the bicycle, is accumulated.

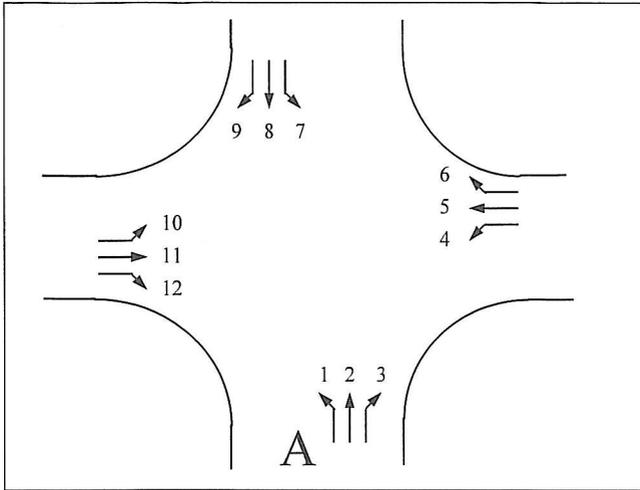


Figure 7.1 The different turning movements for Bicyclists (Q_{1-12}) and Cars (q_{1-12})

The measurement of car-exposure will then be for the right turning bicycle from approach A:

$$Er = q1+q2+q3+q7+q11$$

and for the straight ahead going bicyclist;

$$Es = q1+q2+q3+q4+q5+q6+q7+q10+q11$$

and for the left turning bicyclist

$$El = q1+q2+q3+q4+q5+q8+q9+q10+q11$$

The measurement of "accumulated exposure of cars" is then $Ecb=Er+Es+El$ thus

$$\begin{aligned} Ecb &= (q1+q2+q3+q7+q11) \\ &+ (q1+q2+q3+q4+q5+q6+q7+q10+q11) \\ &+ (q1+q2+q3+q4+q5+q8+q9+q10+q11) \\ &= 3*q1+3*q2+3*q3+2*q4+2*q5+1*q6+2*q7+1*q8+1*q9+2*q10+2*q11 \end{aligned}$$

This result in 9 left turning movements 8 straight a head movements and 5 right turning movements. If we compare this to the more commonly used measurement of car exposure namely the total number of approaching cars,

($Tac = \sum_{i=1}^{12} q_i$), Ecb and Ecp normally gives much higher value. The difference is of course depending on the mix between the amount of different car movements.

If we plot the two measurements of exposure against each other we get the following picture.

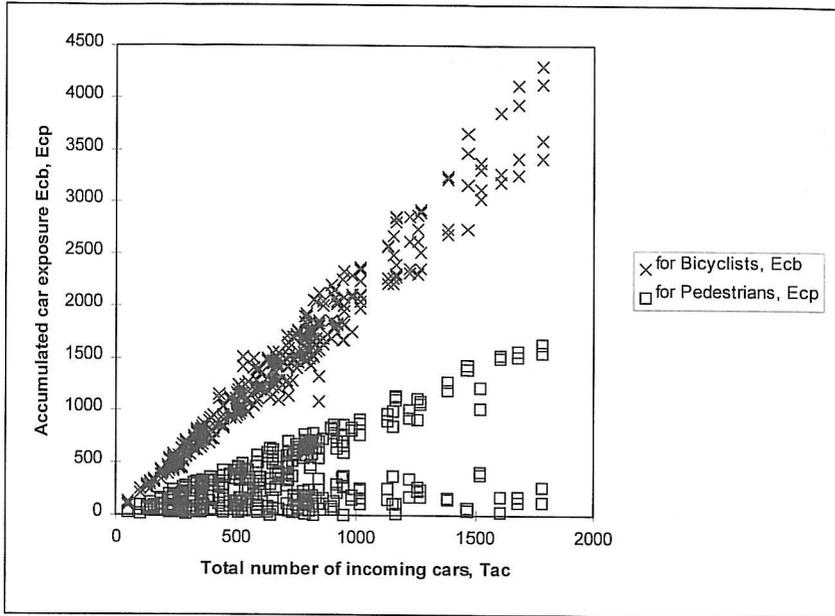


Figure 7.2 The relation between "Total number of entering cars" and "Accumulated car exposure" for Pedestrians and Bicyclists respectively, in the data set.

The accumulated car exposure is on average about twice the total number of approaching cars in this data set ($Ecb \approx 2.12 * Tac$). This value is the resulting coefficient in a linear regression when the constant term is set to zero.

Since the relevant flow is higher than the more commonly used measurement of exposure namely total number of approaching cars, and since I am striving towards increased interpretability, I want to fulfil that need. This could be done by creating a new variable "weighted accumulated car exposure for bicyclists at an approach per hour", $Ewcb$.

In order to construct a scaled value that corresponds to "the average number of approaching cars at an approach" the accumulated value of exposure (Ecb) needs to be scaled. In order to scale it, to correspond to the total number of incoming cars, Ecb needs to be divided by 2.12. For each approach the scaled value

should be further divided by 4 in order get the weighted accumulated car exposure for bicyclists at an approach. $E_{wcb} = E_{cb}/8,48$. The value is then measured in cars per hour. E_{wcb} will then be of the same magnitude as the number of cars entering the intersection at an approach. This is in fact the way the car flow will be interpreted by most professionals anyway.

7.2.4 Accumulated car exposure for pedestrians

In a similar, but easier way, a relevant car flow for crossing pedestrians was constructed. The relevant car flow for pedestrians crossing an intersection approach is then the number of cars entering the intersection at this approach plus the cars exiting the intersection at this intersection leg. For pedestrians crossing intersection, leg A, the "accumulated car exposure" (E_{cp}) is then;

$$E_{cp} = q1 + q2 + q3 + q4 + q8 + q12$$

For the crossing pedestrians, as for bicyclists, the accumulated car exposure includes similarly, both entering and exiting cars. The equivalent value "weighted accumulated car exposure for a crossing pedestrian per hour" should then be; $E_{wcp} = E_{cp}/2$. The denominator "2" is due to that both exiting and entering cars are included in E_{cp} .

7.2.5 Basic measurement of exposure

To conclude we have the following measurements of exposure:

E_p = number of pedestrians crossing the intersection approach per hour.

E_b = number of bicyclists entering the approach per hour.

E_{cp} = accumulated number of cars that may come in conflict with any of the pedestrians crossing at the intersection approach, per hour

E_{wcp} = accumulated number of cars that may come in conflict with any of the pedestrians crossing at the intersection approach, scaled in order to get a value comparable to the number of entering cars, at a specific approach per hour

$$E_{wcp} = E_{cp}/2$$

E_{cb} = accumulated number of cars that may come in conflict with any of the bicyclists entering at the intersection approach, per hour

E_{wcb} = accumulated number of cars that may come in conflict with any of the bicyclists entering at the intersection approach, scaled in order to get a value comparable to the number of entering cars at a specific approach, per hour

$$E_{wcb} = E_{cb}/8,48$$

7.2.6 The environmental database

Some information about the physical environment was also available for each approach. Information about layout and regulation was available. The physical characteristics are width of the street, presence of refuge and special facilities for bicyclists and pedestrians such as zebra crossings.

7.3 Accident data or Conflict data

There are primarily two reasons that I have chosen the recorded serious conflicts instead of the police reported accidents in the majority of my analyses. The first is that the data set is bigger for conflicts than it is for accidents. This gives me more opportunity to understand and explore the relationship to exposure.

The second, and more important, is that the measurement of flow is much better connected to conflicts than it is to accidents, which is essential since the primary aim of this study is to investigate the relation between flow and safety.

The counting was done virtually at the same time as the conflict studies. Since the accident data was collected during several years the relation to the measured exposure might have been changed over time. Especially for bicycle traffic we know that the seasonal variations are considerable. The accidents were collected from the whole year but the counting was done during the spring time, when the conflicts were collected. Conflicts have also shown a good correlation to expected number of accidents (Svensson, 1990). Thus, it is reasonable to assume that relations between conflicts and flow hold also for expected number of accidents and flow.

Since the traffic conflict technique might not be known for all readers I have included a short description of the Swedish technique as it has been used in this project.

7.3.1 The Swedish Traffic Conflicts Technique

According to Hydén (1987) the relationship between different events in traffic, of different degree of severity, could be described as a pyramid, where the top of the pyramid represents accidents and the bottom represents undisturbed passages. This pyramid illustrates the gain of using traffic conflicts as a surrogate for accidents. The basic idea with this is that serious conflicts have very much in common with accidents and that accidents are normally too rare in order to make proper analyses. Those problems are at least partly solved by using a Traffic Conflicts Technique (TCT).

Work with developing the TCT started at the Department of Traffic Planning and Engineering at Lund Institute of Technology in 1973. A technique for operational use was presented in 1977 (Hydén, 1977).

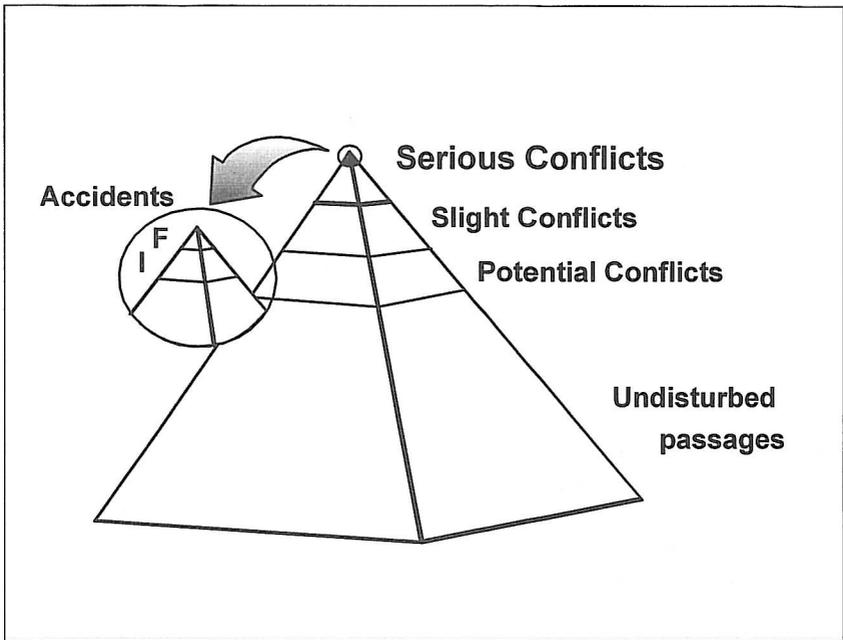


Figure 7.3 Different events in traffic (Hydén, 1987)

The Traffic Conflicts Technique is a complementary technique to accident analysis for safety assessment.

The basic concept is that there is a relationship between serious conflicts and injury accidents. The serious conflicts, are recorded by trained observers in the field. The observers are not only recording and scoring the conflict itself but also describing the events and the behaviour that led to the conflict.

One of the disadvantages of using police reported injury accidents is that they are very rare events. To be able to evaluate the effects of countermeasures one has to wait several years before enough accidents have occurred in order to get significant results. It is also almost impossible to get information from the police report about the events and behaviour leading up to the accident.

7.3.2 *Definition of a serious conflict*

Three important definitions as they are used in the Swedish traffic conflict technique:

Conflict: A situation where two road users are involved, which would have led to an accident if both road users had continued with the same speed and in the same direction.

Time to accident, TA: The time from the moment when one road user starts an evasive action to the moment a collision would have occurred if no evasive action had been undertaken.

Serious Conflict: A conflict with a small margin not to become an accident. The margin is set by the TA-value and the initial⁵ speed. The borderline represents the time margin necessary for braking plus 0.5 seconds. The 0.5 seconds are considered an extra margin and it makes the borderline fit with the border value of 1.5 seconds for all conflicts, used in earlier studies. The median speed in those earlier studied intersections was 35 km/h.

⁵ Speed when the evasive action is taken

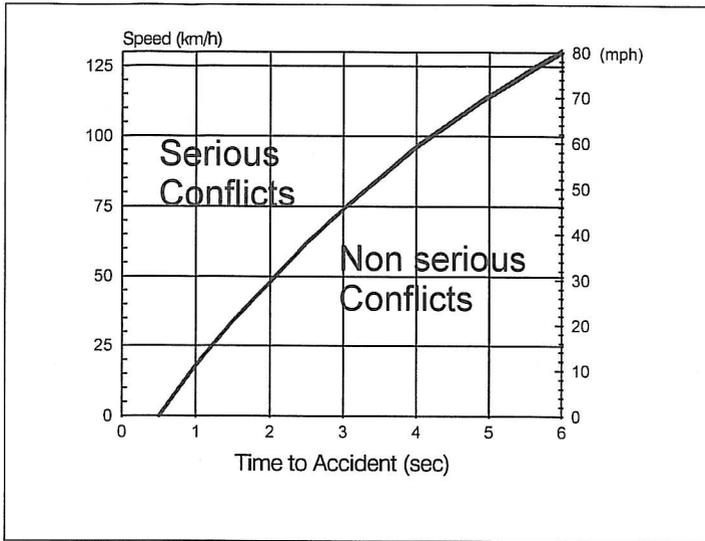


Figure 7.4 The borderline between Serious and Non-serious Conflicts

Two factors of great importance for the usefulness of the technique are:

- 1) *The reliability of the observer.* In specially designed reliability tests we found satisfactory results. They showed that trained observers are able to identify 80-85% of all serious conflicts and not scoring non-serious (Hydén, 1977).
- 2) *The validity of the technique.* Several different studies have shown a clear relationship between conflicts and police reported injury accidents. In one study we found (Svensson, 1990) that if the expected number of VRU accidents per type and year was less than 2, conflict studies during 3 days were better, gave a smaller variance of the estimate of expected number of accidents, than one year of accident data gave. The average accident frequency was 0.15 police-reported injury accidents per year. It has also been shown that the accidents and serious conflicts have the same pattern in terms of evasive manoeuvre, etc. (Hydén, 1987).

A novel indication of the validity of the technique can be observed from the similarities in conclusion I can draw from using both accidents and conflicts to illustrate the relation between conflicts and flow. This could be found in chapter 11.

Since I am familiar with the concept of the pyramid, I should like to use it to illustrate the use of accident rates as well. If we thus, according to the probability approach, want to construct accident rates these could be deduced from the

pyramid. If we then suppose that the entire pyramid is the population, the unwanted outcome is represented by the top of the pyramid. How much of the top we want to define as the unwanted outcome is up to ourselves to decide for each situation. The pyramid could also be cut in slices in order to do the analyses stepwise, as proposed by Thulin and Nilsson (1994) see section 2.1.

In my analysis I have chosen to compare the serious conflicts with the relevant incoming flow of road users. Since the database was constructed for the purpose of validating the Swedish traffic conflict technique the database also includes information about the police reported accidents. For some analyses I will also use these data.

7.4 The need for visual interpretability

In all practical circumstances the traffic safety analyses serve the purpose of solving traffic safety problems. The key issue is then to understand the reality behind the observations. Generally, it is of great value to be able to visualize the data since a graphic representation for most people is easier to grasp than other types of statistical output. Graphic representation often offers a good overview of the data. At the same time as graphical representation offers a powerful tool for data representation, may of course be misleading if handled without care. The aim of this study is to offer tools that can improve the visualisation of traffic safety statistics.

7.4.1 *The problem with "zero-cells"*

This database as well as almost all others, consists of data gathered from many locations. If we want to illustrate the relationship between accidents and flow we will face a specific problem concerning all the locations with no accidents, or no conflicts. When constructing accident rates there will be several locations where we have zero accidents that is to be divided with the flow. Then the level of flow does not matter. No matter if the level of flow is big or small, the rate will be zero. The fact, that locations with high level of flow have zero accidents intuitively holds some kind of information, compared to if the level of flow was small and zero accidents were recorded,

One way to deal with this is to add one accident to each location in order to get at least a number to give the rate a value greater than zero. This was practised by Johansson and Naeslund (1986). In order to avoid the "problem with all the locations where there have not yet been any accidents" they added one accident to all segments of the road they wanted to analyse. They remarked that this procedure had no major influence on the further analyses. Let us assume that there is a "true underlying accident rate" for the locations where no accidents had occurred during the studied period. A fair assumption could be that the true

accident rate should be somewhere between zero and one for this time period, even if the most likely outcome, according to the Poisson assumption, is zero. It is then reasonable to assume that it should be half an accident during this period. Adding one accident to these cells should then be the same as if we doubled the accident rate. Then the rest should be doubled rather than just adding one to all those as well. Adding one accident to a location with just one accident results in twice the accident rate but if we add one accident to a location with ten accidents this increases the rate with only ten per cent. Even if we do not presume linearity between accidents and exposure this procedure of adding one accident to all the segments gives biased results.

In my database the same situation occurs. For many of the approaches no accidents or conflicts are recorded. If we plot the number of conflicts versus the flow we get a scattered picture (Figure 7.5).

