The final paper is available in Transport Policy, 68, 2018, 170-177

How can the notion of optimal speed limits best be applied in urban areas?

ABSTRACT

This paper reviews estimates of optimal speed limits made in the past 30 years. A tendency is seen for optimal speed limits to become higher. In the most recent estimates made for Norway, the optimal speed limit was in no case lower than 60 km/h. Adopting a speed limit of 60 km/h on roads in urban areas now having speed limits of 30, 40 or 50 km/h would most likely lead to an increase in the number of accidents and killed or injured road users. It is a political objective in Norway to reduce the number of killed or injured road users and to encourage more walking and cycling. Raising speed limits would conflict with both these objectives. This paper discusses if a re-interpretation of the notion of optimal speed limits can applied to justify low speed limits in urban areas. Traditionally, analyses of optimal speed limits have included motorised travel only. It is shown by means of simple numerical examples, that by including the effects of motorised travel speed on walking and cycling, optimal speed limits tend to be lower than when only motorised travel is included.

Key words: optimal speed limits; economic analysis; public health; walking; cycling

1 INTRODUCTION

The setting of speed limits is a compromise between considerations pulling in opposite directions. Keeping travel time short favours high speed limits. Keeping roads safe favours low speed limits. Keeping vehicle operating cost low favours a speed of around 70 km/h, not much higher and not much lower. Emissions of pollution tend, broadly speaking, to have the same relationship to speed as vehicle operating costs. Traffic noise tends, like accidents, to increase monotonically as speed increases.

Economic theory proposes that the best speed limit is the optimal speed limit (Crouch 1976). An optimal speed limit minimises the total costs of travel, i.e. the sum of costs of travel time, accidents, vehicle operation and environmental impacts. As applied up to now, the concept of optimal speed limits applies to motorised travel, not to travel by foot or bicycle. To determine the optimal speed limit, one needs to know the physical relationship between speed and the various impacts of speed and assign monetary values to these impacts.

Optimal speed limits, or optimal driving speeds, have been estimated in many studies. Some of these studies are reviewed in section 3 of the paper. Until recently, studies have shown that optimal speed limits tend to be lower than current speed limits. This means that if current speed limits were replaced by optimal speed limits, there would be a reduction of the number and severity of road accidents. However, a recent analysis for Norway (Elvik 2017) suggests that optimal speed limits are higher than most current speed limits. This finding implies that there are too few traffic fatalities and injuries, and that it would bring a net societal benefit to increase their number. Clearly, this implication would widely be regarded as problematic and conflicts with a political objective of reducing traffic injury. This raises doubts about the applicability of the idea of optimal speed limits, particularly in urban areas.

It should be noted that the notion of optimal speed limits is just one of several principles that have been proposed for setting speed limits (Elvik 2017). Other principles include biomechanical tolerance for impacts, as proposed in Vision Zero (Tingvall 1997), road geometry, roadside development, and the 85th percentile of driving speeds. As far as is known, a system of optimal speed limits has not been implemented anywhere. The objectives of this paper are:

1. To review previous studies of optimal speed limits or optimal driving speeds,
2. To discuss reasons why optimal speed limits have tended to become higher recently, illustrated by results for Norway and Sweden, two of the safest highly motorised countries in the world,
3. To discuss whether an alternative framework, embedded in economic theory, can be developed for setting optimal speed limits in urban areas.

2 THE THEORY AND ESTIMATION OF OPTIMAL SPEED LIMITS

Crouch (1976), in developing a framework for determining optimal speed limits included four impacts of speed: travel time, accidents, vehicle operating costs, and enforcement costs. He proposed that the relationship between speed and the sum of these costs was U-shaped and would have a minimum, which would be the optimal speed limit. He further noted that drivers may not perceive all costs correctly. The optimal speed from a private point of view might therefore be different from the optimal speed from a societal perspective. He recognised that speed limits need to be enforced and that the costs of enforcement should therefore be included when optimal speed limits are determined.

Most subsequent studies of optimal speed limits have ignored the costs of enforcement, but have included environmental impacts (noise, pollution), which were not discussed by Crouch. The recent analysis for Norway (Elvik 2017) included:

1. Travel time
2. Accidents
3. Vehicle operating costs
4. Emissions of NO_x and PM_{10}
5. Emissions of CO_2
6. Traffic noise

Figure 1 shows the relationship between speed and these impacts of speed. Panel A and B show that travel time and accidents move in opposite directions and represent the main trade-off to be made in setting speed limits. Vehicle operating costs (panel C) were assumed to be proportional to fuel consumption, as was emissions of CO_2. Traffic noise increases monotonically as speed increases (panel D). The curve for emissions of NO_x and PM_{10} greatly resembles that for vehicle operating costs, but the curves are not identical (panel E) (Jung et al. 2011, Marner 2016).

Figure 1 about here

Not all impacts of speed count equally in determining optimal speed limit. Figure 2 shows the estimated optimal speed limit for roads in Norway that currently have a speed limit of 80 km/h (which happens to be identical to the optimal speed limit). As can be seen from Figure 2, travel time, accidents and vehicle operation make major contributions, whereas the other impacts of speed are barely visible in the diagram.

Figure 2 about here

The contributions of the different impacts of speed in determining optimal speed limits obviously depend on the monetary valuations of those impacts. The effects of different monetary valuations are discussed in section 5 of the paper.

