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**Summary:**

# Alternative understandings of risk and exposure

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Authors: Torkel Bjørnskau, Rikke Ingebrigtsen

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*The report discusses alternative ways to understand risk and exposure in traffic safety research. Both the theoretical foundations underpinning risk calculations and different measures of exposure are presented. The report argues that although the number of events that could result in an accident is the best exposure measure theoretically, we must ensure that our choice of exposure event does not "control away" factors accounting for important differences in accident risk. On this basis we suggest that one should choose a measure of exposure that captures traffic participation, but which is not very strongly correlated with accidents. Similarly we argue that when comparing risk between groups we should be careful not to control for all confounding risk factors influencing these differences. The report compares estimates of risk with time and distance as a measure of exposure and concludes that the traditional measure of exposure - distance - is often preferable, especially if one wants to calculate the effects of transferring traffic between modes of transport.*

## Background and purpose

The Norwegian Public Roads Administration (NPRA) wanted to investigate alternatives to normal conceptions of risk and exposure in road safety research, as a way to improve and increase understanding of risk calculations for pedestrians and cyclists.

In Norway there is a political ambition to achieve future urban traffic growth through cycling, walking and use of public transport. It is of great interest to learn more about what this will mean in terms of injuries to cyclists and pedestrians. To be able to say something about the health consequences of a modal transfer from driving to cycling and walking requires both an assessment of the theory on risk and exposure and the relative findings on risk and exposure for each road user group.

The report discusses various aspects of the concept of risk and different measures of exposure that has been proposed and applied. It presents examples of calculations of risk using various measures of exposure, along with a numerical example of the impact that the transfer from car to bike will have in Oslo, in terms of both the number of injuries and general public health effects .

## Risk estimation and accident modeling in traffic

It is said that most accidents happen at home. This is probably true, but it does not necessarily follow that the home is the most dangerous place to be. This is because it is insufficient to simply investigate the number of accidents when assessing how dangerous an activity is. Instead, some form of probability must be estimated, e.g. the empirical probability of the event A is calculated as the number of actual (un)favorable outcomes of A divided by the total number of possible outcomes.

Thus the probability of having an accident at home is the number of actual accidents divided by the number of possible accidents. In road safety research, the probability of a traffic accident is similarly the number of actual traffic accidents divided by the number of possible accidents.

The number of accidents is (in principle) possible to count, but how can you define and measure the possible accidents? This problem has been addressed using a measure of *exposure* that says something about how exposed one is to situations or events that could lead to accidents. In road safety research "risk" is generally the probability of an accident, injury or death of a given activity or "exposure".

Instead of calculating risk estimates, one can model accidents as the result of a number of risk factors included as explanatory variables in addition to one or more measure of exposure in a model. Such modeling has become widely used, the advantage being that one can estimate and control for the effects of a number of factors alongside each other simultaneously. Instead of calculating risk figures for men and women in various age groups, accident modeling can include gender and age as explanatory variables and provide estimates on how they affect the likelihood of accidents.

There are however many methodological challenges involved in such modeling, in terms of choice of model and variables, and interpretation of the estimates. The advantage of using risk estimation, i.e. to calculate risk for different groups of road users, roads, vehicles, etc., is that such estimates are easy to understand and interpret, and in many cases can be interpreted intuitively and directly. For example, we might find that motorcycle riders statistically are ten times more at risk than drivers of passenger cars, in terms of fatalities per kilometer driven. The instinctive interpretation of this is that it is "ten times as dangerous" to drive a motorcycle compared to a car.

## **Selection of measure of exposure**

There is a big discussion in road safety research about what measures of exposure should be chosen in risk calculations. From early on, contributors pointed out that exposure measures should be consistent with probability theory, i.e. exposure should capture "trials" or "possible accidents". In practice, this has often been difficult to do, and indications of traffic, such as the number of vehicles, annual daily traffic, vehicle kilometers and passenger kilometers, are often the preferred exposure measures.

In recent years researchers have had high hopes of getting better exposure data by utilizing so-called "big data" based on automatic detection of travel activity. In particular, logging travels using people's smart phones has huge potential. Such logging can both occur automatically when using the phone's position indications (Google) and by using customized mobile applications that can also differentiate between type of activity (walking, cycling, motorized transport). One drawback is that such applications generally detect only the distance, time and position - not the characteristics of the road user. There may also be challenges in determining the type of transport used. So far, we are not aware of examples where "big data" have been used to calculate the exposure data in risk estimations.