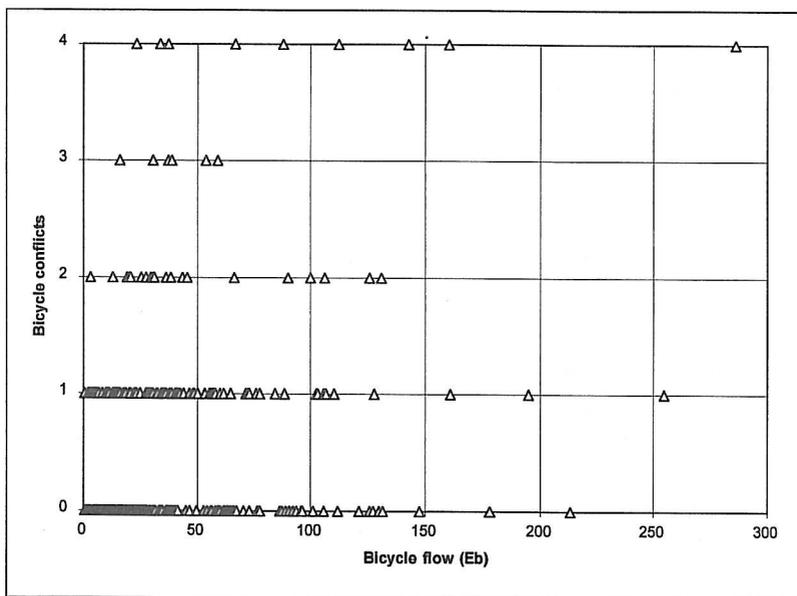


Figure 7.5 Bicycle conflicts versus bicycle ⁶flow(*E_b*)

What we see here is that for many approaches we have not recorded any conflicts, but in some approaches we have as many as four conflicts during the two days. Most of the locations with no conflicts we find at locations with low flow. Also locations where we have recorded conflicts are most frequent at low bicycle

⁶ *E_b* = number of bicyclists entering the approach per hour

flow. This picture gives no real help if we want to do safety evaluations and especially if we want to study the safety to flow relations. If we compute the accident rate for each approach separately we can construct another picture, in order to look at the accident rate for an individual bicyclist. This pinpoints even more clearly that in the case of locations with low value of flow we will either get extremely high accident rates or a zero value.

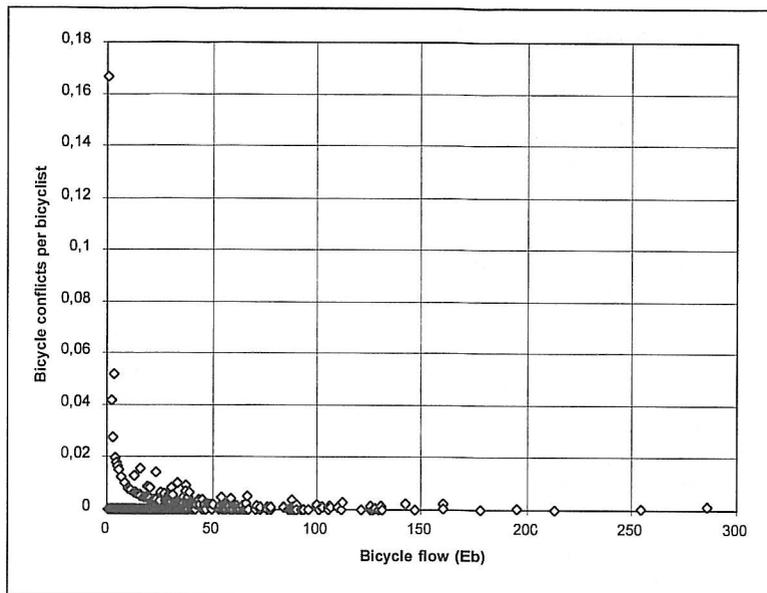


Figure 7.6 Bicycle conflicts per bicyclist versus bicycle flow

The data points are formed along five lines, one is the base line, where there are no conflicts and four curves represent one to four conflicts per approach. We see that the high conflict rates occur at low bicycle flow. This is even less informative since it is quite obvious that if an approach with very low value of flow happens to have a conflict, the rate is bound to be high. Again, the information that there also are lots of approaches with no conflicts, is difficult to visualize.

7.4.2 The problem with heteroscedasticity

If we want to visually interpret data presented in a graph, it is of great importance that data have either equal precision or that the variability could be visualised. If a graph is presented with ten observations it is very difficult to keep in mind the accuracy of each observation if they differ considerably.

If, on the other hand, the data are scattered in one region of the graph and more joint in an other region, this variability could be interpreted once it is visualized.

When looking at Figure 7.6 it is hard to see any other pattern than that the variability is huge in the region of low bicycle flow. This is quite natural since in each approach there will either be zero risk (no recorded conflict) or extremely high risk (a single conflict divided with a small number). Nevertheless it makes figures like Figure 7.6 impossible to interpret from a traffic safety point of view.

7.5 Aggregation, a way to overcome the problem

7.5.1 Different strategies to carry out the aggregation

In a study by Gårder et al (1978) the problem discussed in section 7.4.2 was focused on, namely when lots of locations have low value of exposure and only a few of these locations had any conflicts. All data was aggregated within a fixed interval of exposure. Applying that technique on my bicycle data would look as shown in Figure 7.7. Then we almost circumvent the problem with "zero-cells". One disadvantage, however, with this technique is that in each aggregate the number of observations could differ considerably. As shown in the figure, one aggregate is derived from 272 approaches but another aggregate is derived from only one single approach. The aggregates have different precision and thus each point in the diagram could not be interpreted as equally significant. If we want to evaluate the graph visually this weighting problem is not easily solved. In addition, we do not use the information in an optimal way. In the study by Gårder et al (1978) the solution was weighted linear regression. This gives unbiased end results but does not enable visual interpretation.

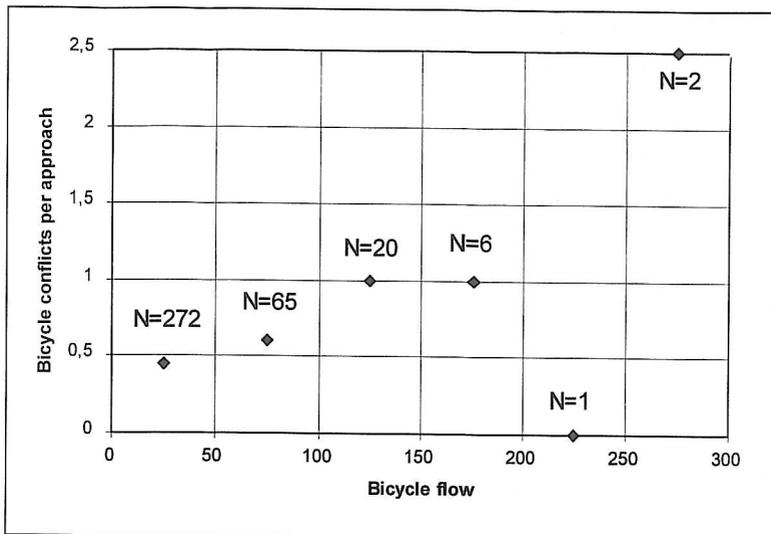


Figure 7.7 *Bicycle conflicts per approach versus exposure. Averages over segments of exposure. The number of approaches (N) behind each average is presented with numbers.*

If we want to create better aggregates we should strive towards aggregates with equal precision. This problem was first addressed in (Brundell-Frej & Ekman, 1990). As I see it this could be done in two different ways. Either we could create aggregates with equal numbers of conflicts or we could create aggregates based on equal numbers of bicyclists.

7.5.2 Aggregation based on the number of conflicts

Aggregating in order to achieve equal numbers of conflicts in each aggregate fulfils the aim of equal precision since the variance is proportional to the number of conflicts. This is due to the assumption that conflicts as well as accidents follow the Poisson distribution. Thereby the variance is equal to the mean, and thus similar number of conflicts would result in similar precision.

The disadvantage with this aggregation concept is that if we have a large segment of the exposure range that is so completely safe (no accidents or conflicts) that information would be hidden. With this method no aggregates with zero conflicts will be found. Since the *counter* number of conflicts will not be incremented and thus an aggregate with zero conflicts is impossible to achieve, despite how many road users that safely appear in that segment. At least theoretically this might introduce bias in the aggregation procedure.

7.5.3 Aggregation based on relevant flow

The other aggregation principle (aggregates based on relevant flow) has the benefit of not hiding areas with no conflicts. The aggregates will be exactly comparable if they are used for looking at the conflict-to-flow relationship from the road user perspective.

The variation between the number of conflicts recorded in different approaches could basically have the following three different sources.

1. The expected random variation if the "true underlying accident rate" is constant.
2. The random selection of true underlying accident rate between locations with identical level of flow.
3. The variation in average true underlying accident rate dependent on flow.

Normally traffic engineers are interested to manage the first and third in order to explore the second. A more thorough investigation of these sources of errors could be found in (Kulmala, 1995). By aggregating I want to manage the first one and test if the second is disturbing but most of all I want to explore the third source of variation.

The first is the variation that could be described by the Poisson process (Nicholson & Wong, 1993, Hydén, 1987). This variation is the random variation in outcome if the true underlying accident rate is constant for all approaches. The second variation is derived from the fact that we aggregate several different locations. If there is a large variation in underlying accident rate, this would lead to increased variation if the number of aggregates is large, compared to if each aggregate is derived from many locations. In the former case the location specific variation could not be hidden within the variety of selected locations in an aggregate. Such location specific variation in safety may be due to the variation in layout, road user population or other location specific factors.

If we can manage the two first random variations, we may explore the third. The significance of the pattern among the aggregates will be tested in two ways, namely simulation and bootstrap. The tests are described later in this work, but for now it is enough to state that the aggregation procedure fulfils the aim of producing aggregates with manageable accuracy in the estimate of individual risk. It is worth mentioning that the number of approaches might vary a lot and still manageable inaccuracy could be achieved. Since this aggregation procedure fulfils my aim I will use this aggregation procedure in the rest of my data analysis.

The aggregates are constructed by sorting the data set according to the flow on the X-axis and then creating aggregates consisting of the averages based on the number of individual approaches that sum up to the same amount of passing road

users. In my case, the road users are either bicyclists or pedestrians. Then the averages are computed both for the flow value (X-axis) and the conflict, or conflict rate values (Y-axis). For the same amount of aggregates the figure should look like the next figure (Figure 7.8).

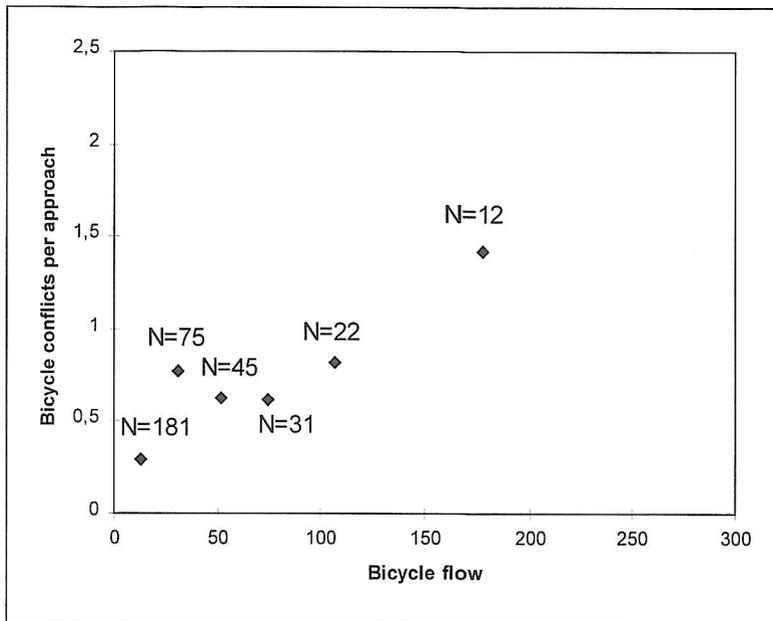


Figure 7.8 *Bicycle conflicts per approach. Averages based on equal number of passing bicyclists. Number of approaches behind each average is also presented with numbers. Based on 6 aggregates*

In order to be able to explore the variation in average true underlying accident rate dependent on flow I need to use more than six aggregates. As trade off between variability and explanatory power 15 aggregates were found suitable for my purposes.

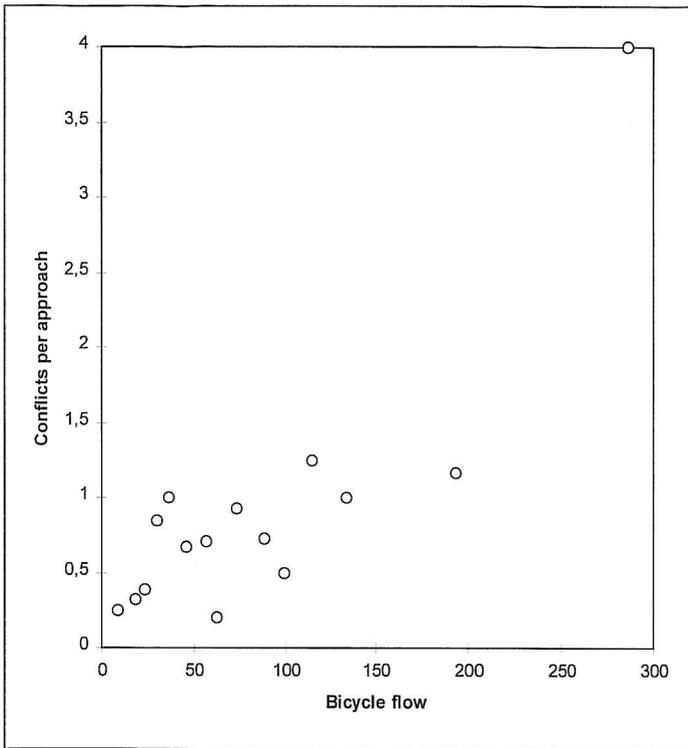


Figure 7.9 *Bicycle conflicts per approach. Averages based on equal number of passing bicyclists. Based on 15 aggregates*

7.6 Different methods to construct a safety performance function

In order to create a continuous safety performance function one could just connect these few aggregates with a line and call that a safety performance function. This would overcome some of the disadvantages with normal model building or regression analyses. Ever so often one comes across regression analyses or model constructions that are interpreted as if they were valid even over segments where no data have been collected. In fact, this is common in many areas and known as, trend extrapolation. As has been argued earlier (in chapter 4) computing accident rates and comparing them is equal to assuming that the safety performance function is a straight line. This line is often based on measurements

at the right end of the figure, as data most often are collected from locations with high flow. It is done in order to ensure effectivity in the data collection. This is why almost all knowledge regarding, e.g., bicycle safety is collected at locations with high bicycle flow although most bicycles are driven at locations with low flow as the network suitable for bicycle traffic normally is found in the residential areas. It is of great importance for the interpretability to clarify when a safety performance function is representing the observations and, on the other hand, when (if ever) the function is used as an attempt to model or extrapolate to areas not investigated. For my data set, several possible methods for constructing safety performance functions have been applied. Three methods are illustrated in Figure 7.10.

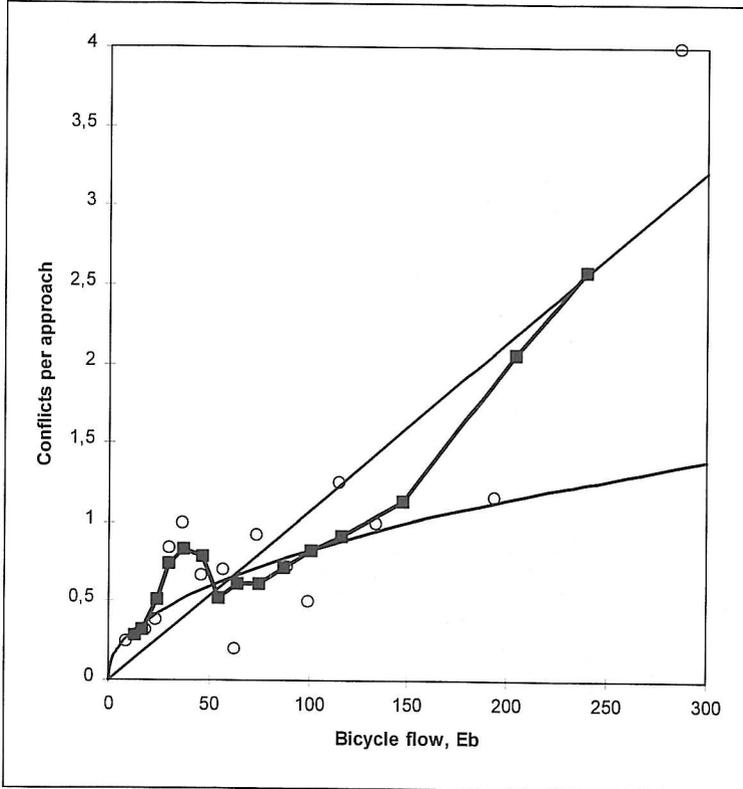


Figure 7.10 *Bicycle conflicts per approach. Aggregates based on equal number of bicyclists(circles). Moving-3-point-averages (line with markers), Linear regression (straight line) and an Exponential model (curve)*

The first, but not recommended, is the linear regression here based on the aggregates and forced through the origin:

$$E(A) = b * exposure ,$$

estimation results: $b = 0,010713, \pm 0,001967$ (90% confidence interval),
corrected $R^2 = 0.65$

The next model type is the most commonly used method in accident modelling (Brüde, 1981, Kulmala, 1995). It is an exponential model, based on the individual observations (individual approaches);

$E(A) = B * Exposure^C$. The parameters were estimated using the computer package GLIM,

estimation results:

$B = 0,106885, c = 0.471$ and corrected $R^2 = 0.07$

The third method is the one I will advocate, floating three point averages based on the 15 aggregates. The moving averages were constructed as the average of three consecutive aggregates, but the first and the last value were based on only two aggregates in order to make the best use of the data. Averages were computed over both the safety value and the flow value.

