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The Dutch road to a high level of cycling safety

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ABSTRACT
Many governments attempt to improve cycling safety to reduce the number of bicycle crashes and encourage people to take up cycling. The Netherlands is a world leader in bicycle use and safety. This paper explores how the Netherlands achieved an 80% reduction in the number of cyclists killed (predominantly bicycle-motor vehicle crashes) per billion bicycle kilometres over a thirty year period. Factors found to contribute to this improvement include the establishment of a road hierarchy with large traffic-calmed areas where through traffic is kept out. A heavily used freeway network shifts motor vehicles from where cycling levels are high. This reduces exposure to high-speed motor vehicles. Separated bicycle paths and intersection treatments decrease the likelihood of bicycle-motor vehicle crashes. The high amount of bicycle use increases safety as a higher bicycle modal share corresponds with a lower share of driving and greater awareness of cyclists among drivers. Low cycling speed was also found to contribute to the high level of cycling safety in the Netherlands.

Keywords: bicycle, road safety, cycling safety, infrastructure, safety in numbers, conceptual model.

1 INTRODUCTION

Many governments are attempting to improve cycling safety to reduce the significant health burden resulting from bicycle crashes [1] and to encourage people to take up cycling since a perceived lack of safety is a deterrent to cycling [2, 3]. It is therefore important to understand how cycling safety can be improved. This study is focused on the Netherlands which, together with Denmark, has achieved the lowest fatality rate amongst cyclists[4]. This is shown in Figure 1 which also includes total road fatalities per 100,000 population as an indicator of the general level of road safety. Figure 1 indicates there may be a correlation between cycling safety and road safety in general, suggesting that road safety policies play an important role in cycling safety. This paper therefore sets out to explain the high level of cycling safety in the Netherlands.

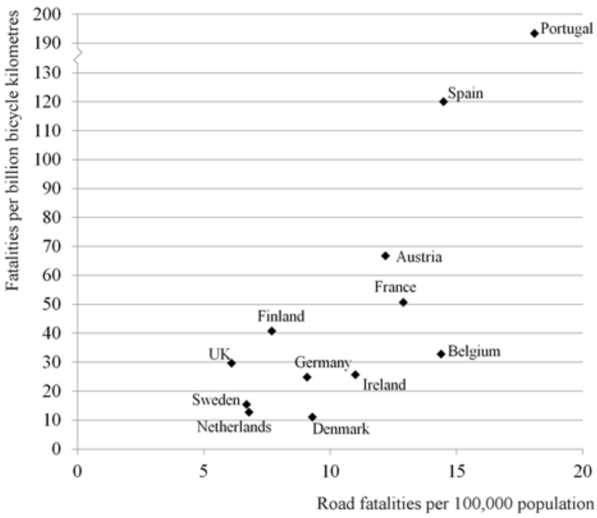

Figure 1: Fatalities per billion kilometres travelled by bicycle in 2002 against total road fatalities per 100,000 population in European countries (the vertical axis is broken to accommodate Portugal) [5, 6]

Conditions in the Netherlands are conducive to cycling, with a flat terrain, mild climate, high quality bicycle infrastructure, abundant parking facilities, and short travel distances within cities resulting from high densities and mixed land use [7, 8]. The Dutch national bicycle modal share amounts to 26% which is higher than anywhere else in the world [4, 8]. It has been at a high level for almost a century [9, 10], and it was only at the beginning of the sixties that the number of kilometres travelled by motor vehicles exceeded the number of bicycle kilometres and that bicycle use started to decline. Since 1975 there has been a gradual increase in the distance travelled by bicycle of some 40%. This corresponds to a 20% increase in per capita usage; the other 20% is due to population increase [11, 12].