## **What is currently used?**

Elvik (2015b) has summarized a number of studies where different measures of exposure have been used and identifies three main types of exposure:

- Activity based (kilometers, ADT)
- Event based (potential conflicts, give-way situations, road user encounters)
- Behavioural based (time spent in traffic)

These types of data are often not available, in which case one is forced to use rougher estimates of traffic scope, such as the number of inhabitants and the number of driving licenses. In international comparisons in particular, such rougher estimates of exposure are often the only data available.

## **What should be used?**

Based on the foundations of probability theory, it is quite clear that it is the number of "trials" that may have an accident as outcome that is the most appropriate exposure metric for calculating risk. In practice this refers to various forms of event-based exposure, for example the number of times a pedestrian enters a pedestrian crossing or the number of times a motorist encounters another on a road.

But even if such a measure of exposure is most correct theoretically, it does not necessarily follow that it is the most informative. For example, say we wanted to calculate risk on two roads, where the one (A) has a lot of traffic in both directions (many encounters) and the other (B) has a greater amount of traffic in one direction or traffic alternating between directions (few encounters). There will be many more "trials" or "opportunities for accidents" on stretch A. If we calculate the risk of accidents per million encounters, the two routes may come out with the same risk. However, if we calculate risk of accidents compared to ADT, stretch A is likely to have the higher risk.

Which calculation method should we then choose? It's not obvious. It could be argued that when we use the number of encounters, we "control" for a risk factor (traffic distribution) that contributes crucially to why stretch A has more accidents than stretch B. In one sense it may therefore seem more reasonable to conclude that the risk is higher on stretch A because the traffic composition provides more encounters that could lead to accidents. But when we use the number of encounters as a measure of exposure we can get the result that the stretch of road with the most encounters has the lower risk, even if more accidents occur there.

Some scholars have argued that the unit of time should be used, either as a supplement or in place of different distance measure such as vehicle kilometers or passenger-kilometers. It is obvious that if we are to compare very different activities, such as risks in traffic with risk in completely different areas, time is often the only possible exposure metric available. When comparing risks in traffic involving different modes of transport, distance will be the most relevant exposure measure for the individual. This is also the most relevant exposure metric for evaluating the implications of moving traffic between modes of transport. As a measure of exposure, distance more in line with underlying probability theory than time, since time may continue to run without any movements or events happening that may have accident outcomes.

## **Selection of accident data**

Most risk calculations in traffic are based on official accident figures. The official Norwegian statistics on road traffic accidents cover traffic accidents occurring on public or private roads, streets or spaces that are open to general traffic. They are based on police reports of road traffic accidents. All traffic accidents involving significant personal injury should be reported to the police. For an accident to be registered as a traffic accident, at least one vehicle must have been involved. A pedestrian injury from a fall on the sidewalk is therefore not a traffic accident. Single accidents on bicycles are however regarded as traffic accidents.

It is well documented that far from all traffic injuries are reported to the police. This "under-reporting" of traffic injuries varies widely between types of accidents and types of road users. Bicycle accidents (single accidents) are reported far less to the police than other traffic accidents are. This means that when using official injury figures for calculating risk in traffic, bicycle risks are usually underestimated.

The official accident data are therefore supplemented with hospital based injury figures where possible. Hospital based injury figures capture multiple injuries, not least bicycle injuries. Such data are, however, not readily available in Norway, unlike in Sweden, which has coordinated police-reported and hospital-reported traffic injuries. In some contexts insurance-reported claims and self-reported accidents and injuries (questionnaire) are also used to calculate risk.

Accidents happen relatively rarely and so-called near-accidents or conflicts, i.e. give-way situations where one or the other road user has to make a sudden brake or turn, have therefore been widely used as a "proxy" for accidents in risk calculations.

## **Continuum from exposure to outcome**

The relationship between exposure and accidents can be seen as a continuum of "events" and "outcomes" in which events at one level are related to outcomes on the next level. Thus near-accidents or conflicts, can be seen as possible outcomes of give-way situations and accidents can be seen as possible outcomes of conflicts; sometimes one can manage to stop in time, sometimes not.

Most of the candidate measures we can use in order to assess exposure can be understood as measuring the "outcome" of a previous "incident." A population can for example have two types of residents, those who participate in traffic and those who do not. Traffic can be seen as events that may have as outcome that you encounter other road users or not. Encounters can have as outcome that you collide or not. Collisions may lead to personal injury or not, and personal injuries may result in death or not.