3 A REVIEW OF PREVIOUS ESTIMATES

Several studies have estimated optimal speed limits or optimal driving speeds. Kamerud (1983) analysed the impacts of the national 55 miles per hour speed limit in the United States on traffic fatalities and injuries, energy consumption, and time consumption of trucks. He found that the economic impacts of 55 mph speed limit were very small, meaning that the total costs of travel changed very little. However, the monetary valuation of a traffic fatality was just around 12,000 US dollars and Kamerud noted (page 56) that: "there has been no attempt to include a dollar value of human life in the fatal accident cost." Had even a low value, like 200,000 US dollars per fatality prevented, been used, benefits would have been greater than costs.

Andersson et al. (1991) estimated optimal driving speeds for roads with different speed limits in Sweden (based on data for 1986-88). Optimal driving speeds were in all cases lower than actual speed limits, by between 3 km/h and 27 km/h. Optimal driving speeds were also lower than the mean speed of traffic.

Rietveld et al. (1998) estimated optimal speed limits for various types of road in the Netherlands. Optimal speed limits were in all cases lower than actual speed limits and lower than the mean speed of traffic in nearly all cases. The differences were largest for roads that had speed limits of 120 or 100 km/h.

Elvik (2002) estimated optimal speed limits for Norway and Sweden. For Norway, results were mixed. Some speed limits were below the optimal speed limit, others were above. See Table 1 for details. Mixed results were obtained for Sweden as well. The optimal speed limit was lower than the actual speed limit in three cases, higher than the actual speed limit in two cases and identical to it in one case.

Table 1 about here

Cameron (2000, 2012) estimated optimal driving speed on residential streets with a speed limit of 60 km/h and on rural highways with a speed limit of 110 or 100 km/h. For residential streets, optimal speed was found to be 55 or 50 km/h, depending on whether the monetary valuation of traffic injury was based on the human capital approach or the willingness-to-pay approach. For rural highways, optimal speeds were 10-15 km/h below actual speed limits. Adopting optimal speed was estimated to reduce accident costs by 34 %.

Hosseinlou, Kheyrabadi and Zolfaghari (2015) estimated optimal driving speed for a six-lane freeway in Iran with a speed limit of 110 km/h. They found that optimal speed was 73 km/h. They state that an important reason for this rather low optimal speed for a freeway is the comparatively low income in Iran, leading to a low valuation of travel time. Finally, van Benthem (2015) concluded, based on an extensive analysis for California, that the optimal freeway speed limit was lower, but not much lower, than 55 miles per hour. The speed limit on interstate freeways in California at the time of analysis was 65 miles per hour.

4 RECENT ESTIMATES FOR NORWAY

Both Andersson et al. (1991) and Rietveld et al. (1998) found that optimal driving speeds, and hence optimal speed limits, were in all cases lower than actual speed limits. Elvik (2002) got more mixed results: some speed limits were below the optimal, others above. In the most recent estimates for Norway, however, all speed limits are below optimal speed limits, except for the speed limits of 80 and 100 km/h (Elvik 2017). The estimates are presented in Table 1.

For the lowest speed limits, optimal speed limits were found to be considerably higher than current speed limits. The optimal speed limit was in no case lower than 60 km/h, even on roads that now have a speed limit of 30 km/h. A more detailed analysis was made for roads with a speed limit of 80 km/h, by far the most common speed limit in Norway. On sections with a high number of serious accidents (about 30 % by length), it was found that a speed limit of 70 km/h was optimal. On less than 1 % of the roads (by length), optimal speed limit was 90 km/h. These roads had median guard rails preventing head-on-collisions. On the remaining roughly 70 % of roads with a current speed limit of 80 km/h, this was the optimal speed limit.

Thus, while roads can still be found where the optimal speed limit is below the actual speed limit, the main impression is that optimal speed limits are above actual speed limits, particularly in urban areas. It is highly likely that if optimal speed limits were consistently adopted in Norway, the number of killed or injured road users would increase. This conflicts with policy objectives of reducing the number of killed or injured road users.

As an example, suppose that drivers fully adapted to a speed limit of 60 km/h on roads that currently have a speed limit of 30 km/h, meaning that the mean speed of traffic increased from 30 km/h to 60 km/h. There would be a large increase in traffic injury. The mean injury cost per kilometre of travel would increase from 0.471 NOK/km (1 NOK = 0.105 EURO as of March 2018) to 2.25 NOK/km. However, even at this increased cost of traffic injury, 60 km/h remains the optimal speed limit. One must ask why the optimal speed limit is so much higher than the current speed limit, which, presumably, has been set for good reasons.

5 WHY ARE OPTIMAL SPEED LIMITS BECOMING HIGHER?

Optimal speed limits depend chiefly on the monetary valuation of travel time, on accident rates and on the monetary valuation of accidents. When optimal speed limits for

Norway were estimated by Elvik in 2002 (Elvik 2002), the data referred to the period 1993-2000. In the most recent estimates (Elvik 2017), the data referred to the period 2010-2015. There has been a dramatic improvement in road safety from the first to the second of these periods. Table 2 shows this improvement.

Table 2 about here

The left part of the table shows the number of injury accidents per million vehicle kilometres of travel. There has been a large reduction in accident rate for all speed limits, in some cases a reduction of more than 50 %. The right part of Table 2 shows injury costs per vehicle kilometre in 2013-prices. The reduction of injury costs is larger than the reduction of accident rate, and in no case less than 50 %. On roads with a speed limit of 90 km/h, injury cost per vehicle kilometre of travel has been reduced by more than 80 %. Roads that had a speed limit of 90 km/h during 2010-2015 were not identical to those that had this speed limit during 1993-2000. Some of these roads had their speed limit reduced from 90 to 80 km/h in 2001-2002. Still, even on roads that have kept the same speed limit in both periods, like those with a speed limit of 50 km/h, injury costs have been reduced by nearly 65 %.