Previous studies have sought to explain the high cycling participation rate in the Netherlands by comparing the circumstances for cycling to those in other countries [4, 13]. A small number of studies with a comparable study approach have focused specifically on the factors explaining the high level of cycling safety. These have concluded that the following policies are critical to the high level of cycling safety in the Netherlands: safe infrastructure (in particular separated cycle paths), traffic calming and intersection treatments, comprehensive traffic education and training of both cyclists and motorists, and traffic regulations that favour cyclist and pedestrians, particularly strict liability (i.e. drivers are almost always liable when they crash into a cyclist or pedestrian) [13-15]. The high incidence of cycling and behavioural adaptation of motorists in the presence of cyclists has also been suggested as an important contributing factor [16]. This has been called the "safety in numbers" phenomenon. These studies are very important in showing how circumstances for cycling in the Netherlands differ from those in other countries, but the results have not yet been sufficiently substantiated by empirical road safety research. Therefore the objective of the present study is to analyse the evidence for the impact of these factors on serious and fatal bicycle - motor vehicle (BMV) crashes. In that context it also considers the effects of policy interventions and their consequences from the 1950's onwards.

In the Netherlands, BMV crashes involving cars account for almost half of cyclist deaths, and those involving goods vehicles and public transport account for 20% [17, 18]. A substantial proportion of the latter occur with right-turning trucks (on a right-hand-drive lorry) [e.g. 19, 20]. Distributor roads and busy arterial roads have the highest share of fatal BMV crashes [21-24] and most crashes occur at intersections [18]. Note that this paper does not address the impact on single bicycle crashes. Although these crashes frequently result in serious injuries, data records and studies are extremely rare and not suited for international comparisons or evaluations [25].

2 STUDY APPROACH AND DATA USE

2.1 Conceptual framework

To visualise the factors and their causal relationships, and to structure the findings accordingly, the study applied a recently published conceptual framework for road safety [26] (see Figure 2) which has been adapted to explain the risk of serious and fatal BMV crashes. In this form, the model closely resembles a conceptual framework by Elvik et al [27]. The model has two main blocks that are also used to structure the results in Section 4, i.e. travel behaviour and exposure to risk (motor vehicles, especially those at higher speed) in Section 4.1 and risk (the likelihood of a collision and injury consequences if a crash occurs) in Section 4.2.

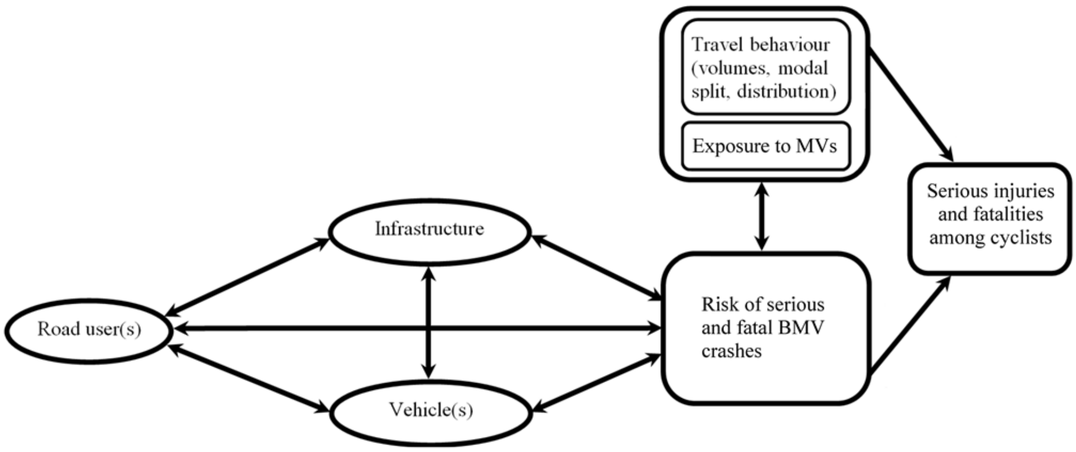

Figure 2: Conceptual framework on factors affecting road safety (adapted from [26])

The modal split and distribution of traffic over space – two aspects of travel behaviour – determine the numbers of motor vehicles encountered by cyclists and thereby their exposure to risk. Volumes of cyclists are important because it has been suggested that the number of cyclists encountered by motorists affects the risk of BMV crashes (an arrow from exposure to risk) [16]. This also works in reverse because perceived risk affects decisions to cycle (an arrow from risk to exposure) [7]. Crash risk results from interaction between three elements, sometimes called the three traffic safety pillars: road user(s), vehicle(s), and infrastructure [e.g. 28].