The moving averages have the advantages of being "non-parametric", i.e. we need no pre-assumption about the form of the relationship between accidents and exposure. This fulfils my aim of being open towards possible complex relations between accidents and flow. The advantage with moving averages based on many aggregates compared with a line directly based on larger aggregates, and thus fewer aggregates, is that I combine the stability of the few with the sensitivity of many aggregates.

The method of moving averages was introduced by Linderholm (1992), to compare safety performance functions for different layout of bicycle facilities. Linderholm was partly criticised for not showing the accuracy of the moving averages lines. It could be argued that smooth curves could always be achieved and hypothesis-generating patterns could be derived from single and extreme observations. There is obviously a need to control the stability of the moving averages lines. This will be dealt with in chapter 8.

7.7 Risk performance functions

Let us consider the situation for an individual bicyclist. This is of central interest in many traffic safety analyses. A reasonable measure of the average risk for individuals, crossing the intersection at the same (or in the case of aggregation, similar) locations, is the number of conflicts per crossing road user (pedestrians or bicyclists). This could be estimated by:

$$R = \frac{\text{Number of recorded conflicts during two days}}{\text{Average hourly flow} * 2 \text{ days} * 6 \text{ hours}}$$

If we had used accident data we would have had to compare accidents recorded over a much longer period than the exposure data were based on. For the aim of computing the relative risk that would not have caused trouble, but since I had the opportunity to create a ratio that has an immediate interpretation as, the number of serious conflicts per crossing bicyclists, I think it has a certain advantage. Normally the denominator and the numerator are not measured in a way that makes it sensible to get values in the same unity and thereby, as interpretable value as this.

If we then for each aggregate compute averages of R and the corresponding values of exposure, a different figure could be made. In this a horizontal line would indicate a constant level of average individual risk. This function representing the individual average risk for road users as a function of flow is in the following called *Risk Performance Function* (RPF)

This is an interesting measure for the individual road user or anyone who wants to look at safety from the individual road user's perspective. As has been argued earlier this perspective may often be good, but is certainly not the only valid perspective. The RPF based on the same data as Figure 7.10 is presented in Figure 7.11.

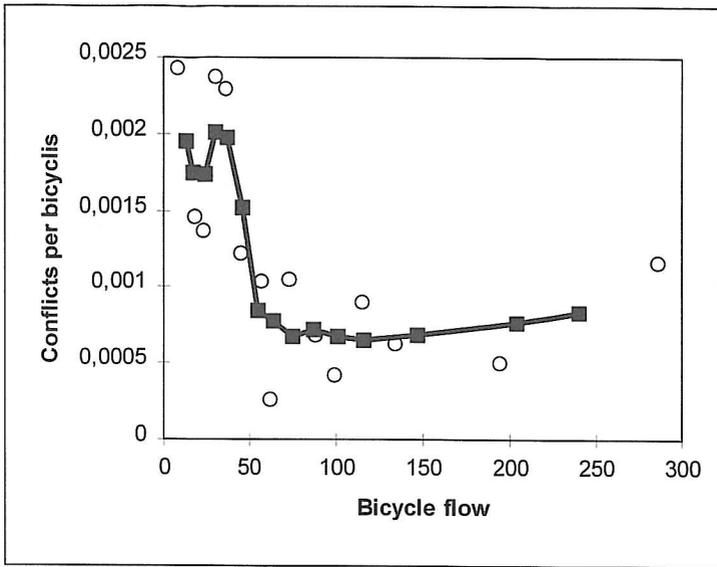


Figure 7.11 Risk Performance Function (RPF) of bicycle flow, moving-3-point averages (line with markers). Aggregates based on equal number of bicyclists(circles).

The interpretation of Figure 7.10 and Figure 7.11 will be discussed from a traffic safety perspective in chapter 9. It can, however, directly be seen that the accident rate is high at low bicycle flow.

8 The Use of Computer Intensive Methods for the Estimation of Accuracy

When describing the accuracy of how the flow influences accidents and accident rates, the need for massive amount of data is obvious. Can we trust the relation we have found between conflicts and flow? Since the analyses always have to be carried out with a too small amount of data, there will inevitably be problems with large random variation. The reason this type of analyses gets so "data hungry" is that, in principle, each section of flow needs data enough for a test of its own, which might, by the way, be the reason that this type of studies have not been done very much before. The normal tests of the stability of the results do either demand even more data in order to use one part as the control group and the other as a test group, or it demands extensive and restrictive assumptions in order to simplify the tests. One assumption that is commonly made is exactly the one, which I myself have found so ungrounded, namely that exposure and accidents are proportional to each other. Another assumption is that conflicts as well as accidents could be described with the Poisson process. I have, however, no objections to this latter assumption. This has been shown by several studies and is commonly agreed upon. (Hauer, 1992(b), Hydén, 1987, Nicholson & Wong, 1993)

The method I have used, "Sophisticated aggregations and smoothing with moving averages" results in a non-parametric function. The variability of my results turns out to be impossible to calculate analytically, at least with my level of statistical knowledge.

If there is no direct way of describing the influence of random variation it may be useful to use some methods that have the benefit of being more general in theory but, on the other hand, not so effective. The two methods I have used required relatively large computer power - at least they are not possible to do "by hand". The two methods are *Simulation* and *Bootstrap*. The simulation method tries to help us by creating several synthetic data sets under known conditions. The bootstrap technique uses the variation in the present data set to calculate the accuracy of the description. Another way to describe Bootstrap is that it is a 'data-based simulation' (Efron & Tibshirani, 1993)

The ineffectivity of these methods can be compensated by the computer's perseverance and high speed. The reason for the need of computer power, is that both methods require that the whole procedure of analyses from raw data through

sorting, aggregating and curve construction, needs to be done over and over again.

8.1 Simulations

The first way I tested whether the found tendency, namely high accident rates for bicyclists driving at locations with low bicycle flow, could be a result of random variation only, or was likely to be a "real effect" worth taking into consideration in traffic planning, was the simulation method. The simulation procedure is based on the following concept or question:

What would synthetic data sets look like, when based on the average value observed in the data set, and with only a random variation in line with the Poisson process?

Synthetic data was constructed for the same number of approaches as in the actual data set. The distribution of exposure over intersection approaches was set to the same as in the "real data set". The number of conflicts was produced with the assumption of a constant conflict rate (number of conflicts per bicyclist) set to the average in the real data set. The random variation was derived from the Poisson process. One thousand data sets were produced. A 90 per cent confidence interval could then be selected as the range within which 90 per cent of the aggregates were found. One advantage with simulation (as well as bootstrap) is that "exact" confidence intervals could be computed. Exact means that the intervals need not be assumed to be symmetric and that they are actually derived from the outcome of the process.

A key to the validity of the simulation is to produce correct random numbers that are Poisson distributed. This was done with a procedure created in a Pascal environment. For the generation of Poisson distributed random numbers the approximate identity of the binomial distribution was used. Blom (1970) suggests that the similarity between the Poisson distribution, $Po(n \cdot p)$ and the binomial distribution $Bin(n, p)$ normally is sufficiently good if $n > 10$ and $p < 0.1$. For the simulation I created random numbers from a binomial distribution $Bin(\mu \cdot 1000, 0.001)$ to obtain an (approximately) Poisson distributed number $Po(\mu)$. The binomial distribution was, in its turn, based on $\mu \cdot 1000$ random numbers from a rectangular distribution $[0, 1]$ generated by the standard routine in Borland Pascal. The count of these numbers which were > 0.999 was used as the binomial (approximately Poisson) distributed number.

This method was used to create "simulated observed conflict numbers" for each approach in the original data set. These numbers were generated according to above, from the distribution $Po(r \cdot q_i)$, where an assumed value was the average conflict rate observed, and q_i was the observed number of bicyclists in approach

i. One thousand full data sets were thus generated, each containing simulated observed conflict numbers for all approaches.

The null-hypothesis is then; The original data set is derived from a "true conflict rate that is constant and at a level equal to the population average".

The result of the simulation can be found in Figure 8.1.

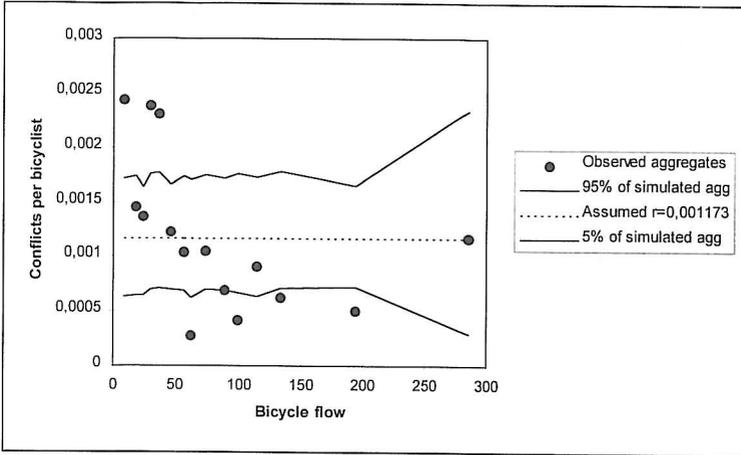


Figure 8.1 Result of the simulation process of the aggregates of conflicts per bicyclists versus bicycle flow. With a 90% acceptance region for the null-hypothesis.

In this figure we can see two important phenomena. Firstly, we can see that the data representing approaches with low value of bicycle exposure falls outside the critical values. This means that it is not likely that the result in the "real data set" could be a random effect only. To be more precise, for each of the aggregates to be outside the interval, the probability is 10% if there was no other effect than random variation. The probability for the extreme outcome we have, 7 out of 15 outside the interval) is less than 10^{-6}

Secondly we can see, from the simulated intervals, that the system of aggregation, under the null-hypothesis, does produce numbers that have similar standard variation. This was one of the aims of the aggregation as it is of great importance that the data aggregates have similar precision if the aim of good visual interpretability are to be achieved. This is evident if we compare this figure with figure 7.6 where the variation in the low region of exposure is enormous. On the very right side of Figure 8.1 we can see that the interval increases around the last aggregate. This is due to the fact that this aggregate is a "rest group". For all the aggregates, the total number of bicyclists is roughly the same but the last group consists of the remaining approaches that not necessarily result in a "full group".

This was the first "proof" that the conflict data does not seem to indicate a linear relationship with bicycle flow. The disadvantage with this test method (apart from the need for a computer and programming ability) is that the method cannot be generally applied. We need to assume a basic random process, such as the Poisson, and we may plot only certain specific "null-hypotheses". As stated above the "problem" with the basic random process is not a major problem in this case. In the area of traffic safety research the Poisson process is found to be both handy and reliable. The specification of the null-hypothesis is more troublesome. Since we have found no reason to assume that the relationship between accidents and exposure should follow a simple mathematic formula, it is of limited interest to test whether data support such an assumption.

A tool that fits the purpose better than simulation is the method "Bootstrap".

8.2 Bootstrap

8.2.1 Background

Bootstrap is a relatively new technique in the area of statistics. It was invented by Efron in 1979 (Efron & Tibshirani, 1993). The main reason that it was not invented earlier is probably that it requires modern computers in order to be useful. The use of the term Bootstrap is derived from the phrase 'to pull oneself up by one's bootstrap' phrased by Baron Munchausen. This sounds like a complete contradiction. In fact, there is something of a contradiction in the method as well. The idea is to use the variability in the present data set in order to test the stability of the conclusion. To put it simply, bootstrap could be described with the following question: Can my findings be the result of a single, or a few, odd observations only? This is, after all the essence of all statistical tests: Are my findings likely to represent a real effect or do they only reflect a normal or expected random variation?

Bootstrap is, in fact, a further development of the statistical method known as "*Jack-knife*" which is a systematic procedure to test what a conclusion might be if single observations were left out. In a similar way, it could be interesting to test what would be my conclusions if I happened to have duplicates of single observations.

Bootstrap is a random selection, with replacement, from the original data observations completed all the way throughout the analyses. It is of vital importance that the bootstrapping is done on the original data in order to simulate the situation that would arise if a new study was carried out.

In Efron's and Tibshiranis' work from 1993, the bootstrap solution to calculate the standard error of a sample median is discussed. It is, by the way, quite

difficult to calculate the standard error of the median with the classical statistical "toolbox".

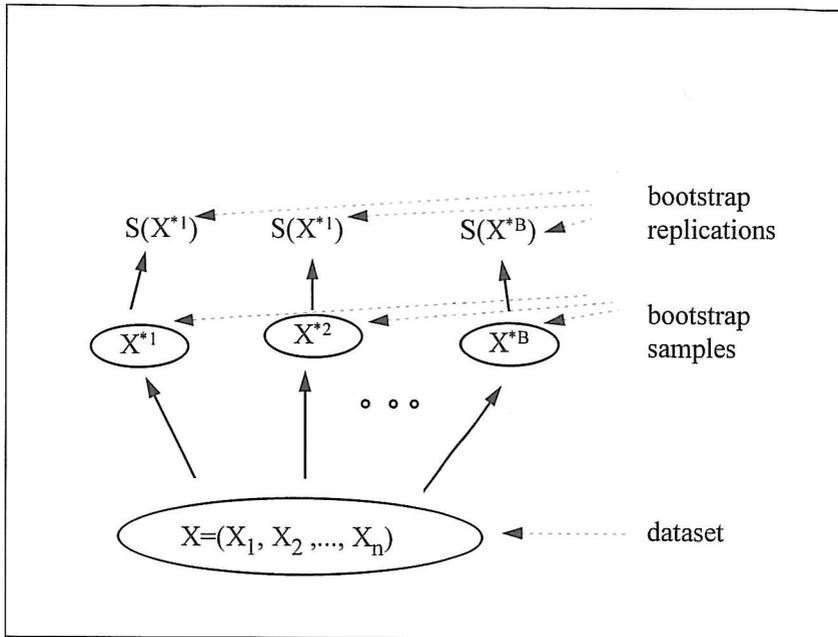


Figure 8.2 Schematic representation of the bootstrap process for estimating the standard error of a statistic $S(X)$ (e.g. median of X). Bootstrap samples are generated from the original data set. Each bootstrap sample has n elements, generated by sampling with replacement n times from the original data set. Bootstrap replications $S(X^{*1})$, $S(X^{*2})$, ..., $S(X^{*B})$ are obtained by calculating the values $S(X)$ on each bootstrap sample. (Efron & Tibshirani, 1993)

The bootstrap algorithm begins by generating a large number of independent bootstrap samples $X^{*1}, X^{*2}, \dots, X^{*B}$, each of the size n . Typical values of B , the number of bootstrap samples, range from 50 to 200 for standard error estimation and about 1000 for estimation of confidence intervals. Corresponding to each bootstrap sample is a "bootstrap replication" of S , namely $S(X^{*b})$, the value of the statistic S evaluated for X^{*b} . If $S(X)$ is the sample median, then $S(X^*)$ is the median of the bootstrap sample. The bootstrap estimate of standard error is then the standard deviation, $\hat{\sigma}_{boot}$, of the bootstrap replications;

$$\hat{se}_{boot} = \sqrt{\frac{\sum_{b=1}^B [S(X^{*b}) - S(\bullet)]^2}{B-1}}$$

$$\text{, where } S(\bullet) = \sum_{b=1}^B \frac{S(X^{*b})}{B}$$

This means that the whole procedure of analyses needs to be completed for each new bootstrap replicate. Therefore, the whole procedure of the analyses has to be “computerized”. In my case the system of aggregation and constructing moving averages has to be done in a computer program. For this purpose, a set of computer programs was developed. The programs were developed using a “Borland Pascal environment”. Program languages suitable for bootstrap are mainly those suitable for simulation. The most commonly used program languages for bootstrap applications are Matlab or S-PLUS, but since I am more familiar with Pascal I have chosen to use that language. The initial analyses (aggregating and smoothing) before the introduction of bootstrap were carried out in a “spreadsheet program” (Lotus 1-2-3). The spreadsheet programs are very user friendly and handy for several purposes but were found unsuitable for Bootstrap applications.

8.2.2 *Bootstrap based on single intersection approaches*

The bootstrap algorithm begins by generating 999 independent bootstrap samples. Each bootstrap sample has 364 observations, generated by sampling with replacement 364 times from the original data set. The reason that I have used 999 replications and not 1000 is that it is common practice when bootstrapping. One can prove that this method produces more accurate results (more correct estimates of the median) if we deal with small numbers, but in practice it is of no importance since the number of replications normally is very big.