The lower injury costs are, the less they count when optimal speed limits are estimated. Hence, the safer roads become, the more likely it is that optimal speed limits will be found to be higher than actual speed limits. Roads with a speed limit of 90 km/h can be used to illustrate this. At the currently optimal speed limit of 100 km/h on these roads, injuries represent 4.1 % of the total cost at a speed of 100 km/h. If the 1993-2000 cost rate is used, optimal speed limits drops to 90 km/h, at which injuries contribute 11.8 % of the total cost. Elvik found in 2002 that the optimal speed limit for roads with a speed limit of 90 km/h was 80 km/h. The higher optimal speed limit found in the most recent analysis is not fully explained by the decline in injury costs. Other cost components have also changed. Table 3 sheds light on this.

Table 3 about here

Table 3 shows the monetary valuations of impacts of speed used when estimating optimal speed limits in Norway in 2002 and 2017. The monetary valuations have been taken from reports by Sandberg Eriksen, Markussen and Pütz (1999), Statens vegvesen (2014) and Thune-Larsen et al. (2014). They are stated in 1999-prices and 2013-prices. Comparing 2013-values to 1999-values shows the adjustments that have been made between these two years.

It is seen that the valuation of travel time, especially for cars, has increased more than the valuation of traffic injury. Cars typically make up about 90 % of traffic. On average, therefore, the real increase in the valuation of travel time has been greater than the real increase in the valuation of preventing traffic injury. Environmental impacts appear to be valued lower in 2013 than in 1999. Travel time savings count more when estimating optimal speed limits based on 2013-values than when relying on 1999-values.

6 THE APPLICABILITY OF OPTIMAL SPEED LIMITS IN URBAN AREAS

The Norwegian government, like governments in many other countries, has two major policy objectives for urban transport (Samferdselsdepartementet 2017):

1. Growth in traffic should be entirely by cycling, walking or public transport. There should be no growth in car travel.
2. The number of killed or seriously injured road users should be reduced. The target for 2030 is a maximum of 350 killed or seriously injured road users. The recorded number in 2016 was 791.

The adoption of optimal speed limits, as estimated above, would most likely counteract both these objectives. Higher speed makes car travel more attractive and acts as a barrier to travel by foot or bicycle (Petritsch et al. 2007, 2010, Jacobsen, Racioppi and Rutter 2009, Meltofte and Nørby 2013, Litman 2017). Analysts would go beyond their remit if they were to argue that government should abandon the objectives of encouraging walking and cycling, and of reducing traffic injury, because these objectives are inconsistent with the adoption of optimal speed limits. The task of policy analysis is to help governments find the best way of realising political objectives, not tell them that the objectives are misguided. Woodcock et al. (2013) explain this in clear terms:

"Decisions on investments in transport are often dominated by travel time savings. Travel time savings are mainly achieved by increasing the speed of motorised transport. There is a good case for prioritising the health benefits from investments in transport over travel time savings benefits. Although considerable uncertainty remains around quantification of these health benefits they may still represent more tangible benefits than those from time savings, which will usually be taken first as improved accessibility for those using cars and then over time become changes in land use, with increasing urban sprawl …Beyond this, a case can be made for starting from normative goals of what healthy and low carbon transport systems should be like and then working backwards around the question of how to get there."

It would thus seem that the concept of optimal speed limits, as interpreted until now, is not very applicable to urban areas. Optimal speed limits as estimated until now refer to motorised travel only; estimates do not consider how the speed of motor vehicles affects travel by foot or bicycle and are hence not relevant to the objective of getting more people to walk or cycle. The question is whether another approach to setting urban speed limits can be developed, to help determine speed limits whose benefits are greater than the costs.

7 A REDEFINITION OF OPTIMAL SPEED LIMITS IN URBAN AREAS

Motor vehicles travelling at high speed are known to deter walking or cycling (Jacobsen et al. 2009). To encourage walking or cycling, the speed of motor vehicles should be low. A low speed for motor vehicles discourages their use (Litman 2017) and reduces traffic risk. For motorists, a low speed is unattractive. There is, in other words, a conflict of interest between motorists on the one hand, and pedestrians and cyclists on the other, regarding the best speed for motor vehicles in urban areas. Suppose a low speed limit, say 30 km/h, is adopted (the default speed limit in urban areas in Norway is 50 km/h). Possible impacts are:

1. The speed of motor vehicles will be reduced.
2. There will be a reduction in motor vehicle traffic volume
3. There could be an increase in walking or cycling

If these impacts can be reliably estimated and monetary valuations attached to them, they can be compared to determine whether the favourable effects (benefits) exceed the unfavourable effects (costs) for various urban speed limits.

Ideally speaking, a transport model should be used to estimate changes in total travel demand and any modal shift resulting from a change in the speed of motor vehicles. This is currently not possible, at least relying on transport models available in Norway, because data on walking and cycling are usually not detailed enough to be assigned to specific routes. Simple numerical examples have therefore been developed to illustrate the potential magnitude of effects. To determine realistic volumes of motor vehicles, pedestrians and cyclists, traffic volume data given in three Swedish PhD dissertations have been used (Nilsson 2003, Jonsson 2005, Kröyer 2015). A summary of these data is given in Table 4.