2.2 Methods and data

A brief review was conducted encompassing two lines of research; international comparisons [e.g. 4, 14] and road safety reviews [e.g. literature reviews by Twisk et al. and Wegman et al. 29, 30] (Section 4) including longitudinal data (Section 3). Most data on road safety in the Netherlands is publicly available at the website of SWOV Institute for Road Safety Research [31].

3 THE DEVELOPMENT OF CYCLING SAFETY

To understand cycling safety in the Netherlands, not only is its level compared to other countries important (as for instance shown in Figure 1), so too is its historical development. To illustrate this development since 1950, Figure 3 shows the number of police-recorded cyclist fatalities per billion bicycle kilometres for those years. The number of cyclist fatalities per billion bicycle kilometres amounted to almost 25 in the 1950s and doubled to almost 50 during the 1970s. However, from the 1970s onwards there has been a strong (five-fold) and continuous reduction to the current level of approximately 10 fatalities per billion bicycle kilometres. This is an impressive reduction as the number of motor vehicle kilometres doubled in this period [12]. It is even more impressive when one takes into account that although the representation of cyclists over 75 years in the population has doubled [12], they are ten times more likely to be killed per billion bicycle kilometres than cyclists in other age groups [29].

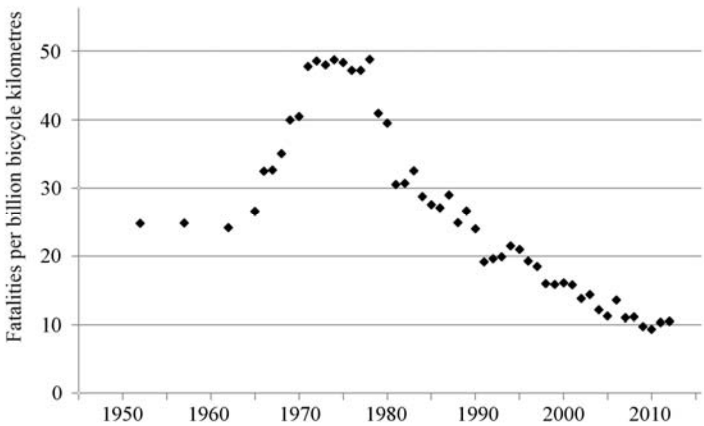

Figure 3: Number of recorded cyclist fatalities per billion bicycle kilometres (figures up to the first half of the 1970s are 5-year averages as the estimates for the amount of bicycle kilometres were not yet based on the National Travel Survey) [11, 12]

It has been suggested that the improvement the Netherlands has achieved results from increased amounts of cycling i.e. more cyclists on the road leads to behaviour modification by motorists (the safety in numbers phenomenon) [16]. The distance travelled by bicycle per capita increased only by some 20% during the period of the five-fold reduction in bicycle fatalities. An increase in the amount of bicycle use has thus, at most, played a small role in the risk decrease. Moreover, the majority of the countries in Figure 1 now have fatality rates under 50 per billion bicycle kilometre which is less than what the Netherlands had in 1970. However, the distance travelled by bicycle per capita in these countries is much less than what was travelled in the Netherlands in those days. These results suggest that compared to other factors, the direct effect of the amount of bicycle use is not the main explanation for the large decrease of the fatality rate in the Netherlands.

4 RELEVANT FACTORS

This section explores explanations for the high level of Dutch cycling safety. Factors are structured according to the conceptual framework depicted in Section 2. Section 4.1 followed on travel behaviour and exposure to risk (the upper part of the conceptual model), while section 4.2 is related to risk (the lower part of the model).