Calculations of risk based on the extremes of this "outcome-event" scale will be fairly meaningless. Population figures are for example not necessarily a good indication of possible traffic accidents. On the other hand, one can question the usefulness of calculating risk with metrics located very close to each other on the scale, such as the number of accidents per conflict. The number of conflicts can be seen as a good indication of the risk of accidents, but risk expressed as accidents per conflict is rather uninformative. The reason for this is that when we use the number of conflicts as exposure, we "control away" factors that create important differences in risk between the two intersections.

We must therefore be pragmatic when selecting an informative measure of exposure in traffic. It must capture traffic participation, but at the same time it should not be too closely correlated with and thus a proxy for the accident. In other words for risk calculations to make sense and be fruitful, we should not control for all possible confounding factors through our choice of exposure measure.

## Traditional and alternative risk calculations

Based on official injury figures from Statistics Norway (SSB) and exposure data from the nationwide travel survey (RVU) in Norway in 2013/14, we have calculated traditional risk figures per million person kilometers and alternative risk figures with time as a measure of exposure. The results are shown in Figure S1.

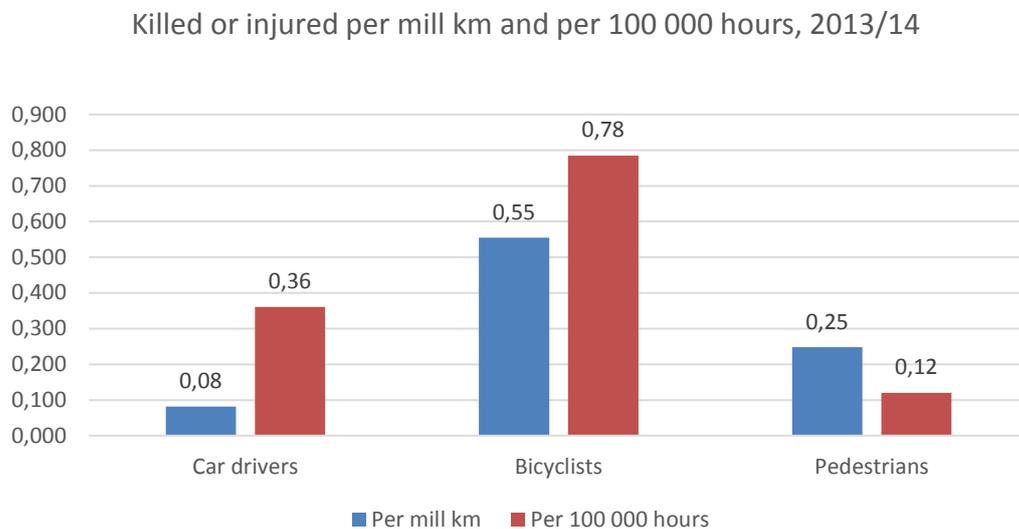


Figure S1. Number of killed or injured car drivers, bicyclists and pedestrians in traffic accidents in Norway per million person kilometers and per 100 000 hours of traffic. Injury figures from 2013 and 2014 (means). Exposure data is taken from The National Travel Survey 2013/2014.

When kilometers traveled is used as a measure of exposure, drivers have very much lower risk than cyclists and pedestrians. Cyclists have about seven times as high risk as drivers while the risk of pedestrians is ca. three times as high as that of drivers. When we use time in traffic we get a different picture. Cyclists still have higher risk than car drivers, ca. twice as high, while pedestrians have lower risk than motorists when time is used as a measure of exposure. The explanation is of course that motorists drive a much greater distances per hour (about 45 km) than the normal walking distance per hour (about 5 km). Such calculations based on official injury figures are however slightly misleading when comparing different groups of road users because under-reporting of accidents is very different. Single accidents on bicycles, which are the most common accident type for cyclists, are rarely included in official statistics.

Oslo University Hospital has registered systematically all injuries among cyclists who came for treatment in 2014. Based on these data and the official accident data from Oslo, traditional and alternative risk figures have been estimated using exposure data calculated on the basis of the nationwide travel survey in Norway 2013/2014. Risk is

calculated as the number of officially registered injured cyclists and the number of hospital treated injuries per million person kilometers and per 100 000 hours. The results are shown in Figure S2.