Table 4 about here

It is seen that the mean daily volume of motor vehicles driving along road sections is typically around 6,000 to 12,000. Cyclist volume is typically between 600 and 1,200 and pedestrian volume 200-300. There is less data about volumes in junctions and at crossing facilities. Two numerical examples have been developed. In one, a comparatively low volume of cyclists and pedestrians was assumed; in the other a larger volume of cyclists and pedestrians was assumed. A travel distance of 1 kilometre was assumed for all groups of road users.

According to Litman (2017), the long-term elasticity of trips as a car driver with respect to car travel time is -0.76. This value is very close to the elasticity of -0.74 quoted by Graham and Glaister (2004). If the speed limit in urban areas is reduced from 50 to 30 km/h, one may expect the mean speed of traffic (Elvik 2012) to be reduced by about 8 km/h. In the numerical example developed below, a reduction from 49.5 to 41.3 km/h has been assumed. Applying the elasticity of -0.76, this speed reduction will be associated with a reduction of 12.8 % in car driving. This was estimated as follows. Speed was reduced in steps of 1 percent: 49.5; 49.0; …; 41.7; 41.3. Mean speed was converted to travel time per kilometre: 60/49.5 = 1.212; 60/41.3 = 1.453. The change in the volume of motor vehicles for each 1 percent increase in travel time was estimated as:

$$\text{Volume after} = \text{volume before} \cdot \left(\frac{Travel\ time\ after\ (1.01)}{Travel\ time\ before\ (1.00)}\right)^{-0.76}$$

Each increase of 1 percent in travel time was found to be associated with a reduction of motor vehicles volume of 0.8 %. For the total change in travel time (19.8 %), motor vehicle volume was reduced by 12.8 %. Figure 3 shows how the change in consumer surplus associated with this change in travel demand can be estimated.

Figure 3 about here

The initial amount of car driving has been given a value of 1. The reduces to 0.872. The rectangle shows the loss of consumer surplus for those who continue to driver at the lower speed. The triangle shows the loss of consumer surplus for those who cease driving. The societal cost of driving, as applied when estimating optimal speed limits, has been used as an estimate of the generalised cost of driving. The speed reduction is associated with an increase in the generalised cost of travel from 7.65 to 8.85 NOK per kilometre.

Litman (2017) states that the elasticity of walking or cycling with respect to travel time as a car driver (all trip purposes combined) is 0.19, i.e. a 1 % increase in car driver time will increase walking or cycling by 0.19 %. This elasticity is considerably lower than the elasticity for car drivers, suggesting that not all those who stop driving when it takes more time will take up walking or cycling. The increase in walking or cycling is a result of a reduction of the generalised costs of travel when walking or cycling. Factors influencing the generalised costs of walking or cycling are not fully known, but the volume of motor vehicles is an important factor. Thus, Petritsch et al. (2007) found that the level of service for cyclists on arterial roads had a negative association with motor vehicle volume. The coefficient they found indicates that level of service declines nearly proportional to the increase in motor vehicle volume. Based on this, it was assumed that the generalised costs of walking or cycling are proportional to motor vehicle volume. If an elasticity of -0.5 with respect to generalised costs of walking or cycling is assumed (Litman 2017), it can be worked out, based on official Norwegian values (Statens vegvesen 2014) that the generalised cost of walking 1 kilometre will be reduced by NOK 4.69. These costs are the sum of the costs of travel time (NOK 32.08 per km), insecurity when crossing a road (NOK 4.8 per km), and insecurity when walking along a road (NOK 33.9 per km). The generalised cost of cycling will be reduced by NOK 2.47 per kilometre, from an initial cost of NOK 37.26 per km (NOK 10.86 for time and NOK 26.40 for insecurity). The benefits of walking and cycling will consist of: (1) reduced generalised costs of travel, and (2) gains in public health as a result of the increase in walking and cycling.

Estimates based on the numbers given above have been made for a period of 10 years, applying an annual discount rate of 4 %. To estimate the gains in public health from increased walking and cycling, the HEAT tool developed by the World Health Organization (2017) has been used with respect to mortality and Norwegian guidelines (Statens vegvesen 2014) with respect to morbidity. The main results are presented in Table 5. All effects refer to trips of 1 kilometre.

Table 5 about here

The loss of consumer surplus to car drivers equals the net increase in the generalised costs of travel per kilometre (1.20), multiplied by the number of car drivers affected by the increase (8,284), multiplied by 365, multiplied by the aggregated present value factor for 10 years at an annual discount rate of 4 % (8.111). A similar multiplication was made for displaced drivers (1,216), but applying a cost increase of 0.60. Changes in the generalised costs of travel for pedestrians and cyclists were estimated by means of similar multiplications.

Public health effects were estimated by relying on two sources. Changes in mortality were estimated by means of the WHO HEAT tool, applying the same monetary valuation of the welfare effect of preventing a traffic fatality (NOK 31,255,000) as in Elvik and Sundfør (2017). Changes in morbidity were estimated by applying the monetary values listed by Statens vegvesen (2014). Per kilometre of walking there is a reduction in the cost of short term illness of NOK 3.44 and a reduction in the cost of long term illness of NOK 49. The corresponding values for cyclists are, respectively, NOK 1.78 and 24.60.