In the present case, it was not the standard error of the mean or the median that required the bootstrap tool but rather the stability of the graphs consisting of the resulting moving averages curves. Bootstrap result could, preferably, be presented graphically since the result often consists of a huge amount of data. In this case we want to create a number of new curves, each curve representing a bootstrap replication of the original data set. Following the structure proposed by Efron and Tibshirani the method would then be as follows:

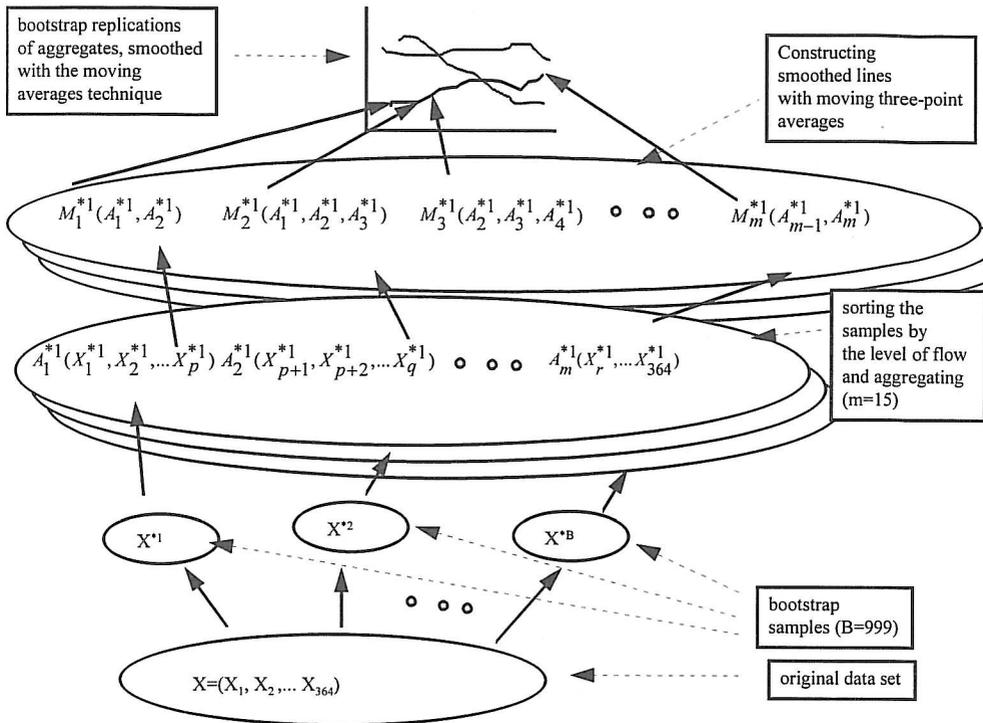


Figure 8.3 Schematic representation of the bootstrap process for estimating the accuracy of moving averages $M(X)$. B bootstrap samples are generated from the original data set. B was set to 999. Each bootstrap sample has 364 observations, generated by sampling with replacement 364 times from the original data set. Bootstrap replicates $A(X^{*1}), A(X^{*2}), \dots, A(X^{*B})$ are obtained by calculating the aggregates $A(X)$ on each bootstrap sample. Based on these aggregates moving averages lines $M(X^*)$ were constructed for each replicate.

999 sets of bootstrap replications of A , the sorted aggregates, were computed according to the method described in chapter 7. The aggregates are vectors consisting of one exposure element and one risk or safety element, safety element if we work with safety performance functions and risk element if we work with risk performance functions, i.e:

$$A_1 = \left(A_1^{*1}(e_l), A_1^{*1}(s_l) \right) = \left(\frac{\sum_{i=1}^p e_i}{p-1+1}, \frac{\sum_{i=1}^p s_i}{p-1+1} \right),$$

$$A_2 = \left(A_2^{*1}(e_l), A_2^{*1}(s_l) \right) = \left(\frac{\sum_{i=p}^q e_i}{q-p+1}, \frac{\sum_{i=p}^q s_i}{q-p+1} \right) \dots \text{ in safety performance}$$

functions

$$A_1 = \left(A_1^{*1}(e_l), A_1^{*1}(r_l) \right) = \left(\frac{\sum_{i=1}^p e_i}{p-1+1}, \frac{\sum_{i=1}^p r_i}{\sum_{i=1}^p e_i} \right),$$

$$A_2 = \left(A_2^{*1}(e_l), A_2^{*1}(r_l) \right) = \left(\frac{\sum_{i=1}^q e_i}{q-p+1}, \frac{\sum_{i=1}^q r_i}{\sum_{i=1}^q e_i} \right) \dots \text{ in risk performance functions}$$

The smoothed lines are then computed in a similar way based on the aggregates A. Here the first and the last point were treated separately in order to make better use of the data. The first and the last point were thus based on only two aggregates, for safety performance functions:

$$M_1^{*1} = \left(\frac{A_1^{*1}(e) + A_2^{*1}(e)}{2}, \frac{A_1^{*1}(s) + A_2^{*1}(s)}{2} \right)$$

$$M_2^{*1} = \left(\frac{A_1^{*1}(e) + A_2^{*1}(e) + A_3^{*1}(e)}{3}, \frac{A_1^{*1}(s) + A_2^{*1}(s) + A_3^{*1}(s)}{3} \right)$$

and correspondingly for Risk Performance Functions.

In order to interpret the output, a computer program was developed which delivered both graphical output and numerical output. A characteristic result of a first bootstrap run with 9 replicated lines can be found in Figure 8.4. Remember that each run of the program creates a unique set of replicates and thereby unique

lines. (The number of possible unique data sets is $\binom{2n-1}{n} = \binom{2*364-1}{364}$)

which is indeed a very large number) (Efron & Tibshirani, 1993).

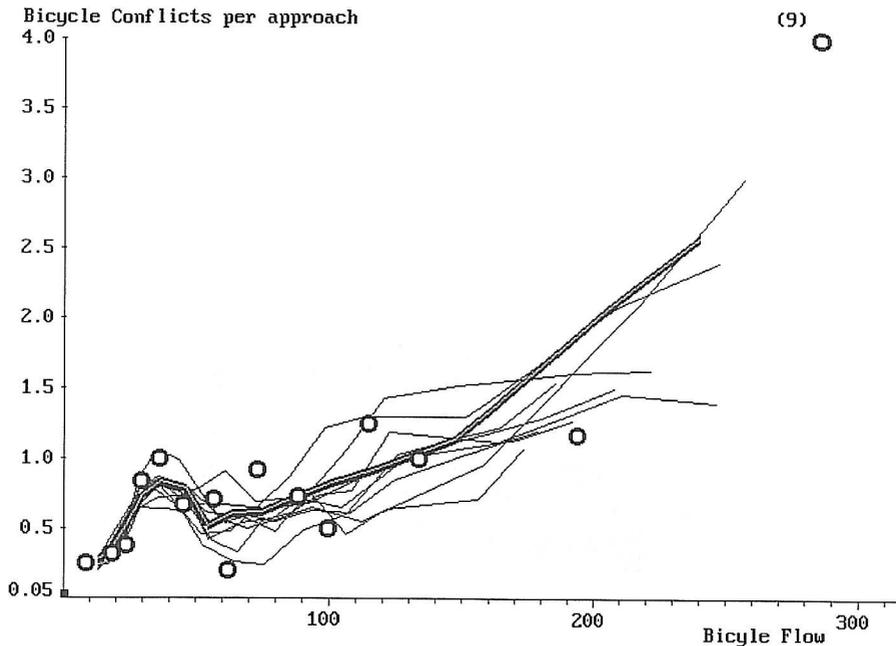


Figure 8.4 *Bootstrap runs with 9 replicate moving averages. Each replicate (moving average line) is illustrated with a thin line while the original moving average line is illustrated with the thick line. The original aggregates are marked with circles.*

This is the direct output of the program "bootstrap1" created to generate bootstrap replicates of the safety performance function. Here we see the original aggregates (15 circles) and the curve representing the three points moving averages derived from those aggregates. The thinner lines are the nine first replicates of the moving averages lines. This indicates that there is a variation around our original line. According to the bootstrap theory this has to be repeated over and over again in order to get a valid representation of the variation of our interest. If we keep on bootstrapping and create 999 replicates we get the following figure:

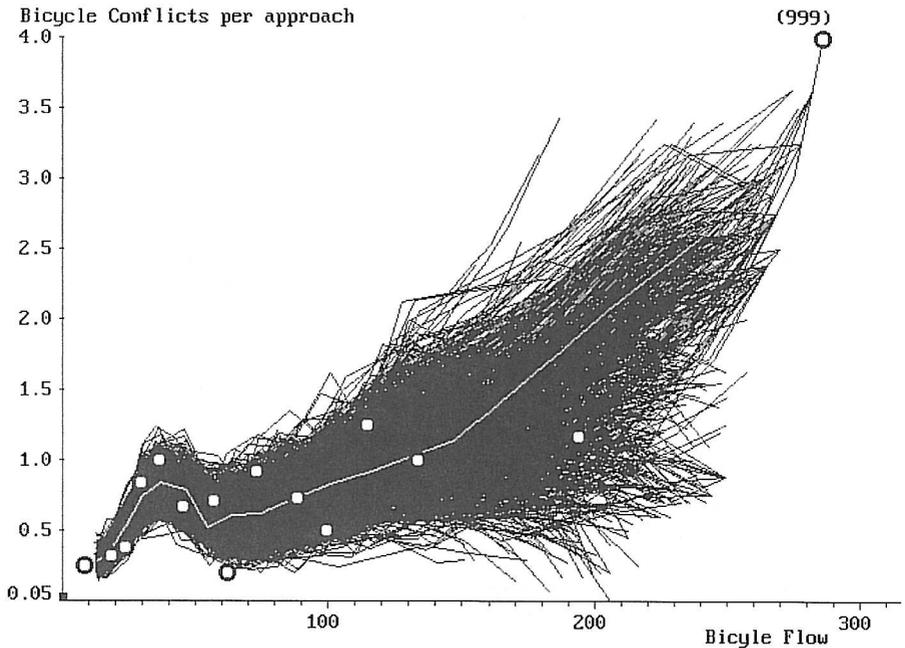


Figure 8.5 Bootstrap runs with 999 replicate moving averages. Each moving average curve is illustrated with a thin line and the original moving average line is illustrated with the thick line. The original aggregates are marked with circles.

In this figure a more systematic picture can be seen. First of all, the form of the multitude of lines seems to indicate an irregularity in the low regions of bicycle flow. This does not seem to be derived from random variation exclusively. In order to get a more correct picture, with confidence intervals, we need a procedure to define the area around the original line where a certain percentage of the bootstrap replicates can be found.

In the area with high level of bicycle flow the figure gives the impression that the variability decreases. This is not a true effect and is a phenomena which needs to be treated separately (see section 8.2.4).

8.2.3 Confidence interval of the smoothed lines

A confidence interval is by definition an interval or an area wherein the "true", "expected" value is included with a given probability. In this case I decided to estimate a 90 % confidence interval by the range around the smoothed original

line where 90 % of the replicate lines are found. This is one of the methods that are recommended when estimating confidence intervals from bootstrap results.

Since the replicate lines constitute the result of an averaging process over the replicate aggregates, one line may be extreme at one section of the flow but not at another. Most often there will thus not be any single replicate line that is extremely high all the way. This means that we can not sort out and select the extreme of the complete replicate lines. Instead I slice the x-axis into a number of sections. At these sections I look for the highest and lowest values. I am looking not for the maximum and minimum values but rather looking for the 5- and 95 percentile of the outcomes. I need to find the range in which 90 per cent of the replicate lines is covered. To this aim, for any section S_i , the value of the safety or risk value r needs to be calculated for each replicate line. The 5 per cent highest and lowest r values need also to be stored in order to get the confidence interval for the section S_i . For each replicate line the r_i values at a set of specific sections were computed through interpolation based on the 3-point-averages(M^*) around section S_i .

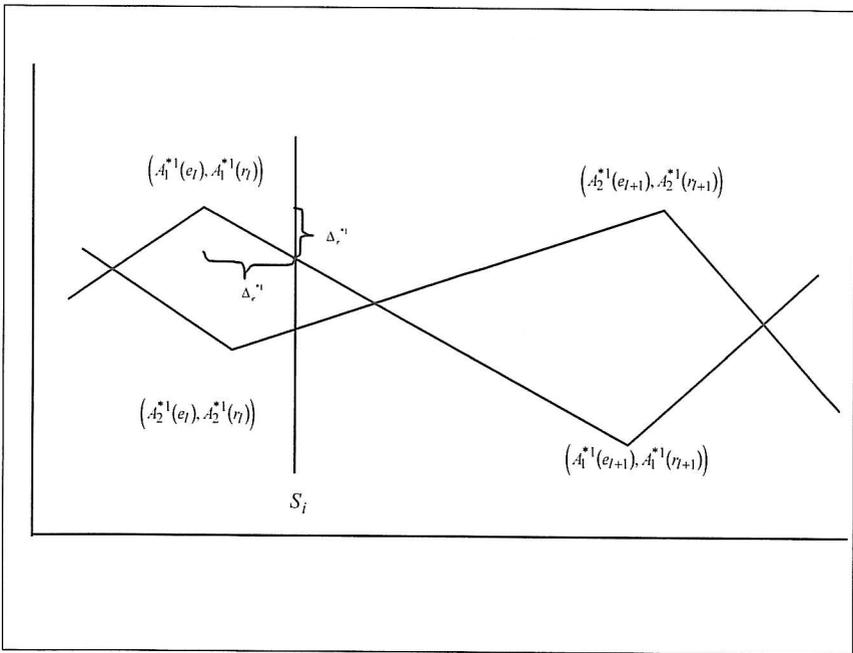


Figure 8.6 The interpolation procedure

The value $r_i(S_i)$ is $r(A_i^*) + \Delta_r$

This was carried out in a range of sections. I chose to slice the exposure axis in 50 equidistant sections. A specific computer program was developed to handle this task. Thereby, a proper confidence interval for the original smoothed line was derived.

This method enabled me to create non-parametric smoothed SPF's and still have an interpretable illustration of the accuracy of those functions.

8.2.4 The edge problem

As noted above, the replicate lines in Figure 8.5 give the impression of a decreased variability in the high regions of the exposure. This is not a correct interpretation but rather an effect of the fact that lines in the far right only could be constructed if much of the original data with high level of flow is selected. This means that this present data material does not hold to compute proper confidence intervals in the high region of flow. The process of creating the confidence interval will, therefore, only be able to compute intervals where we have enough replicate lines. We need at least the number of lines that corresponds to 90% of the total amount of replicates, in this case 899 lines. This is an important restriction of this non-parametric approach. We can, thus, only compute the accuracy of the safety performance function or the risk performance function in regions where we have "enough" observations. With this method I ensure that we do not construct performance functions where we have no observations.

The results of the computation of confidence interval for the SPF and RPF from earlier figures are presented in Figure 8.7 and Figure 8.8.

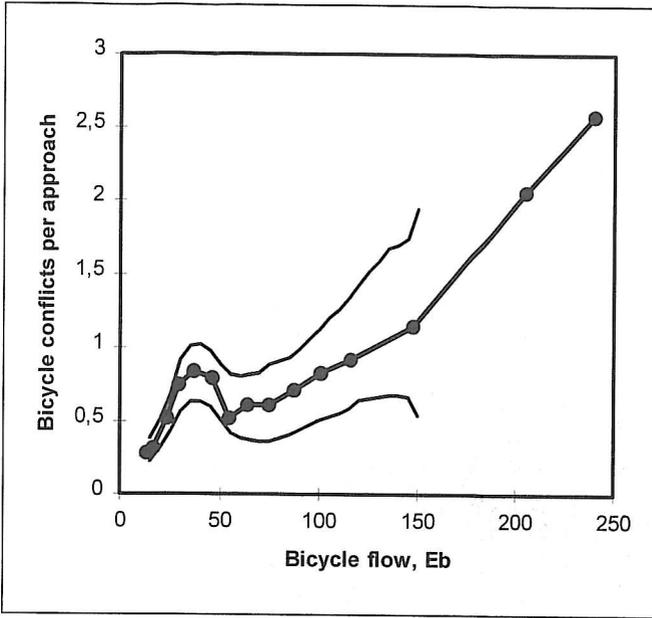


Figure 8.7 Bicycle conflicts per approach versus bicycle flow. Moving average line (SPF) with an estimated 90% confidence interval.

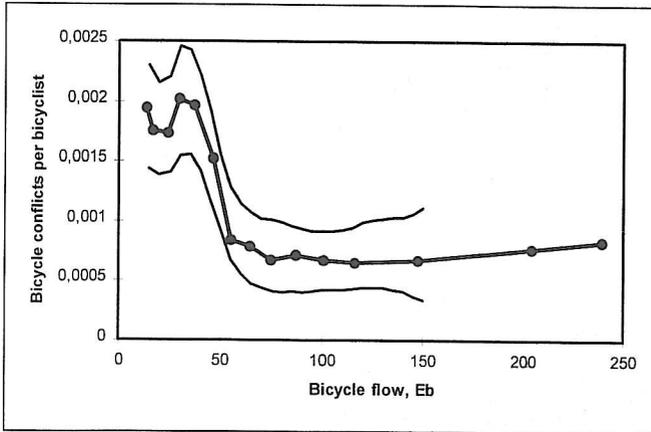


Figure 8.8 Bicycle conflicts per bicyclist versus bicycle flow. Moving average line (RPF) with an estimated 90% confidence interval.

The traffic safety implications of those results will be discussed later, while some more methodological reflections are made in section 8.2.5.

8.2.5 Test of the Bootstrap for confidence interval on synthetic data sets

In order to both test the validity of the method to produce the confidence intervals and to learn how to interpret the result I wanted to test the method on a synthetic data set. To this aim a synthetic data set, with a fixed expected underlying accident rate, was constructed. The construction of the synthetic data set was carried out in the same way as for the simulation, described in section 8.1. I thus obtained a data set with an expected accident rate fixed to 0.001173 conflicts per bicyclist and with a random variation in accordance with the Poisson distribution. What mainly needs to be discussed concerning this procedure is:

Are the estimated confidence intervals correct?

How distinct are the patterns found in a data with no underlying trend?

One result of such a run (generating synthetic data, bootstrapping with 999 replicates and computing confidence intervals) is illustrated in Figure 8.9.