4.1 Travel behaviour and exposure to risk

4.1.1 Distribution of traffic over the road network

Important to cyclists' exposure to motor vehicles is the distribution of cycle and motor traffic over the road network, which is strongly affected by the Dutch 'street hierarchy'. This hierarchical structure is based on the two key principles of *Homogeneity* and *Functionality*. Homogeneity implies that differences in speed, direction and mass should not be too large, e.g. a safe speed for mixing cyclists with motorised traffic is no higher than 30 km/h [32]. A 30 km/h speed is the standard in traffic-calmed areas. On distributor roads where the limit is 50 to 70 km/h, cyclists are separated from motorised traffic on road sections by bicycle paths, while motor vehicle speed is to be reduced at intersections. Functionality refers to classification of roads in a hierarchical road network. The function of higher order through roads (mostly freeways) is traffic flow, whereas lower order access roads provide access to origins and destinations. Distributor roads distribute traffic from through roads to access roads. Table 1 lists the speed limits and the location of cyclists for the three road classes.

Table 1. Road classification and speed limits in the Netherlands

	Speed limit in urban areas	**Location of cyclist**
Access roads	30 km/h	Mixed with other traffic
Distributor roads	50 or 70 km/h	Separated from motorised traffic by bicycle paths or lanes*
Through roads	100 or 120 km/h	Cycling not allowed

* Paths are physically separated from the carriageway, whereas lanes provide a visibly delineated space on roads

The street hierarchy has a long tradition starting with experiments in the 1960s with so-called 'Woonerfs' (literally translating to "home zones") to enable children to play safely in residential streets. Woonerfs, an example of which is given in Figure 4, were legally recognised in the 1970s with a 15 km/h speed limit (Hass-Klau 1990). Subsequently, the 30 km/h zone was legally recognised in 1984 to achieve traffic calming in larger areas, up to 2 km^2 and in new towns, even larger [33]. Agreement on implementation of the street hierarchy on a national scale (along with a number of other road safety measures) was reached in 1998. By 2008, the speed limit on 85% of the roads in built-up areas classified as access roads had been reduced to 30 km/h [34].

Figure 4: Example of a woonerf (home zone)

The Dutch 'street hierarchy' strongly reduces cyclists' exposure to motorised traffic by shifting vehicles away from where there is a lot of cycling. The Netherlands has the densest motorway network in Europe at 57 km per 1000km², where about half of all motor vehicle kilometres are travelled [35]. This network shifts away motor vehicles from where cycling levels are high. For comparison, less than one-third of all vehicle miles in the US are travelled on motorways (interstate and other freeways) [36]. Access roads are designed for low speeds and use speed-reducing measures and street closures to deter through motor traffic. These areas are still relatively permeable to cyclists ('filtered permeability'[37]) as a result of authorization of contraflow cycling in one-way streets (see Figure 5, left), short cuts for cyclists where roads are closed to motor vehicles (see Figure 5, right), and standalone bicycle paths that offer additional route options to cyclists, etc. [34]. In terms of road use, it is estimated that almost 60% of bicycle kilometres in urban areas are travelled in traffic calmed areas [24, 38].

Figure 5: Example of a street closure (left) and one-way street with allowance of contraflow cycling, indicated by the traffic sign (right)

The importance of this form of 'network level separation' to cycling safety is indicated by a lower likelihood of fatal and serious crashes in Dutch municipalities with a higher share of bicycle kilometres in traffic-calmed areas. More bicycle kilometres through traffic-calmed areas, along with the installation of grade separated intersections (bicycle bridges or tunnels) to cross distributor roads was found to be related to strong reductions in the fatality crash rate. One standard deviation on a score that was developed to measure network level separation for Dutch municipalities corresponded to a 24% decrease in the likelihood of fatal bicycle crashes [24].