It is seen that the very small increase in walking and cycling implied by the elasticity of 0.19 does not generate a benefit which is large enough to offset the loss of consumer surplus for car drivers. In the right half of Table 5, two key assumptions were changed. First, a higher volume of cyclists and pedestrians was assumed. Second, the elasticities given by Litman (2017) with respect to travel time for commuting trips, -0.96 for motor vehicles and 0.50 for cyclists and pedestrians, were used. It is seen that benefits exceed losses by a wide margin. In principle, therefore, it is possible to justify a low speed limit of 30 km/h in urban areas despite the fact this speed limit inflicts losses on motorists. Even if cars represent about 80 % of all traffic, and even if displaced car traffic is not fully replaced by an increase in walking or cycling, a low speed limit can bring net benefits in terms of a lower generalised cost of walking or cycling (walking or cycling becomes more attractive when there is less car traffic moving at a lower speed) and gains in public health as a result of an increase in walking or cycling.

As a sensitivity analysis, the elasticities in the right half of Table 5 (-0.96; 0.50) were applied to the volume data in the left half of the Table (9500, 200, 250). Total benefits for cyclists and pedestrians were estimated to 18.3 million NOK, which is less than the loss of consumer surplus for cars drivers (31.1 million NOK). In a similar manner, the elasticities in the left half of Table 5 (-0.76; 0.19) were applied to the volume data in the right half of the Table (9500, 900, 1050). Total benefits for cyclists and pedestrians were estimated to be 29.8 million NOK, which is again less than the loss of consumer surplus for cars drivers (31.6 million NOK). Thus, given the assumptions made in the numerical examples, it would seem that the benefits to cyclists and pedestrians of reducing the volume and speed of motor vehicles can only outweigh the loss of benefits to car drivers if cyclists and pedestrians make up more than about 20 % of traffic and motor vehicle volume is reduced by more than about 15 %.

8 DISCUSSION

In the 1980s and 1990s optimal speed limits used to be lower than actual speed limits and introducing optimal speed limits was regarded as a road safety measure: it would reduce the number of traffic injuries. Today, this is no longer clear, at least not in urban areas. The most recent estimates of optimal speed limits for Norway indicated that all speed limits currently applied in urban areas ought to be raised and were in no cases lower than 60 km/h. The chief reasons for this are that: (1) Over time, the monetary valuation of travel time has increased more than the monetary valuation of traffic injury, and (2) The risk of traffic injury per kilometre of travel has declined considerably. Traffic injury therefore contributes much less to the total societal costs of travel than it did only 15 years ago.

It is nevertheless not acceptable to use estimates of optimal speed limits as an argument for turning the improvement of road safety around and taking action to reverse it. If analysts were to give such a policy recommendation, they would in effect recommend giving up current political objectives of reducing traffic injury and encouraging walking and cycling. It is not the task of analysts to act as a political opposition. Rather, when estimates of optimal speed limits give results that counteract current political objectives, analysts should ask whether a new perspective on setting urban speed limits can be developed that would be consistent with political objectives. The principal task of policy analysts is to advice government on how best to realise its political objectives, not to tell government that it should have different objectives.

There are many reasons for adopting an objective of increasing walking and cycling. If people drive less, and rather walk or cycle, the contribution to global warming will be reduced and there will be less traffic congestion, noise and pollution. A sedentary life style increases the risk of illness and more physical activity improves health and longevity. If the increasing number of old citizens can stay healthy for longer, it will save society from huge expenses. The health benefits of walking and cycling are sufficiently well known to be estimated and valued in monetary terms. Public health benefits of walking and cycling may therefore be included in analyses of optimal speed limits in urban areas. Moreover, both the number and speed of cars is known to deter walking and cycling. Hence, if car traffic volume can be reduced and cars slowed down, this by itself will make walking and cycling more attractive.

The simple estimates made in this paper show that, when the benefits of walking and cycling are included in analysis, low speed limit in urban areas can yield benefits that exceed the costs, even if such a speed limit is unequivocally negative for car drivers, i.e. it only has costs and no benefits. There were net benefits even when cars initially made up 80 % of traffic and even if walking or cycling increased by no more than 9.5 %. It will not always be the case that the benefits of low urban speed limits exceed the costs. If the modal split is very imbalanced, and cars make up, say, 95 % of traffic, the losses to car drivers of imposing a low speed limit are likely to exceed any gains from walking or cycling.

How can it be possible that two economic analyses show so different results? One analysis concluded that 60 km/h or higher would be the optimal speed limits in urban areas. The other analysis found that a speed limit of 30 km/h can bring benefits that exceed the costs. The answer is that the analyses rest on different perspectives. The first analysis includes motor traffic only. It does not consider how different speed limits influence walking and cycling, and it does not include the health benefits of these modes of transport. The choice of perspective strongly influences the results of the analyses.

Ironically, more walking and cycling may increase traffic injury, thus counteracting the objective of reducing it. Is it likely that the number of injured road users will increase if, for example, the modal shifts shown in the right part of Table 5 take place? There are two effects to consider in this case. First, the reduction of speed will reduce the risk of accidents for all road users. A speed reduction from 49.5 to 41.3 km/h, as assumed in the example, will reduce injury accidents by about 24 % (Elvik 2013). Second, the modal shift to walking and cycling may offset some of this reduction. Using the coefficients estimated by Elvik and Bjørnskau (2017), i.e. 0.499 for motor vehicles, 0.511 for pedestrians and 0.432 for cyclists, the modal shift in the right part of Table 5 can be estimated to increase the number of injured road users by about 1.8 %. Thus, the net effect on the number of injured road users would be $0.757 \cdot 1.018 = 0.771$, or a reduction of nearly 23 %. It is, however, important to note that this reduction will only take place if speed is reduced. If speed is not reduced, one may expect the number of injuries to increase.