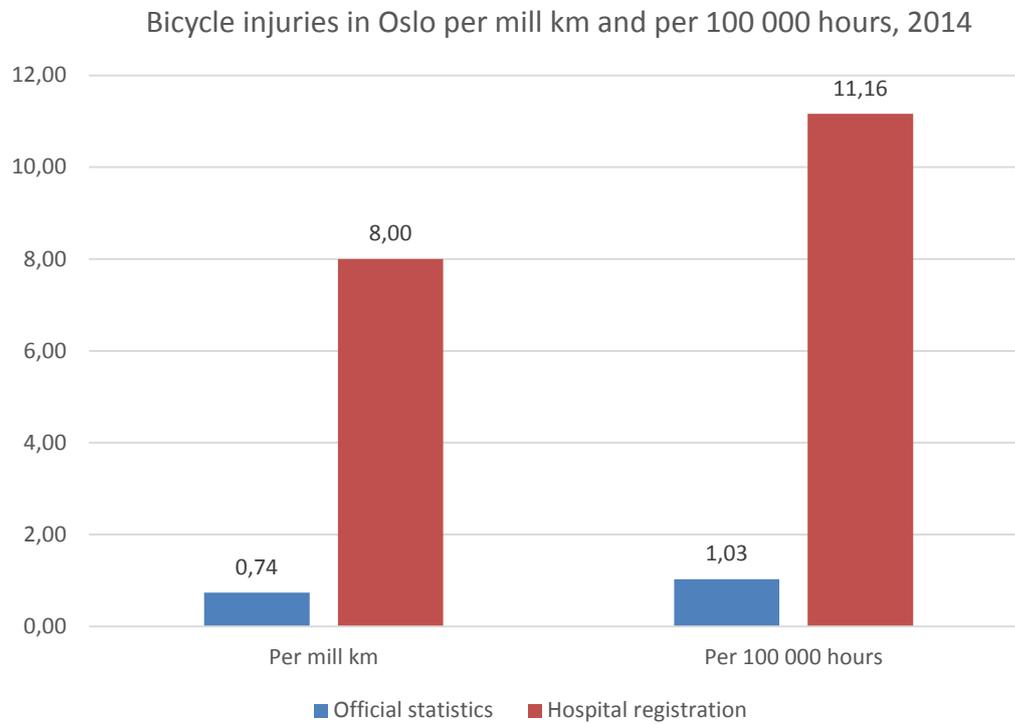


Figure S2. Number of injured cyclists in traffic accidents in Oslo per million person kilometers and per 100 000 hours of traffic. Injury figures from 2014 taken from Statistics Norway and Oslo University Hospital. Exposure data is taken from The National Travel Survey 2013/2014.

When we use hospital registry cyclist injuries the injury rates for cyclists is approximately ten times as high as when we use official injury figures from Statistics Norway. The risk per kilometer for motorists is estimated at 0.08 in Figure S1. A common estimate of underreporting of injuries to drivers is 50 %, so to compare hospitals based risk figures for cyclists with the corresponding figure for motorists, we can estimate the "real" risk for motorists to be  $0.08 \times 2$ , i.e. 0.16. This means that the risk of injury among cyclists in Oslo, is about 50 times as high as for motorists when the exposure measure is person kilometers ( $8 / 0.16$ ), and 16 times as high as when the exposure measure is per unit time in traffic ( $11.16 / 0.72$ ).

## Own risk, foreign risk and total risk

In the section above we have shown calculations for different road user groups at risk of being injured in traffic. These are calculations of the road user's "own risk" in traffic. But many transport modes inflict risk to other road users, which can be termed "foreign risk." To get a full picture of how dangerous different road user groups are, we should have information about both their own risk and their foreign risk. The sum of these risks may be described as "total risk" to a group of road user. It's not always obvious which accidents should be included in the foreign risk nor what is the most correct exposure metric in the calculation of foreign risks. In Figure

S3 own risk is calculated as the number of injuries per person (passenger) kilometer and foreign risk as the number of injured (others) per vehicle kilometer.