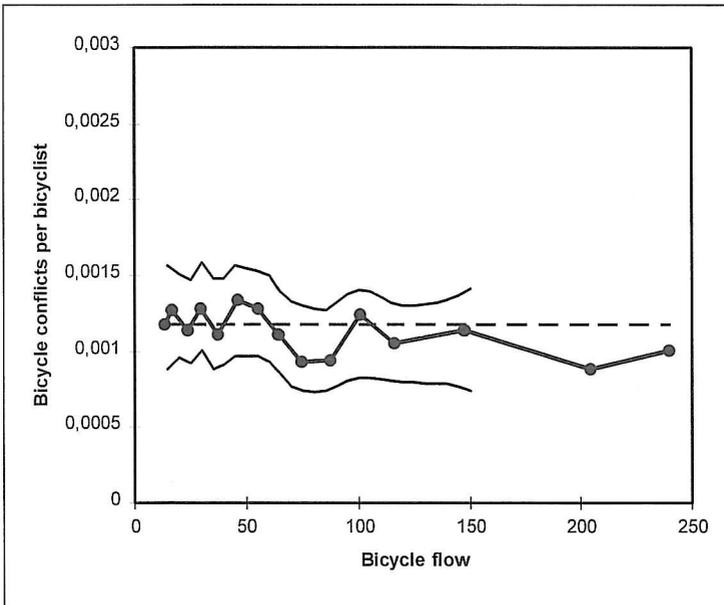


Figure 8.9 *Bicycle conflicts per bicyclist versus bicycle flow on a synthetic data set. Moving average line (RPF) with an estimated 90% confidence interval. The horizontal lines illustrate the expected value.*

What we can see in the figure is that the width of the confidence interval seems to be reasonably correct and that the expected value (the mid-dotted line) is well

within the confidence interval. We can also notice that with a data set like this, with no expected trend or pattern, the moving averages lines could still give tiny indications of a pattern. One could be tempted to say that there is a safe area (low individual risk) in the region of 75 bicyclists per hour. If we, however, use the confidence interval we have no reason to believe in such an explanation.

Furthermore, the confidence intervals seem to be a bit "conservative", since 90% confidence interval should cover the correct value in only 90% of the region. Looking at the figure above, and others created, the correct value (the horizontal line) seems to be within the area covered by the confidence interval in more than 90% of the flow-sections. This led me to set the level of significance to 80% instead of 90%.

Even if this test showed that the moving-3-point averages, and the confidence interval seem to create stable and reasonable data, there still might be a "concealing effect" of the smoothing. Is the procedure able to detect different levels of true-underlying-conflict rate? Or, to put it differently, what is the power of the test method developed? For this purpose I created new synthetic data but now with two different levels of expected values. The result of a new run (generating synthetic data(two levels of expected rate), bootstrapping with 999 replicates and computing confidence intervals (80% level)) is illustrated in Figure 8.10.

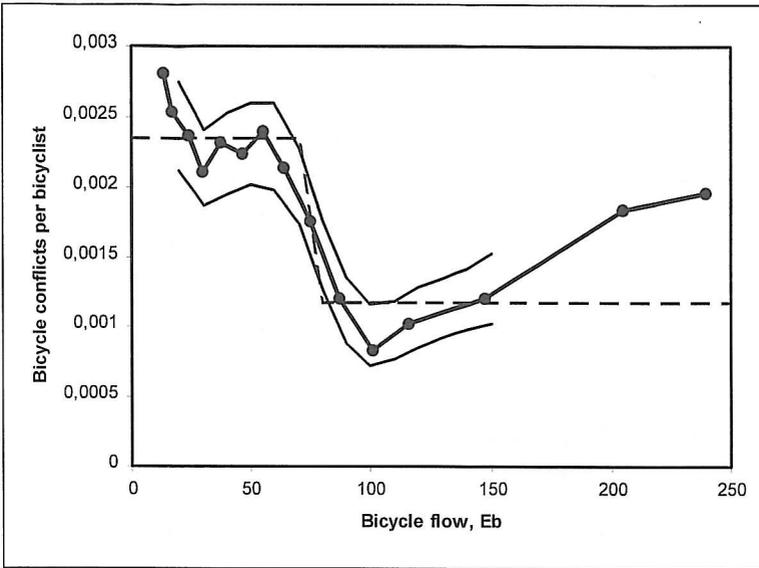


Figure 8.10 *Bicycle conflicts per bicyclist versus bicycle flow on a synthetic data set with two levels of expected value. Moving average line (RPF) with an estimated 80% confidence interval. The horizontal line illustrates the expected value.*

The moving-3-point-averages line with its confidence interval, does not seem to conceal the jump in expected conflict rate. It also seems clear that even a 80% interval covers the correct value in more than 80% of the sections of the confidence interval. Six other simulations further supporting this conclusion can be found in appendix B. In bootstrap literature (Hjorth, 1994) methods for correcting the level of confidence corresponding to empirical outcome are discussed. At the moment I am satisfied with using "80% confidence intervals", knowing that they seem to be on the "safe side". My explanation to the results, showing a more conservative interval than expected, is that the intervals seem to be skew in a conservative manner. If the 3-point-line is at an extreme, the confidence interval is skew in the other direction. In the further analyses I will use the "80% confidence intervals".

9 Results on Bicycle Safety

9.1 Bicycle safety as a function of car flow and bicycle flow

As has been argued, the safety versus flow or exposure relationship is vital to all traffic safety analyses. The result from this empirical study was produced with the proposed method described in chapter 7 and 8. The safety performance function of bicycle flow for bicyclists is presented in Figure 9.1:

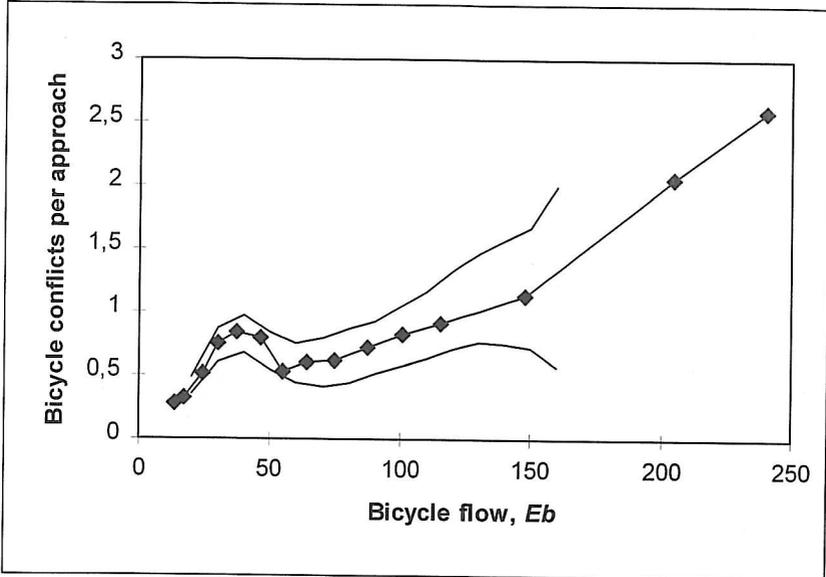


Figure 9.1 *Bicycle conflicts per approach versus bicycle flow. Moving average line (SPF) with a estimated 80% confidence interval*

Here we can see an increasing function with some irregularity in the region of flow below 50 bicyclists per hour. This irregularity indicates that the individual risk for a bicyclist seems to vary with the presence of other bicyclists. This will be even clearer if we look at the risk performance function (Figure 9.2):

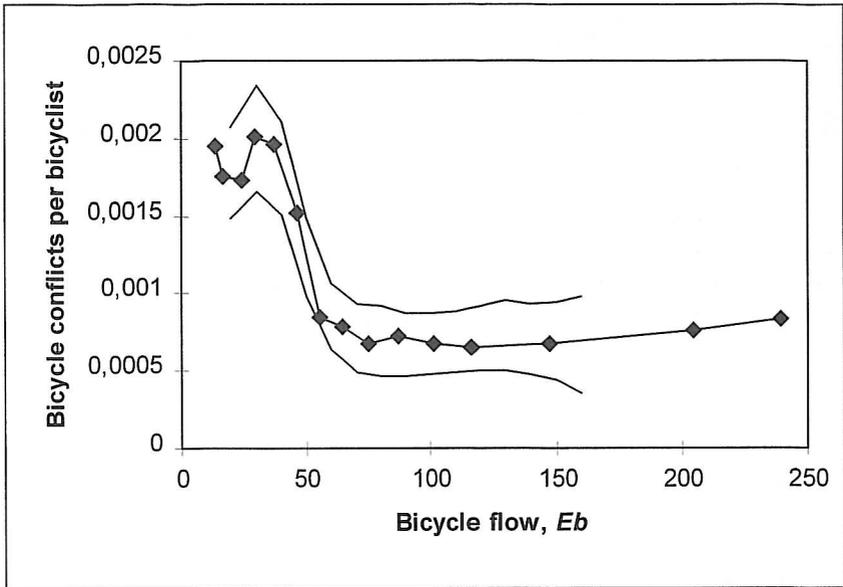


Figure 9.2 Bicycle conflicts per bicyclist versus bicycle flow. Moving average line (RPF) with an estimated 80% confidence interval.

In Figure 9.2 we see that the individual risk for a bicyclist is significantly higher if the level of bicycle flow is below 50 bicyclists per hour. The difference in rate, between locations with low bicycle flow and locations with high bicycle flow is, more than a factor 2. The first thought that comes to a traffic planner's mind is that this could have to do with the level of car flow since all included conflicts are between cars and bicyclists. If we look at the safety performance function with bicycle conflicts as a function of the exposure of cars we get a different picture (Figure 9.3)

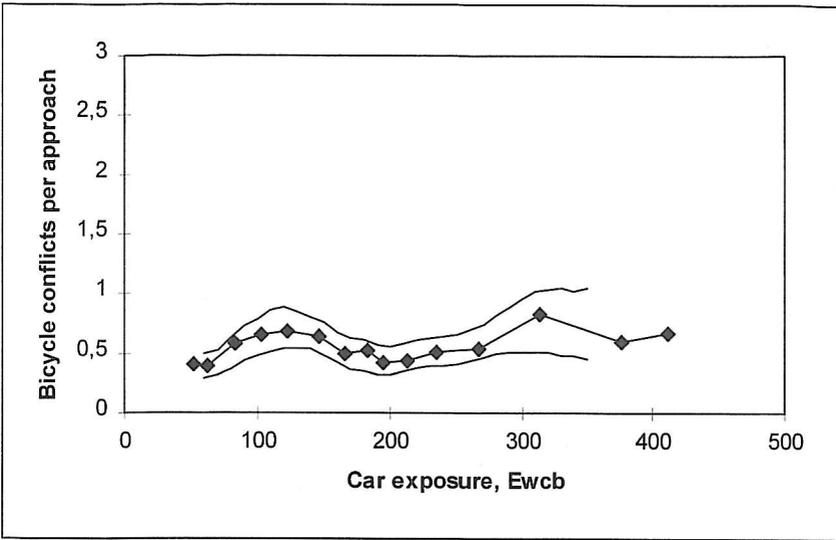


Figure 9.3 *Bicycle conflicts per approach versus accumulated and weighted car flow (Ewcb) "entering cars per hour". Moving average line (SPF) with an estimated 80% confidence interval.*

Here we can see that the number of conflicts and, thus, the expected number of accidents, does not seem to increase continuously with increasing car exposure. This may seem strange but may be explained as "there are cars enough already at 100 cars per hour" (Ewcb)⁷. What also may seem surprising is that the number of conflicts seems to decrease again, and reach a minimum when the car flow is around 200 cars per hour.

If we want to take the perspective of the individual bicyclist we can construct a risk performance function versus the car flow. The following result will then be at hand (Figure 9.4):

⁷ For the definition of Ewcb see section 7.2.5 on page 38

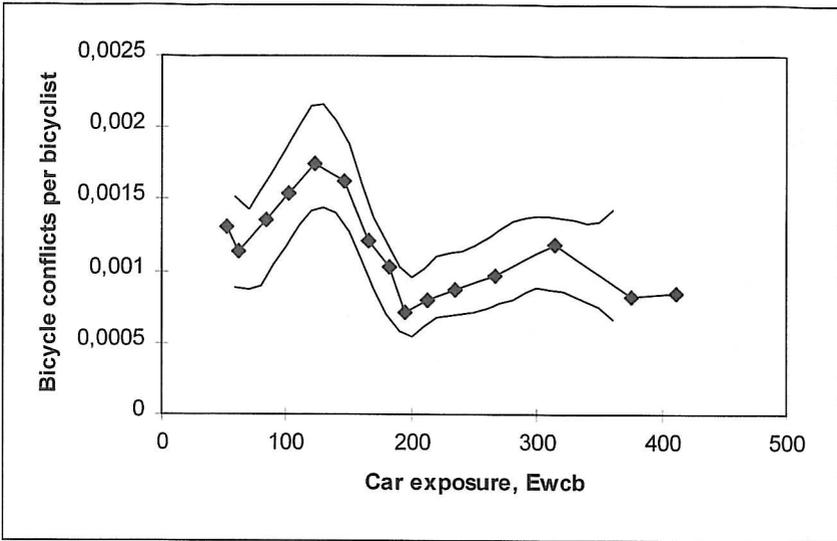


Figure 9.4 *Bicycle conflicts per bicyclist versus accumulated and weighted car flow (Ewcb). Moving average line (RPF) with an estimated 80% confidence interval.*

Looking at the individual risk for bicyclists there does **not** seem to be generally increased risk for a bicyclist at intersection approaches with increasing car flow. Instead a smaller range of lower car exposure seems to result in an increased risk for the bicyclists. Even if the data indicates a significant effect in my data set, the generalization of this result should be made with some caution. It may well be a combination of other effects, such as differences in expectation from bicyclists on the appearance of cars, differences in intersection design, different mix of road user groups, etc. One other possible explanation may be a "spurious effect arising from correlation between bicycle and car flow", since Figure 9.2 shows that bicycle flow has a large impact on individual risk. To investigate this let us look at the covariation between car flow and bicycle flow. The bicycle flow and car exposure for each approach are plotted in Figure 9.5.

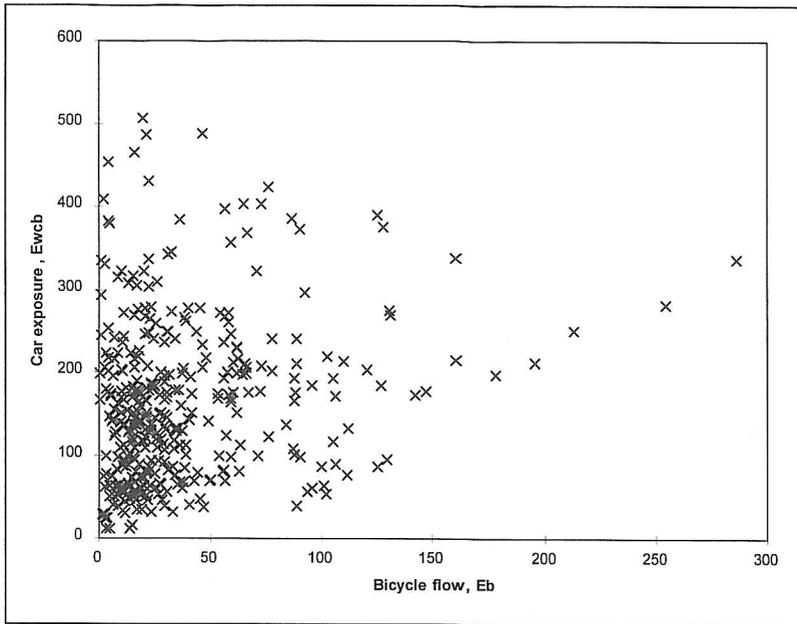


Figure 9.5 Car exposure versus bicycle flow for each approach

There seems to be no clear correlation between the bicycle flow and the car exposure in the observations. The highest bicycle flows seem to only appear at locations with medium level of car exposure. In the lower region of car exposure, where the irregularities in the risk performance functions are found, the observations seem to be scattered all around. There does not seem to be any concentration around the smallest values of bicycle flow, which were shown above to give extremely high individual risk.

Nevertheless it could be interesting to look at an attempt of making a three dimensional picture in order to check if the local increase of individual risk around 125 incoming cars per hour in car exposure could be found at locations with both high and low level of bicycle flow. In order to make the most out of the limited data I split the data in two groups.

The division was made between approaches with $Eb \geq 50$ and $Eb < 50$ in order to split the data set in two where the different levels of risk found in Figure 9.2 were separated.

The results are shown in Figure 9.6 and Figure 9.7.