9 CONLUSIONS

The main conclusions of the study presented in this paper can summarised as follows:

1. A tendency can be seen for optimal speed limits, i.e. speed limits that minimise the total societal costs of travel, to become higher.
2. A recent estimate for Norway indicated that optimal speed limits were higher than all actual speed limits, except those of 80 and 100 km/h. The lowest optimal speed limit was found to be 60 km/h.
3. Implementing speed limits of 60 km/h or higher in urban areas would conflict with political objectives of reducing traffic injury and encouraging walking and cycling.
4. Elements a new approach for setting urban speed limits, which includes the generalised costs of walking and cycling, and the health benefits of walking and cycling, were illustrated by a simple numerical example.

5. It was found that a speed limit of 30 km/h can give benefits that exceed costs even if cars make up 80 % of traffic and walking and cycling increase by only about 10 %. The benefits consist of lower generalised costs of travel for walking and cycling (gain in consumer surplus for pedestrians and cyclists) and public health gains associated with increased walking and cycling.

ACKNOWLEDGEMENT

The study presented in this paper was funded by the Norwegian Public Roads Administration

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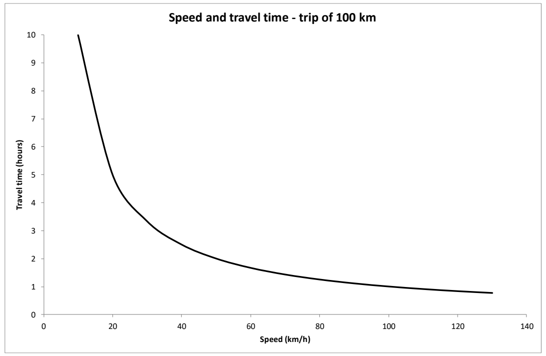
LIST OF FIGURES AND TABLES

Figure 1:

A



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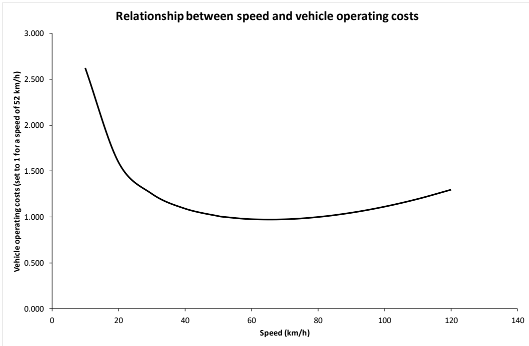

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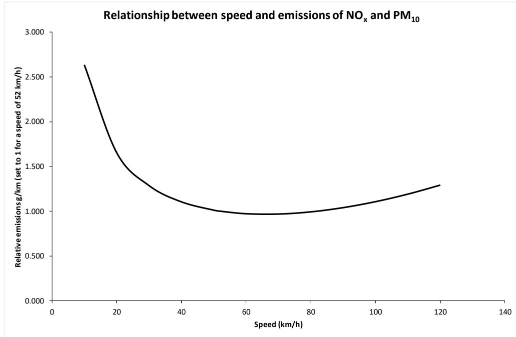

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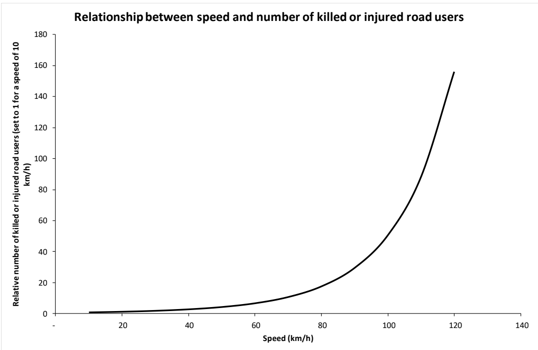