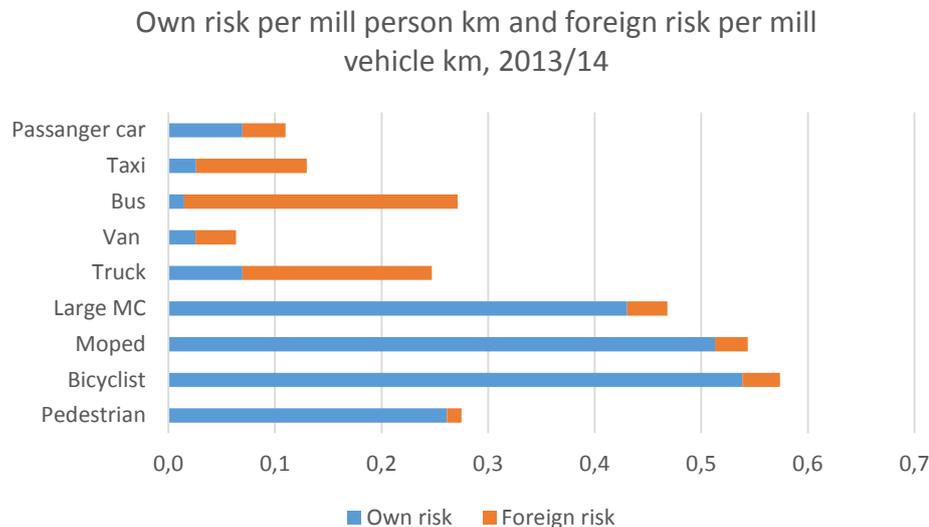


Figure S3. Own Risk and foreign risk, measured as the number of killed or injured per million person (passenger) kilometers (own risk) and per million vehicle kilometers (foreign risk). Injury figures from Statistics Norway in 2013 and 2014 exposure figures from The National Travel Survey 2013/2014 and from TOI statistics on transport performances in Norway. Average 2013/2014.

It is particularly heavy vehicles and vehicles that drive a lot in urban areas that have the greatest foreign risk. This is to be expected both because large vehicles have large mass and thus pose a danger to other road users, and because pedestrians and cyclists who are the most vulnerable road users, most frequently travel in urban areas.

## Consequences of transferring traffic from car to bicycle

It is a political aim that traffic growth in urban areas will be achieved through more cycling, walking and using public transport. With such large differences in risk between cycling (and walking) and car, this means that such a policy could lead to many more traffic injuries.

We carried out a calculation of the impact on traffic injuries and the general health if 1,000 motorists in Oslo switch to the bicycle. The calculations take into account the so-called "safety in numbers" effect, i.e. that accidents do not increase proportionally with an increase in traffic. We take into account under-reporting of injuries by using bicycle injury figures from Oslo University Hospital, and estimate the reporting rate for injuries among motorists as 50%. We have also taken into account that fewer cars reduce the risks that bicyclists face from motor traffic. Finally, we have attempted to account for the public health impact of increased exercise because of increased cycling.

The calculations of injury consequences show that such a transfer from car to bicycle will give an expected annual increase of 10 injury cases in Oslo. But the health benefits gained by cycling are much larger than the damage to health resulting from injuries in traffic, according to established economic valuations of health and injuries.

Our calculations provide a cost-benefit ratio for a modal switch of 6, indicating that the health benefits of increased cycling are six times higher than the losses associated with cyclist injuries. These estimates are uncertain and based on a number of assumptions that can be discussed. But they clearly show that a transfer to the bicycle will have overall favorable effects on health. This is in line with previous Norwegian and foreign studies.

## **Conclusion**

The report argues that there is no clear answer to what is the most appropriate use of different metrics of exposure and risk. We have argued that in some sense there is a continuum from exposure to accidents, and one should choose a measure of exposure which while reasonably close to the activity one wishes to assess the risk of, is not synonymous with the outcome.

This project was stimulated partly by the aim to achieve traffic growth in urban areas through walking, cycling and public transit. Most people travel to cover the distance from A to B. In this respect, time is not a very meaningful measure of exposure; one cannot replace a car journey to work lasting 20 minutes with a bicycle journey of 20 minutes. Over the longer term people may adjust and reduce their travel distances. Yet, when the problem is to replace the car with other means of transport certain journeys must be replaced, and thus distance is a more apt measure of exposure than time.

When assessing risk for pedestrians and cyclists, the risk of being harmed should be assessed against the benefits of increased exercise. Most studies show that the beneficial effect of exercise far outweighs the negative effects of cycling. Our calculations also show such beneficial effect, even when we use hospital reported injury figures.

Perhaps the most important contribution to providing a more fruitful understanding of risk and exposure for pedestrians and cyclists from this project is the fact that the absolute greatest accident problem for cyclists (and probably for pedestrians) are not collisions with motor vehicles, but single-vehicle accidents. Since 70-80 % of bicycle injuries result from single-vehicle accidents, the safety focus should be more on infrastructure and maintenance of bicycle paths and lanes.

That one of the most important safety measures for cyclists is to remove sand and gravel from the road surface, is hardly something one previously anticipated. Most pedestrian injuries are probably also single accidents, i.e. falls without vehicles being involved. The consequence of such insights for road safety work is that measures relating to the design and maintenance of infrastructure such as bike facilities, sidewalks, pedestrian and cycle paths become even more important.

Consequently, any changes in the understanding of exposure when assessing the traffic risks faced by pedestrians and cyclists will not be decisive in road safety work. The most important finding is that a better and more comprehensive registration of their accidents will provide a better understanding of risk factors that occur most frequently and are of greatest importance for accidents and injuries.