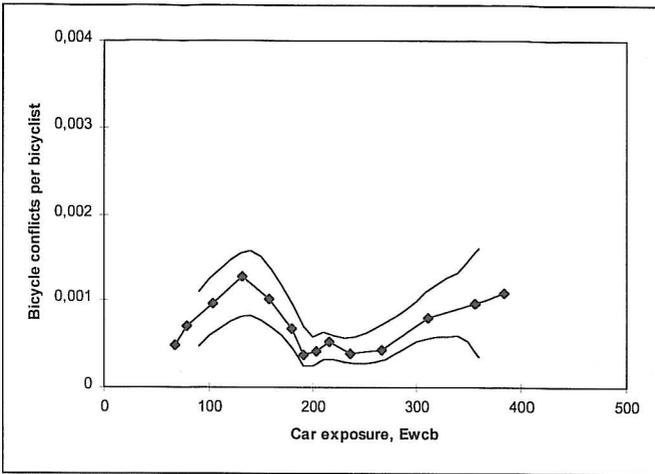


Figure 9.6 *Bicycle conflicts per bicyclist versus accumulated and weighted car flow (Ewcb). Moving average line (RPF) with an estimated 80% confidence interval. For approaches with high level of bicycle flow (≥ 50 bicyclists per hour)*

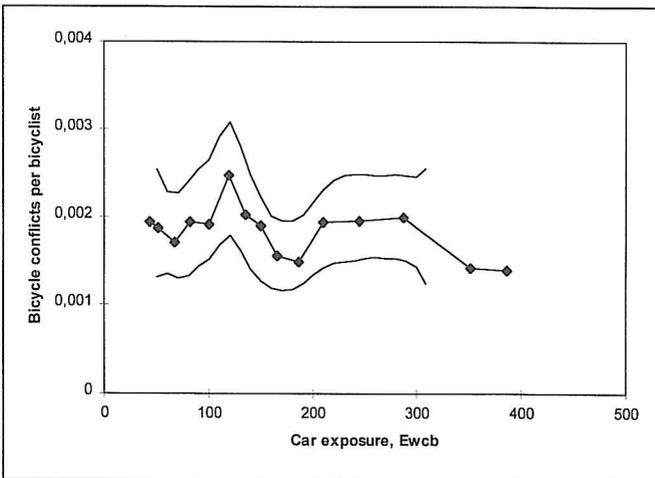


Figure 9.7 *Bicycle conflicts per bicyclist versus accumulated and weighted car flow (Ewcb). Moving average line (RPF) with an estimated 80% confidence interval. For approaches with low level of bicycle flow (< 50 bicyclists per hour)*

The result of splitting the observations in two groups gives us some important findings:

- The level of bicycle flow is much more important for bicycle risk than the level of car exposure
- The increase in bicycle risk at car exposure level around 125 approaching cars per hour, could be found in both figures

In this data set the importance of the presence of other bicyclists seems to be of greater importance than the exposure to cars. This might be somewhat surprising since the bicyclists in fact are in conflict with, and thus would be involved in, accidents with cars. As has been argued earlier, the behaviour and awareness of the road users are supposed to be of great importance for whether an encounter of two road users, in this case a bicyclist and a car driver, will lead to a serious conflict and as a consequence an accident. If the bicycle flow is low, below 50 bicyclists per hour, this means that there is less than one bicyclist per minute. A single bicyclist is normally appearing in an intersection for just a few seconds. Together this means that a car may pass such an approach many times without noticing any bicyclists.

In other studies regarding very rare events such as car drivers awareness towards wild animals Åberg (1981) and bus accidents with trains (Draskóczy, 1988) the general conclusion is that drivers have almost no awareness of really infrequent events. The bus drivers approaching an uncontrolled railway crossing took less notice if there were few trains passing compared with awareness in locations where the train came more frequently.

The explanation to the found differences in the level of risk, that most traffic engineers would give, is differences in intersection design or network planning. The most natural design element to explain the found differences would probably have been the presence, or absence, of specific bicycle facilities. But, the intersections selected in this data set do only include few intersections with such facilities. I have therefore tried to find some general measurement of different level of size for the intersection.

A split of my data in two groups: wide and narrow streets respectively, gave the results described in Figure 9.8 and Figure 9.9. The definition of a wide street was selected to "streets with a total width of more than 9 metres at the approach from which the bicyclist is approaching". The motive for the 9 metres is that this is the most narrow section that can allow car traffic in more than one lane per direction.

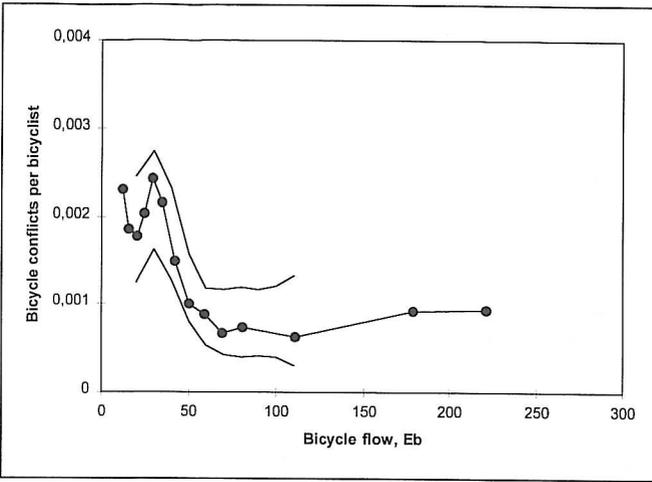


Figure 9.8 Bicyclists approaching on a *Wide street* (>9m)

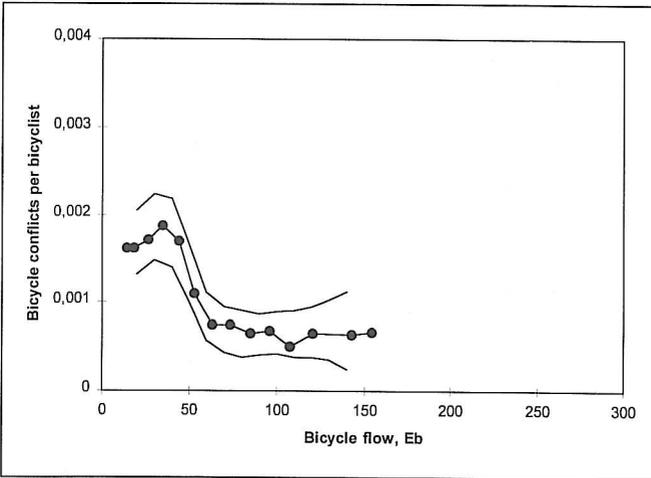


Figure 9.9 Bicyclists approaching on a *Narrow street* (<9 m)

The difference between approaching on a wide or narrow street does not seem to play any major role for the bicyclists' level of risk. This could be due to the bicyclists being able to compensate for the higher speeds on the wide streets, or the width of the street where the crossing cars drive being more important than the width of the street from which the bicyclist approaches. Neither of these causes could, however, be examined from this data set.

If we take a more general planning view it may be interesting to look at it from a network perspective. Splitting my data in two groups related to network planning, namely whether the bicycle is driving on the main street or the minor street, gave the results described in Figure 9.10 and Figure 9.11, respectively. In a normal intersection two of the approaches could be defined as belonging to a main street and the two other to a minor. The definition of major or minor was based on the car flow at the four approaches in question. Intersection without formal main street is, thus, also divided and then we have an "informal" main street and an "informal" minor street.

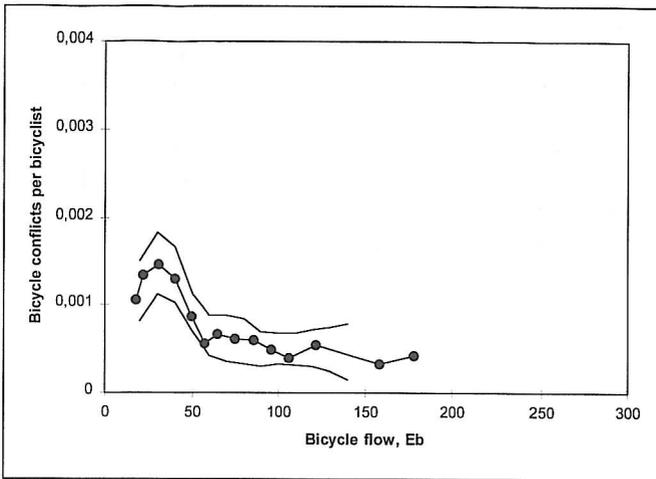


Figure 9.10 Bicyclists approaching the intersections from the **Main street**

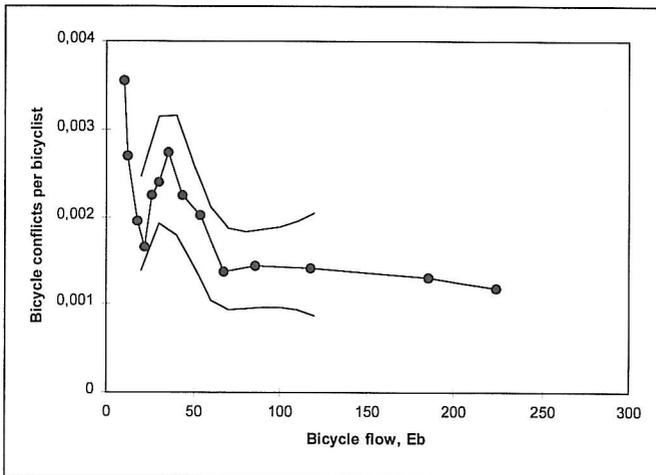


Figure 9.11 Bicyclists approaching the intersections from the **Minor street**

Here we can see a significantly lower level of risk for the bicyclists driving on the main road. Whether this is due to differences in facilities is of course an interesting issue but never the less it is interesting to note that a bicyclist crossing a street from the minor street seems to be at a higher risk than one going on the main street, whatever the underlying reason may be for this difference. When giving recommendations, or on a personal level, to know which route I shall choose, it is interesting to know that I shall follow the main stream no matter what is the reason.

9.2 The implications for traffic planning

The results used as an example of the proposed method hold some interesting facts with implications for design and traffic planning. Not surprisingly, I first want to stress that we need to treat the flow information more carefully in traffic safety analyses. Some concrete recommendations for traffic planning could also be drawn from the empirical results:

- put bicyclists together rather than spreading them out
- avoid recommending bicycle routes on minor streets

The results could also be interpreted in a very positive way, namely that a major increase in the use of the bicycle as a mode of transport may not lead to a major increase in bicycle accidents. If we increase bicycle traffic marginally the expected increase in bicycle accidents is rather high. If we, however make a significant increase in bicycle flow, the increase might be big enough to create bicycle traffic that changes car drivers' expectations. The irregularity in the bicycle safety performance function will then have effect.

10 Results on Pedestrian Safety

10.1 Pedestrian safety as a function of pedestrian flow

In chapter 9 we could see that in the case of bicyclists the influence of the number of bicyclists was of major importance when it came to the number of conflicts. If we construct a Safety Performance Function (SPF) of pedestrian flow, for pedestrians, we get a similar picture. The SPF is presented in Figure 10.1.

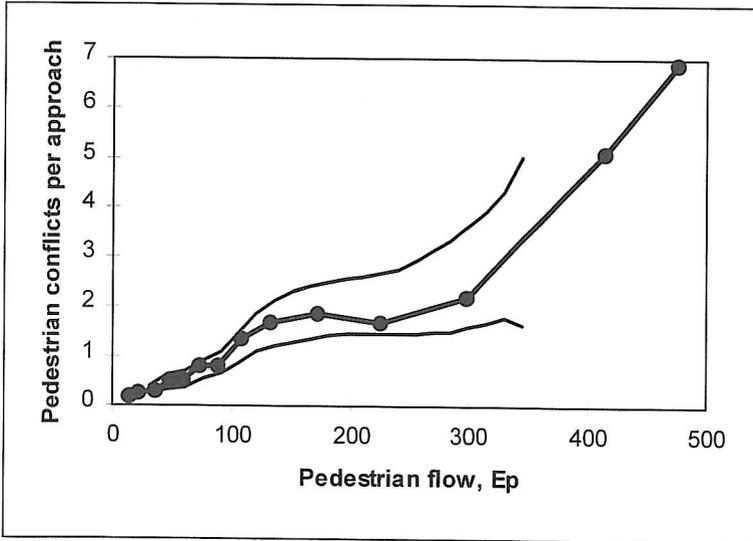


Figure 10.1 Pedestrian conflicts per approach versus Pedestrian flow. Moving average line (SPF) with an estimated 80 % confidence interval

As expected, the number of conflicts increases with increasing number of pedestrians. The increase seems to be more stable than was the case for bicyclists. If we construct a Risk Performance Function (RPF) of pedestrian flow we get a function with no significant trend. The RPF of pedestrian flow is presented in Figure 10.2.

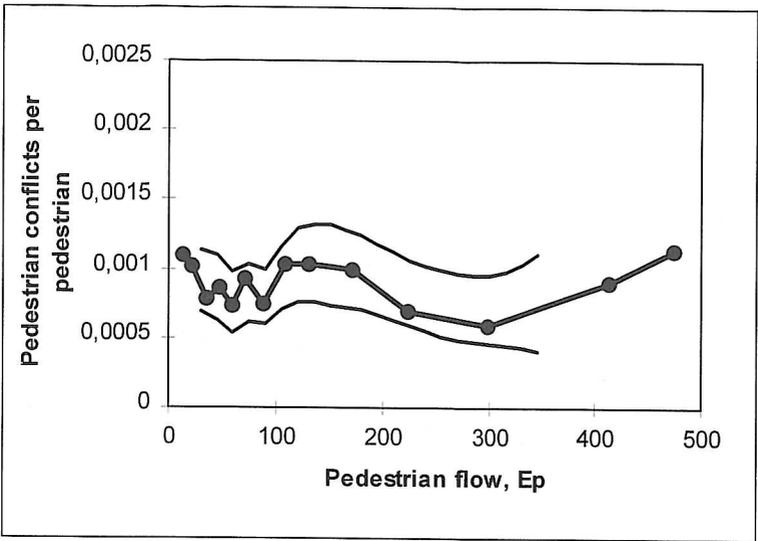


Figure 10.2 Pedestrian conflicts per pedestrian versus Pedestrian flow. Moving average line (RPF) with an estimated 80 % confidence interval

In Figure 10.2 we can not see any significant trend or pattern. This could be interpreted as follows: the individual pedestrian does not seem to benefit from presence of other road users. Another interpretation is that the vehicle drivers do expect pedestrians, at least if the pedestrian flow exceeds 30 pedestrians per hour.

10.2 Pedestrian safety as a function of flow

If the responsibility to solve interactions in a safe way, is more dependent on the pedestrian then on the car driver we might expect that the number of vehicles plays an important role in predicting the expected number of conflicts. The relationship is illustrated in Figure 10.3.

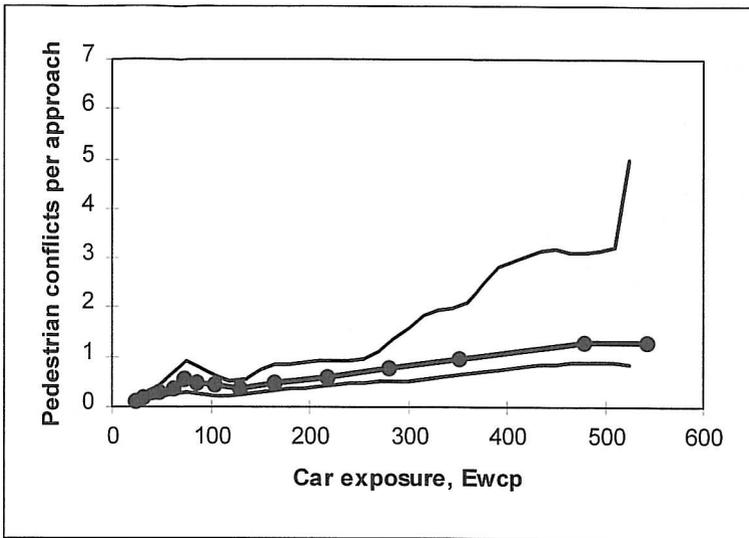


Figure 10.3 Pedestrian conflicts per approach versus car exposure (incoming cars per hour). Moving average line (SPF) with an estimated 80% confidence interval

Here we can notice an increasing function. The number of conflicts per approach seems to increase when car exposure increases. We can also notice a large irregularity in the confidence interval in the higher region of the car exposure.

This might be due to some extreme values. In order to investigate this we may study the co-variation of pedestrian flow and car exposure. The pedestrian flow and car exposure are plotted in Figure 10.4.

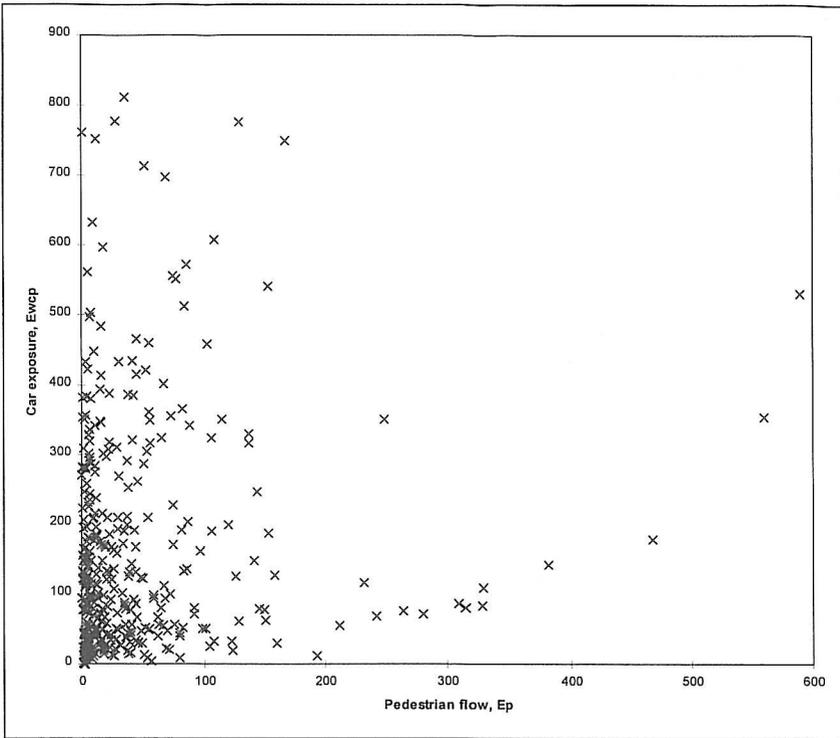


Figure 10.4 Car exposure versus pedestrian flow for each approach

The increased confidence interval in Figure 10.3 is actually derived from some few approaches with very high pedestrian flow with about ten conflicts each. The increased confidence interval is then the effect of the fact that these approaches are selected several times in some replicates. The variation due to whether such approaches are selected is in practice equivalent to the result we get if we include such approaches or not in the investigation.