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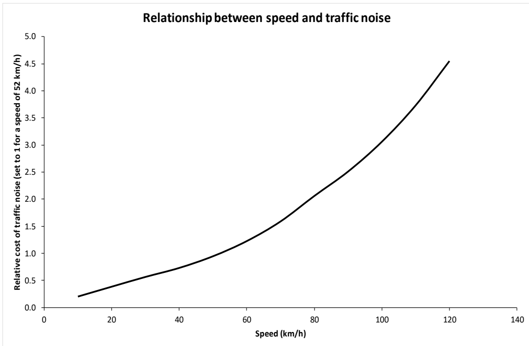
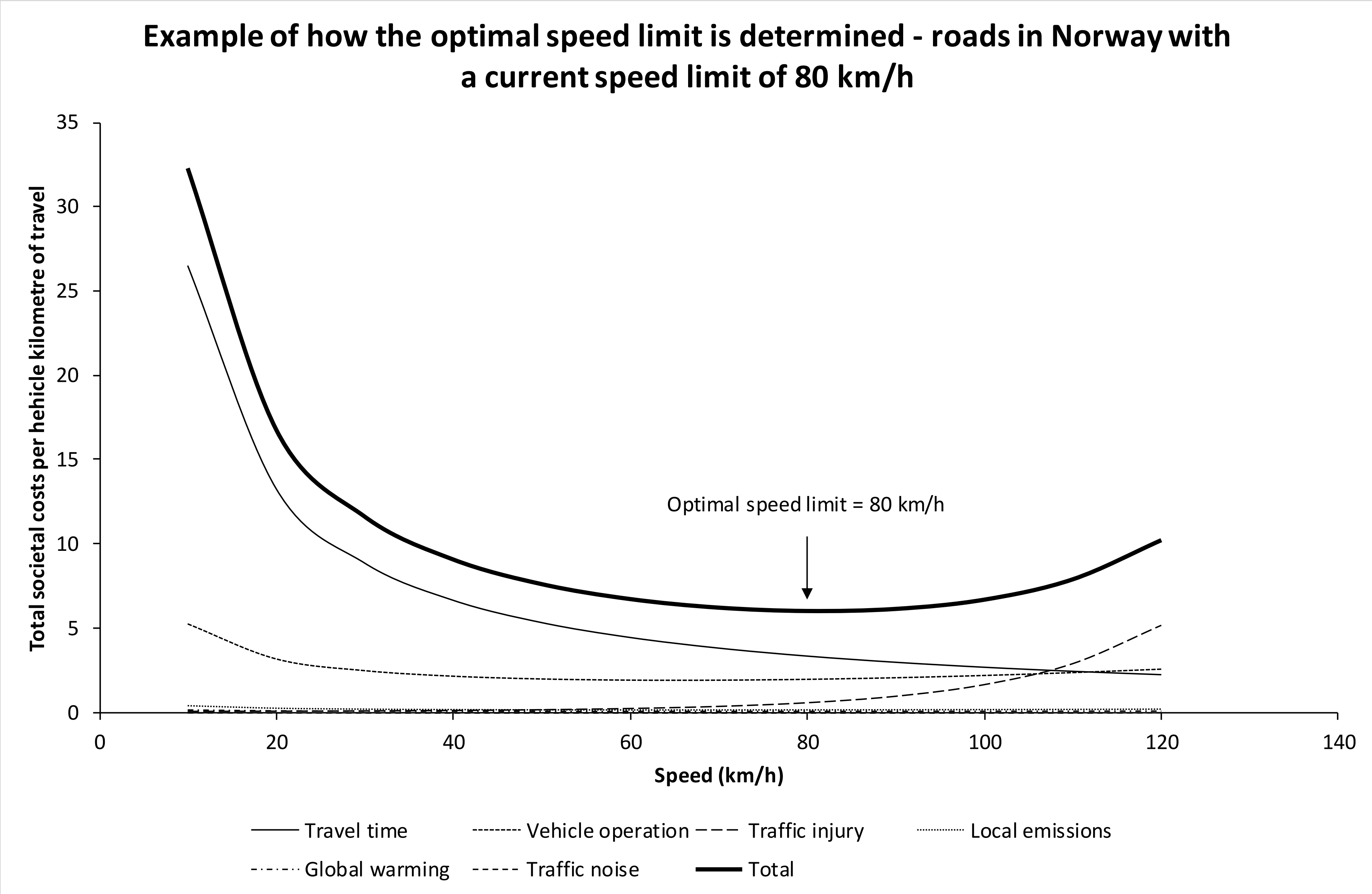
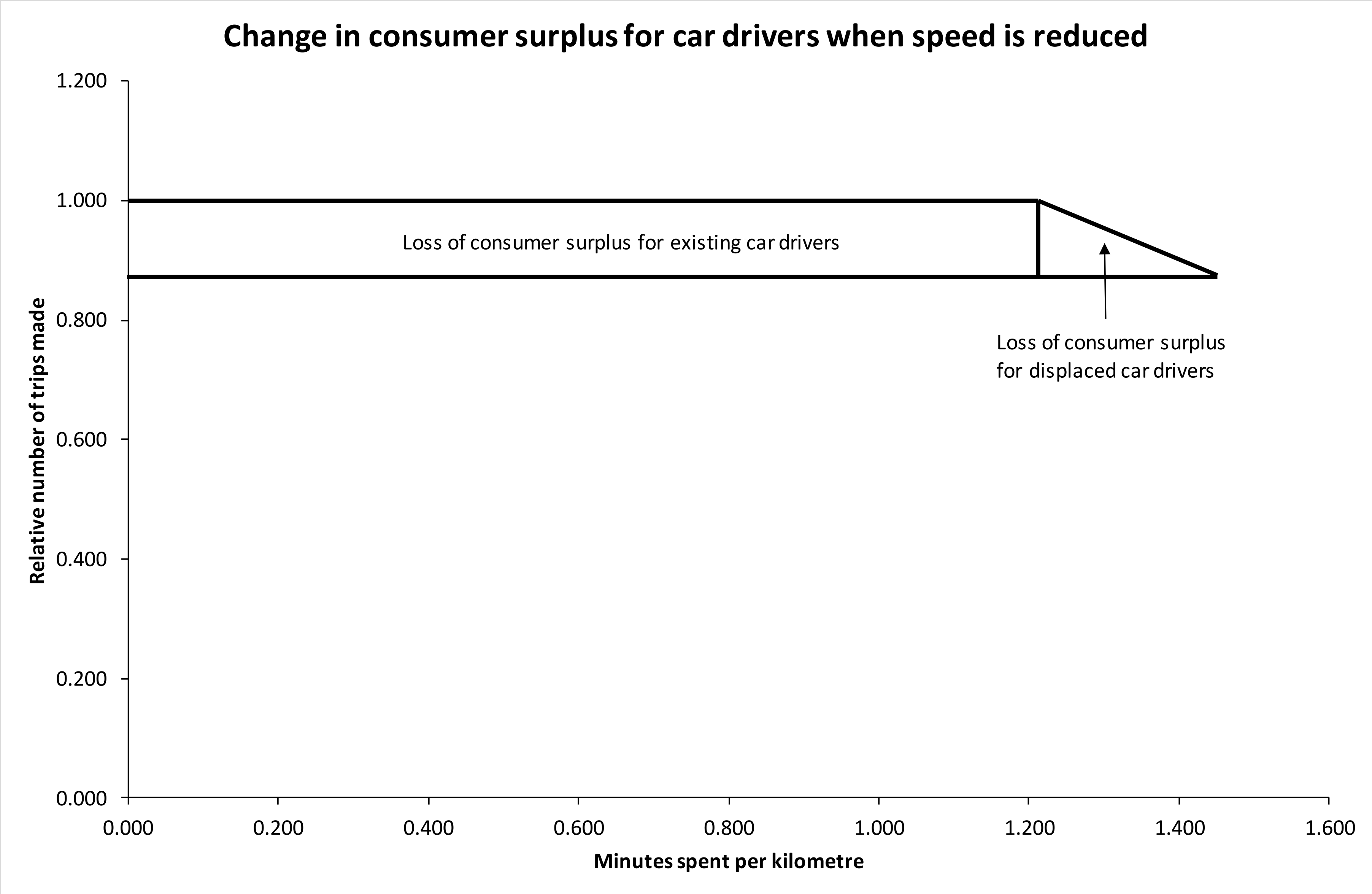


Figure 2:



Example of how the optimal speed limit is determined - roads in Norway with a current speed limit of 80 km/h
Total societal costs per hehicle kilometre of travel
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
Speed (km/h)
Optimal speed limit = 80 km/h
Travel time
Vehicle operation
Traffic injury
Local emissions
Global warming
Traffic noise
Total

Figure 3:



Change in consumer surplus for car drivers when speed is reduced
Loss of consumer surplus for existing car drivers
Loss of consumer surplus
for displaced car drivers
Relative number of trips made
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
Minutes spent per kilometre

Table 1:

		Estimates for Sweden		Estimates for Norway	
Type of road	**Speed limit (km/h)**	**Optimal speed (1991)**	**Optimal speed limit (2002)**	**Optimal speed limit (2002)**	**Optimal speed limit (2017)**
Motorway	110	93	110		
Motorway	100				100
Motorway	90			100	100
Motor traffic road	110	85	90		
Motor traffic road	90		80	80	
Rural highway	110	83			
Rural highway	90	77	80		
Rural highway	80			70	80
Rural highway	70	65			80
Suburban arterial	60				70
Urban arterial	50	47	60	50	70
Urban collector	40				70
Access road (residential)	30		60	40	60

Table 2:

	Injury accidents per million vehicle kilometres		Injury costs (NOK) per vehicle kilometre	
Speed limit (km/h)	1993-2000	2010-2015	1993-2000	2010-2015
50	0.455	0.182	1.208	0.432
60	0.246	0.127	0.916	0.368
70	0.196	0.100	0.986	0.419
80	0.173	0.099	0.955	0.479
90	0.092	0.042	0.723	0.134
Motorway (90/100)	0.056	0.032	0.307	0.111

Table 3:

Type of impact	Valuation per unit	Values for 1999 (NOK 1999)	Values for 2013 (NOK 2013)	Ratio 2013/1999
Travel time	1 vehicle hour by car	82	235	2.87
	1 vehicle hour by truck	321	617	1.92
	1 vehicle hour by bus	838	1264	1.51
Vehicle operation	1 kilometre by car	0.92	1.74	1.89
	1 kilometre by bus or truck	2.73	5.34	1.96
Traffic injury	1 fatality	20,150,000	35,300,000	1.75
	1 seriously injured person	5,750,000	11,100,000	1.93
	1 slightly injured person	600,000	700,000	1.17
Environmental impacts	1 kilogram of carbon dioxide (CO_2)	0.37	0.21	0.57
	NO_x and PM_{10} per km of driving	0.175	0.137	0.78
	Traffic noise per km of driving	0.057	0.011	0.19

Table 4:

	Mean daily traffic volumes					
	Along road sections – mean values (range in parentheses)			In junctions or at crossing facilities – mean values (range in parentheses)		
Study	**Motor vehicles**	**Cyclists**	**Pedestrians**	**Motor vehicles**	**Cyclists**	**Pedestrians**
Nilsson 2003	6,260 (1,600 – 25,000)	910 (100 – 2,000)				
Jonsson 2005	8,000 (800 – 31,000)	500 (10 – 5,000)	300 (10 – 10,000)		50 (10 – 5,000)	70 (10 – 10,000)
Kröyer 2015	10,000 (1,500 – 35,000)	1,190 (1 – 15,090)	230 (1 – 1,960)			720 (10 – 4,120)

Table 5:

	Mean elasticities applied (-0.76 for motor vehicles; 0.19 for cyclists and pedestrians)				Elasticity for commuting applied (-0.96 for motor vehicles; 0.50 for cyclists and pedestrians)			
Transport mode	**Initial modal split**	**New modal split**	**Consumer surplus**	**Public health gain**	**Initial modal split**	**New modal split**	**Consumer surplus**	**Public health gain**
Car driver	9500 (95.5 %)	8284 (94.6 %)	-31,590,000		9500 (83.0 %)	7990 (79.5 %)	-31,070,000	
Pedestrian	200 (2.0 %)	207 (2.4 %)	2,830,000	1,310,000	900 (7.9 %)	986 (9.5 %)	32,690,000	17,750,000
Cyclist	250 (2.5 %)	259 (3.0 %)	1,860,000	792,000	1050 (9.1 %)	1150 (11.0 %)	20,100,000	9,750,000
Total	9950 (100.0 %)	8750 (100.0 %)			11450 (100.0 %)	10126 (100.0 %)		
Total as share of initial		87.9 %				88.4 %		
Total monetary values (NOK)			-26,900,000	2,102,000			21,720,000	27,500,000