If we once again take the perspective of an individual pedestrian we can construct a RPF of car flow. The result of this is presented in Figure 10.5.

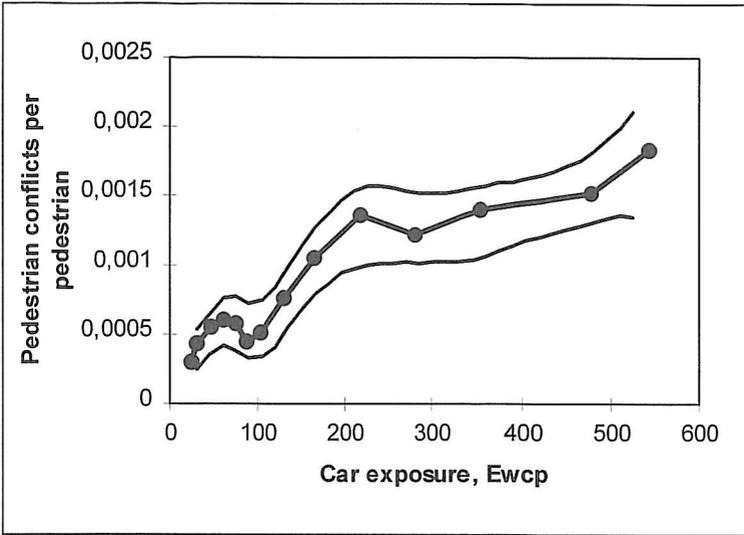


Figure 10.5 Pedestrian conflicts per pedestrian versus car exposure (incoming cars per hour). Moving average line (RPF) with an estimated 80% confidence interval

Here we can make some interesting findings. First of all, the accident rate for pedestrians seems to increase with increasing car flow. However the increase looks like a "step-function" and start at the level of exposure equal to 125 cars per hour.

Secondly, we can notice that the width of the confidence interval does not seem to be extra wide in the high region of car exposure. This is due to the fact that those approaches which were extreme in Figure 10.3 are not extreme in Figure 10.5, since the approaches with a very high number of conflicts also have very high pedestrian flow.

10.3 Pedestrian safety versus different countermeasures

As mentioned earlier, the explanation most traffic engineers would give to found differences in the level of risk, is differences in intersection design or network planning. This data set suites actually analyses of design differences for pedestrians better than it does for bicyclists, since the pedestrian crossing manoeuvre is a true "intersection approach activity".

10.3.1 With and without zebra crossing

It is in line with my previous research to look at the differences between locations with and without zebra crossings. This is a completely new data set compared to the one presented in chapter 6. In some ways it is similar and in some others it is different. The difference is that in this new data set we have conflict observations and traffic counts carried out at the same time. This data set is, however, not specifically designed to compare locations with and without zebra markings. The similarities are, apart from the conclusions, that the data represent the same cities and also represent major streets even if the concentration to major streets was more at hand in the previous study presented in chapter 6.

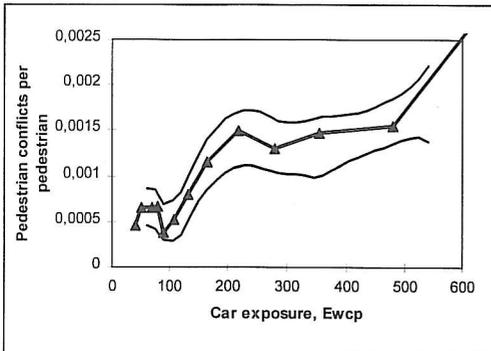


Figure 10.6 Pedestrian conflicts per pedestrian versus car exposure. Approaches **with Zebra crossing.** Moving average line (RPF) with an estimated 80% confidence interval

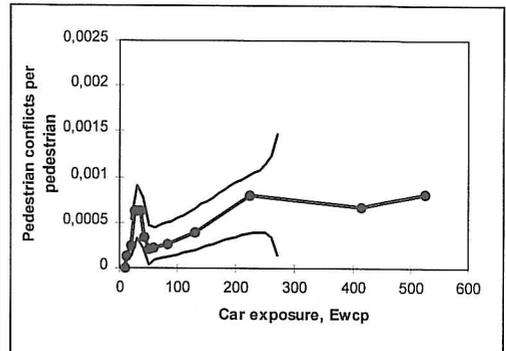


Figure 10.7 Pedestrian conflicts per pedestrian versus car exposure. Approaches **without Zebra crossing.** Moving average line (RPF) with an estimated 80% confidence interval

Two main conclusions could be drawn from the figures above.

- Zebra crossings seem to have higher accident rate than approaches without zebra marking.
- The increased accident rate for approaches with zebra crossings is only valid on locations where the car flow is large (>100 cars per hour).

This data set does not include enough locations without zebra crossings for locations with car exposure higher than 250 cars per hour, to construct a valid confidence interval.

The locations, with and without zebra crossings, do not only vary according to the car exposure. The pedestrian flow is naturally much higher at locations with a zebra crossing. If we look at the RPF of pedestrian flow we get the results presented in Figure 10.8 and Figure 10.9.

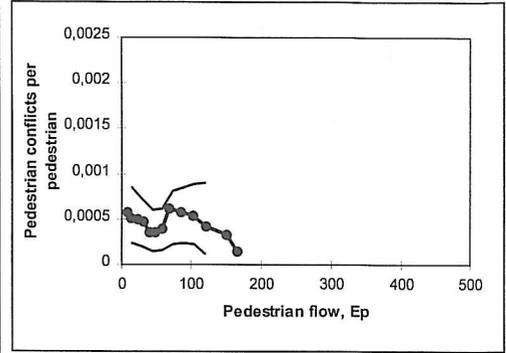
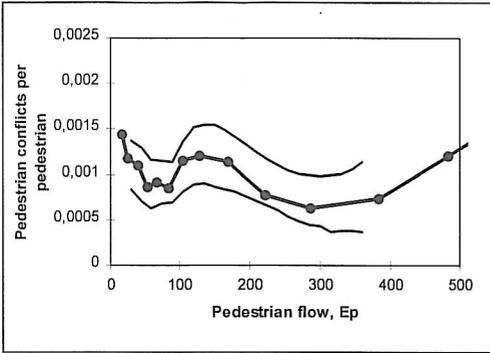


Figure 10.8 *Pedestrian conflicts per pedestrian versus pedestrian flow. Approaches **with Zebra crossing**. Moving average line (RPF) with an estimated 80% confidence interval*

Figure 10.9 *Pedestrian conflicts per pedestrian versus pedestrian flow. Approaches **without Zebra crossing**. Moving average line (RPF) with an estimated 80% confidence interval*

Here we can notice that the approaches with zebra crossings generate higher conflict rates. Approaches without zebra crossings have generally much lower pedestrian flow in this data set. This is quite natural, since a high number of pedestrians is a major argument for installing zebra crossings. The shape of the RPF below 100 pedestrians per hour seems identical for approaches with and without zebras even if the irregularities is insignificant for both curves. The difference in the level of conflict rate is, however, significant between approaches with and without zebra marking.

10.3.2 With and without refuge

A common countermeasure for improving the situation for pedestrians is a refuge. The idea is to both decrease the speed of approaching vehicles and to make the crossing process easier for the pedestrian by enabling crossing in "two steps". I have made a division of the data set in two groups: 161 approaches

have refuge and 206 have no refuge in my data set. The RPF, of car exposure for the two groups are presented in Figure 10.10 and Figure 10.11, respectively.

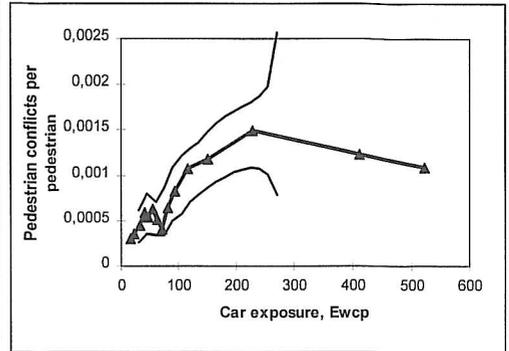
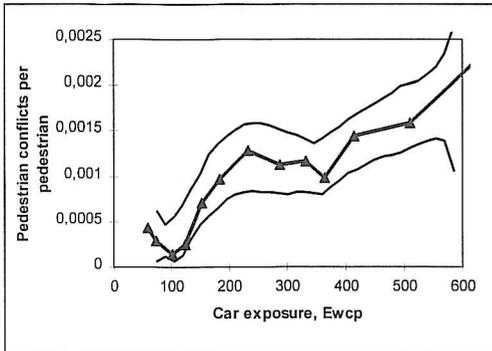


Figure 10.10 *Pedestrian conflicts per pedestrian versus car exposure. Approaches with refuge crossing. Moving average line (RPF) with an estimated 80% confidence interval*

Figure 10.11 *Pedestrian conflicts per pedestrian versus car exposure. Approaches without refuge crossing. Moving average line (RPF) with an estimated 80% confidence interval*

Despite the fact that most approaches are without refuge we get information over a larger exposure region at locations with refuge. In the low region of car exposure we get, just about, significantly lower conflict rate than at location with refuge. We have to keep in mind on the other hand, that locations with refuge normally have zebra marking as well. The positive safety effect of refuge seems to be stronger than the negative effect of zebra crossing, at least in the lower region of car exposure.

If I then distinguish between with-and-without refuge but only for those locations with zebra marking, we get the results illustrated in Figure 10.12 and Figure 10.13.

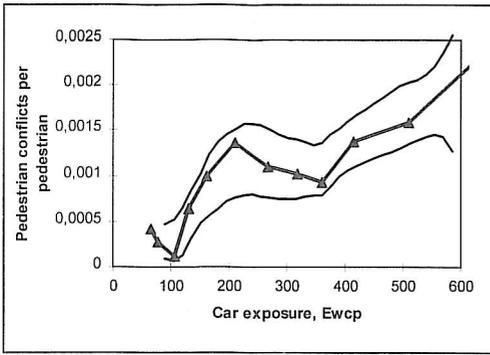


Figure 10.12 *Pedestrian conflicts per pedestrian versus car exposure. Approaches with refuge crossing and zebra. Moving average line (RPF) with an estimated 80% confidence interval*

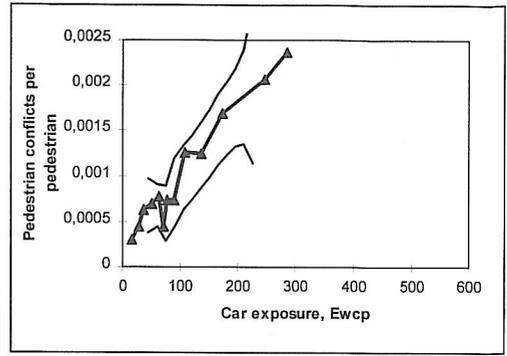


Figure 10.13 *Pedestrian conflicts per pedestrian versus car exposure. Approaches without refuge crossing, but with zebra. Moving average line (RPF) with an estimated 80% confidence interval*

In Figure 10.12 and Figure 10.13, we can see that the positive effect of refuge is slightly increased. One interesting methodological reflection could be done by comparing Figure 10.10 and Figure 10.12. The only difference between these two figures is that some few locations with refuge but without zebra is lacking in Figure 10.12. Then due to the aggregation procedure the RPF happened to change a little at some sections of the function. The confidence interval is, however, remaining the same. This is another indication that the confidence interval is rather conservative.

10.3.3 Narrow and wide streets

Looking at wide or narrow streets is another way to study general design effects on pedestrian safety. Splitting the data into one group with wide streets, wider than 9 metres, and one with narrow streets smaller than 9 metres, that not allow driving in more than one lane per direction, gave the results showed in Figure 10.14 and Figure 10.15. This divided the data in such a way that equal amounts of approaches were found in each group.

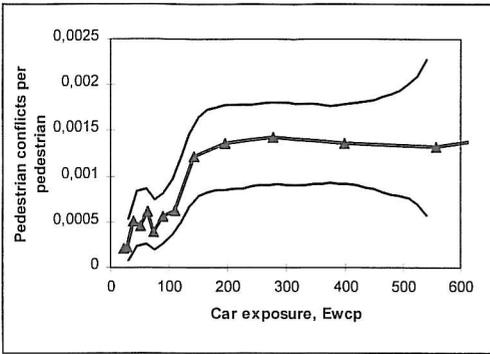


Figure 10.14 Pedestrian conflicts per pedestrian versus car exposure. Approaches at wide streets. Moving average line (RPF) with an estimated 80% confidence interval

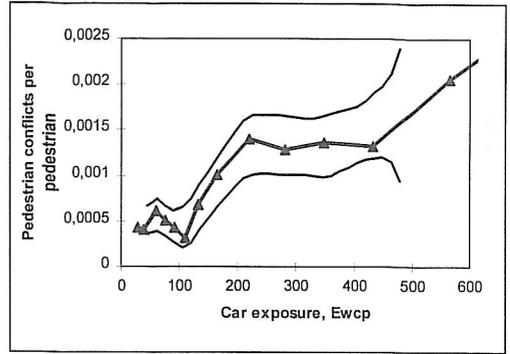


Figure 10.15 Pedestrian conflicts per pedestrian versus car exposure. Approaches at narrow streets. Moving average line (RPF) with an estimated 80% confidence interval

Figure 10.14 and Figure 10.15 do not indicate any significant differences in this data set regarding the width of the street. The confidence interval is, however, larger for the wider streets. This is probably due to a larger variation in other background variables such as vehicle speeds, etc.

10.3.4 Main streets and minor streets

If I divide the material in two other groups, one with main streets and one with minor streets, I get the results showed in Figure 10.16 and Figure 10.17. The definition of main or minor was based on the car flow at the four approaches in question for each intersection

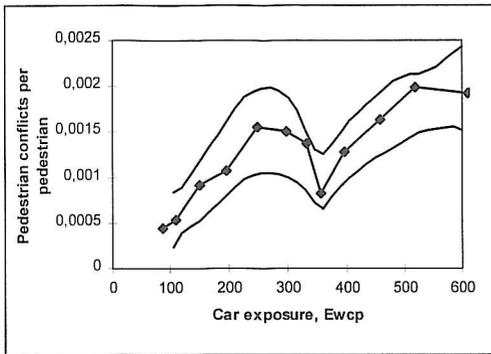


Figure 10.16 Pedestrian conflicts per pedestrian versus car exposure. **Main streets.** Moving average line (RPF) with an estimated 80% confidence interval

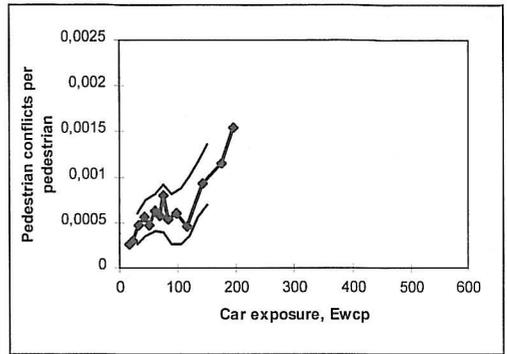


Figure 10.17 Pedestrian conflicts per pedestrian versus car exposure. **Minor streets.** Moving average line (RPF) with an estimated 80% confidence interval

Figure 10.16 and Figure 10.17 indicate the obvious differences namely that the car exposure is lower at the minor streets. The conflict rate, at a given level of car exposure, seems to be the same irrespective of whether the approach is considered main or minor. In Figure 10.16, we notice a good example of the confidence interval being "very conservative" as described earlier, when the RPF takes a deep "dip" around 360 cars per hour the interval is very skewed. This skewness is probably correct, since this "dip" most probably is not a significant effect but rather a coincidental effect.

As to pedestrians we may conclude that car exposure plays an important role in describing their safety or risk situation. The relation between conflicts and car exposure is, however, far from trivial and seems to have different effect depending on the situation of comparison.

11 Conclusions from the empirical study

The general conclusion I draw from the empirical study, presented in chapter 9 and 10, is that the influence flow has on conflicts is complex and holds interesting information. The proposed method, using the method of aggregating approaches (or intersections), constructing a moving-3-point-averages function seems to enhance traffic safety analyses. The confidence interval further improves the interpretation of the SPF and RPF.

The traffic safety effect of countermeasures, such as zebra crossings or refuges, may be further evaluated by using SPFs and RPFs. The interpretation of the countermeasure can thus be more generalized, since the effect at locations with different level of flow can be distinguished. Suggestions of transferring pedestrian flows, e.g. by recommendations, can be discussed based on SPFs or RPFs depending on the perspective of the analysis.

For bicyclists especially the transfer of bicyclists from minor streets to major streets seems to be beneficial. The effects of countermeasures are, however, smaller than the effects of even small changes in the amount of bicycle flow or car exposure. Thus we see that large traffic safety improvements may be achieved from changing traffic flow. These changes may be as large as those achieved from traditional risk-reducing countermeasures.

The proposed method shows that conclusions can only be drawn from those intervals of flow where data is available, i.e. in the used data set. Conclusions about pedestrian crossing without zebra could not be drawn regarding locations with high pedestrian flow. In order to investigate the effect of countermeasures at a wide range of flow it has also been clear that data need to be collected even at locations with low flow. Due to effectiveness reasons, data are often collected at locations with high flow. If we try to answer questions about the safety situation in the entire flow region by studying locations at one specific level of flow, this is like looking for a lost key in the lit up area rather than looking for it where you dropped it.

11.1 The effect of expectation

One importing finding regarding the bicyclist's individual conflict rate, was that low bicycle flow seems to generate high conflict rates. This is probably due to low expectation from car drivers on meeting a bicycle.

This effect could not be found in the pedestrian data. It could, however, well be the case that such an effect would have been found if more locations with low pedestrian flow had been in the data set. If the increased conflict rate in the low

bicycle flow region is due to lack of expectation to encounter bicyclists from the car drivers, this effect would, as the following shows, appear at even lower pedestrian flow. If a crossing bicyclist is "appearing during some few seconds" it takes much longer time for a pedestrian to cross an intersection. A simplified computation would give: If the width of the street including side walks is 15 metres, a crossing bicyclist with the speed of 10 km/h appears for about 5 seconds in the area. For a pedestrian with a walking speed of 5 km/h the appearance time would be 10 seconds.

For bicyclists the increased conflict rate was below 50 bicyclists per hour. If we believe that the expectation from car drivers to arise from the total time they have observed bicyclists, the increased conflict rate would be expected at pedestrian flow below 25 pedestrians per hour. From the data it was, however, not possible to construct valid confidence intervals below 30 pedestrians per hour. In addition to this decreased expectation locally, based on road user appearance time in the specific intersection, there might be a more general expectation for pedestrians at intersections in an urban area.

11.2 Accidents instead of conflicts

At an early stage I chose to use conflicts instead of accidents in these analyses. The motives for using conflicts instead of accidents are presented in chapter 7. Nevertheless it could be interesting to see what conclusion could be made if accidents were used instead of conflicts. The main question then is if RPFs based on accidents differ from the one based on conflicts.

RPF of pedestrian flow based on conflicts is presented in Figure 11.1 and RPF of pedestrian flow based on accidents is presented in Figure 11.2.

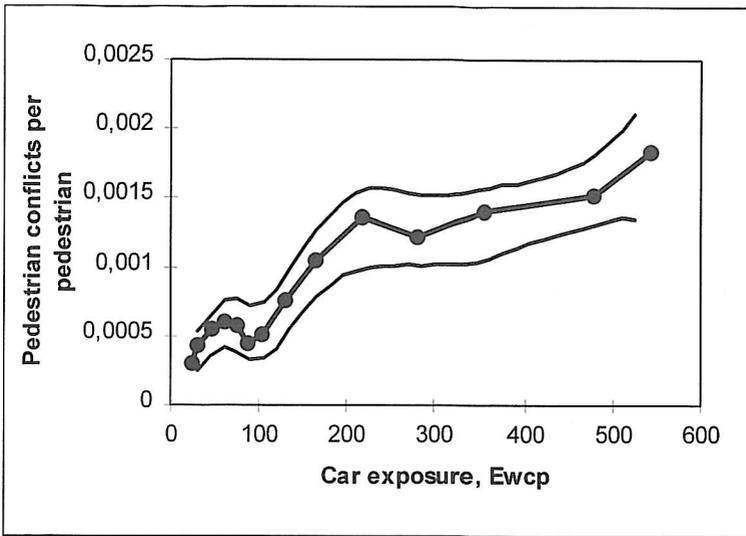


Figure 11.1 Pedestrian *conflicts* per pedestrian versus car exposure

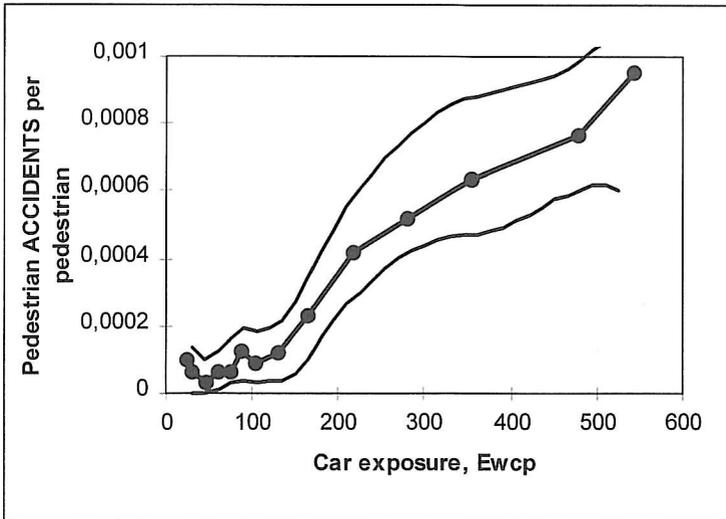


Figure 11.2 Pedestrian *accidents* per pedestrian versus car exposure

If we compare Figure 11.1 and Figure 11.2 the main difference is that the confidence interval is wider when the RPF is based on accidents. The increasing trend is approximately the same and the "steady level" below 150 cars per hour is found in both. The differences between the low and the high region might be slightly larger when the RPF is based on accidents. This difference is, however within the confidence interval and should thus not be paid too much attention.

In Figure 11.3 and Figure 11.4 the RPF for bicyclists based on conflicts and accidents respectively, are presented. In the computation of the RPF based on accidents the bicycle flow was "scaled" in order to produce comparable levels of flow. The reason for this was that all the counting of bicyclist was carried out during spring time when bicycle flow is at a peak. This causes no problem when comparing conflicts and bicycle flow since the conflict observation was carried out at the same time. When comparing accidents, gathered from the whole year, the flow had to be scaled. The scaling factor was taken from a study by Brundell (1982).

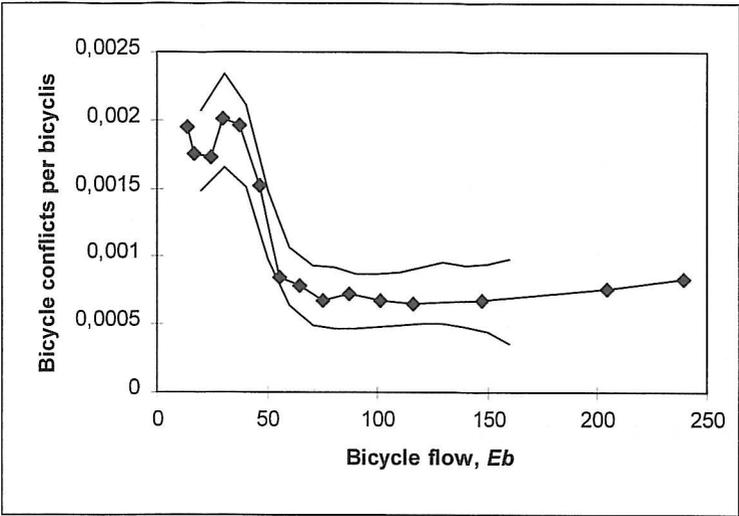


Figure 11.3 Bicycle *conflicts* per bicyclist

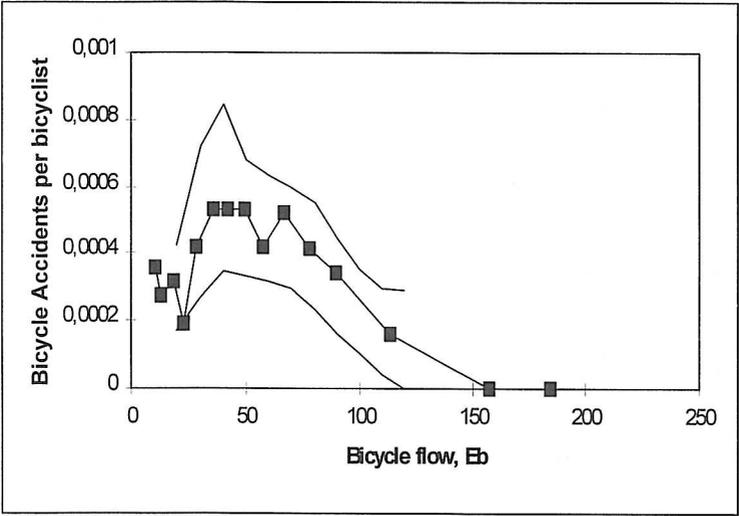


Figure 11.4 Bicycle *accidents* per bicyclist

Again the main difference between RPF based on conflicts and RPF based on accidents is that the confidence interval is wider when using accidents. The increased level of accident rate at low bicycle flow is found in the accident data as well. In the accident data there is a decrease in accident rate at the lowest

bicycle flow that could not be found in the conflict data. This decrease in the accident rate is, however, non significant since the confidence interval is so wide.

Thus the initial assumption (see section 7.3), that relations found between conflicts and flow would hold also for accidents and flow, is supported. If we want to estimate "police reported injury accidents" from the conflict results a conversion factor with an uncertainty has to be used. Thus the confidence interval will increase. Further if we want to compare with true underlying accident rate also the uncertainty in the police reported accidents needs to be taken into account. Such comparison is far beyond the scope of this thesis. However, the similarity between conflicts and accident graphs further supports the conflict technique.

11.3 Safety performance functions in future evaluations

Safety performance functions may be used as I used them in chapter 9 and 10, i.e. by comparing SPF and RPF for different systems and thus drawing conclusions about the general safety situation for road user groups or evaluating the general effect of countermeasures. The functions could also be used to compare traffic safety results for a single location with what is "normal" for such a location given the level of flow. A use of this kind would be a relevant substitute for the, irrelevant, standardization approach to accident rates.

In order to construct safety performance functions one needs quite a lot of data. In order to create new SPFs one could either use national accident statistics, supplemented with corresponding flow counts, or use conflict data. When using conflicts, one either has to use data collected for other purposes or use an improved data collection, in order to get enough data at a reasonable cost. Especially at locations with low flow the need for data is great. Regarding conflicts this could be achieved by either adding results from many locations or by carrying out the studies during longer periods. Especially for conflict studies over longer periods the image processing technique, which at the moment is being developed at the department, seems promising.

11.4 Concluding remarks

The empirical application has, thus, confirmed that:

- the method of aggregating and averaging gives a function with good visual interpretability
- the bootstrap method gives an accurate and useful description of the stability of the estimated non-parametric function

- the relationship between conflicts and flow is complex
- knowledge about such relations could improve traffic safety evaluations that include comparisons between groups of locations with different flow
- analyses of the non-parametric functions may be the base for suggesting active flow manipulation as a traffic safety measure
- information about the effect from flow on safety may be used to generate hypotheses about the processes underlying traffic safety problems

Thus, the question is not anymore whether flow contains valuable information for traffic safety analyses, but rather, if we are going to make use of that information in improving traffic safety.

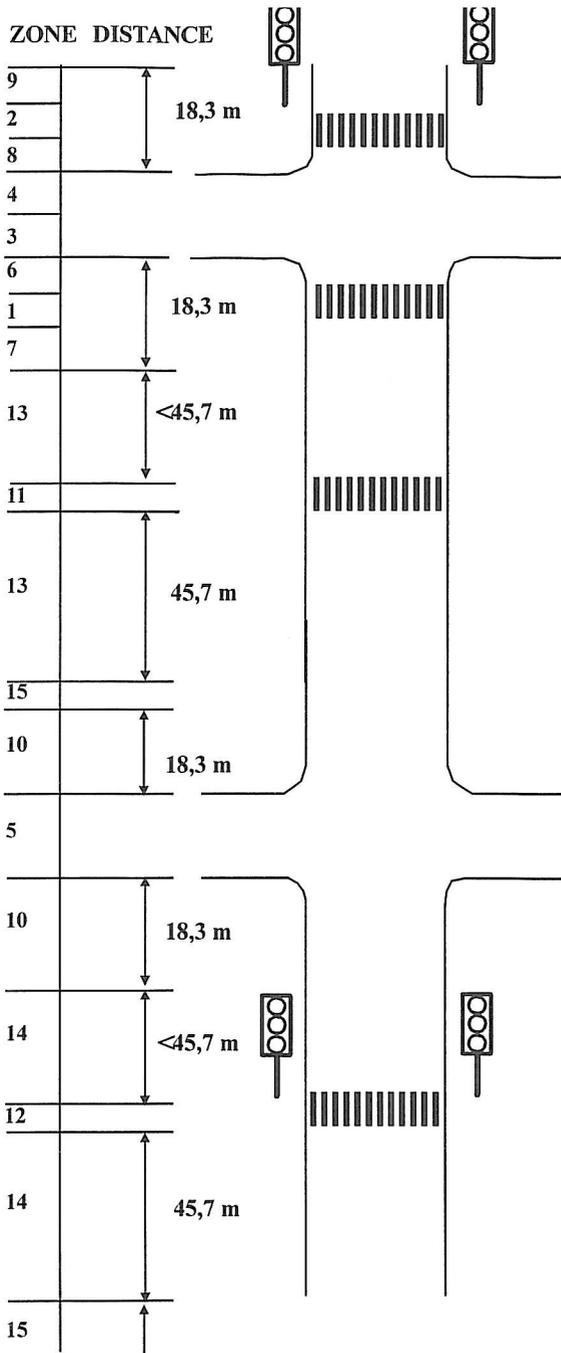
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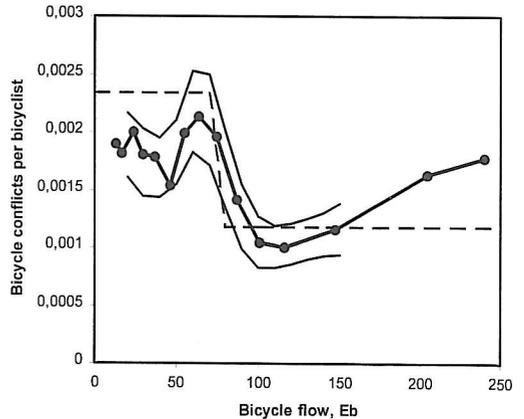
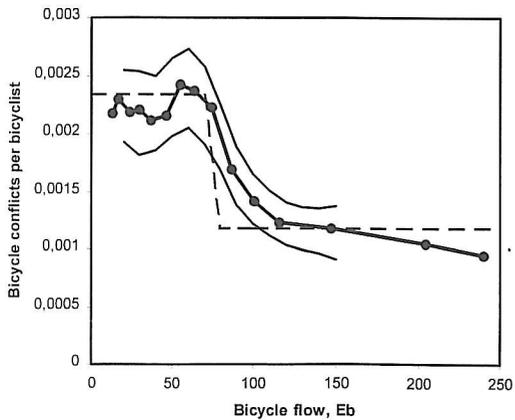
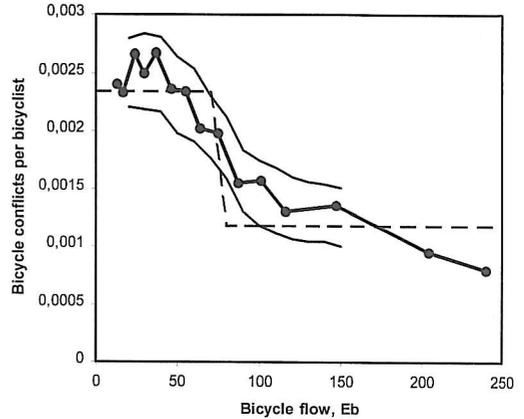
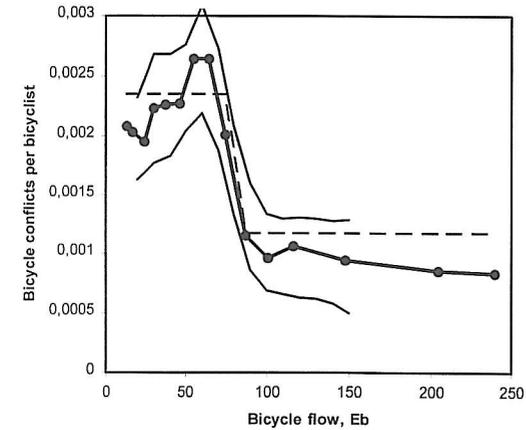
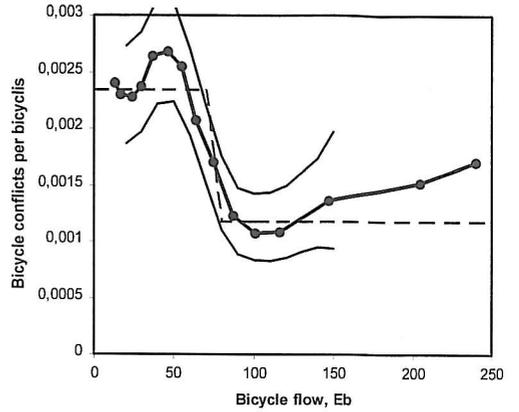
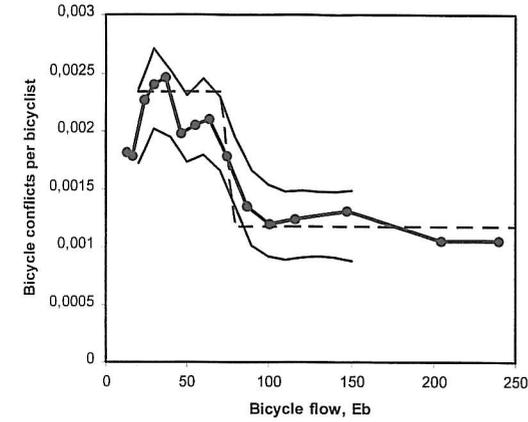
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The division of the streets into different zones in (Ekman, 1988)



Result of six different simulations with an estimated 80 % confidence interval. Data was generated with two different levels of true underlying conflict rate. The synthetic data set was generated under the Poisson assumption.