4.1.2 Other effects of travel behaviour and exposure
A second aspect of travel behaviour affecting exposure to risk is the modal split. The Netherlands has high individual levels of cycling (2.4 km per person per day), with cycling having a high modal share (35% of all trips up to 7.5 km) and driving having a correspondingly lower modal share (also 35% of all trips up to 7.5 km) [39]. The latter is important to cycling safety as it reduces cyclists' exposure to motor vehicles, especially for the vast number of short utilitarian bicycle trips travelled within urban areas [40]. In contrast to recreational cycling, utilitarian car trips can, for a large part, be exchanged for cycle trips.

A third aspect of travel behaviour concerns the safety in numbers phenomenon, which states that higher volumes of cyclists on the road reduce the risk of BMV crashes when the number of motor vehicles on the road is kept constant [16], an explanation consistent with expectancy theory [see e.g. 41]. Others have suggested that improvements in road infrastructure may provide an explanation [e.g. 42]. When more road users take up cycling, there will be a greater push for developments towards safer cycling infrastructure [30]. Note though that the phenomenon is also found in studies (including one Dutch study[43]) that statistically control infrastructure factors such as the presence of bicycle infrastructure [43, 44], thereby giving some support for the safety in numbers explanation.

A study comparing Dutch municipalities provides an indication of the relevance of these last two factors [45]. Using the results of this study it can be estimated that a modal shift resulting in a 7% higher bicycle modal share (corresponding to one Standard Deviation for Dutch municipalities and some 25% more bicycle kilometres per capita) would reduce the number of fatalities per billion bicycle kilometres by 10%. Road safety policies do not differ very much between Dutch municipalities, suggesting that a large part of this risk reduction is due to changes in bicycle modal share (reduced exposure to motorised vehicles when drivers shift to cycling) (the second explanation) and the safety in numbers phenomenon (the third explanation).

To summarise, network level separation (cycling through traffic-calmed areas and grade-separated intersections to cross distributor roads) and a high bicycle modal share both contribute to improved cycling safety. Both factors reduce the exposure to motorised vehicles. However, the former explains more of the variation in fatality rate amongst Dutch municipalities than the latter [24, 45].

4.2 Risk factors related to road user behaviour, infrastructure and vehicle design

4.2.1 Road user behaviour
Crash risk is also influenced by the behaviour of road users. Here we discuss the following aspects: speed choice, experience, training and assessment, legal liability, and safety measures to reduce risky behaviour. We compare these practices in the Netherlands with those in other countries, its main purpose being the identification of practices that might have contributed to greater cycle safety in the Netherlands.

Cycling speed
Concerning speed choice, Fyhri, Bjørnskau [46] distinguished two groups of cyclists with different risk profiles and riding speeds, i.e. a speed-happy group with lots of cycle equipment, including helmets, and a group of cyclists cycling slowly in regular clothes

without helmets. With operational speeds (excluding stops) between 16 and 18 km/h [47-49], the Dutch cycle more slowly than cyclists in most other countries. This may be related to the dominance of utilitarian trip motives (e.g. cyclists do not want to be suffering from the ill effects of over-exertion when they arrive at their workplace or school) and the broad overall composition of the cyclist population. Higher average operational speeds of between 18 and 26 km/h have been reported in the UK, US, and Canada where bicycle modal shares are much lower [50]. Higher cycling speeds have been found to be related to injury severity [51]. Low cycling speeds have been suggested as an explanation for lower injury rates among users of bicycle-sharing systems compared to private bicycle users [52]. Low cycling speeds allow car drivers more time to respond to cyclists at intersections [53]. Another aspect not mentioned in the literature may be that a lower cycling speed offers greater reaction time for cyclists to take action to avoid collisions. Although there is empirical support for the role of cycling speed, the available data and research do not allow for quantitative assessment of the effect of this behavioural factor.

Experience as a cyclist
The Dutch are experienced cyclists. Having learned to cycle at a young age, by the time they cycle independently, usually at around 12 years of age [18], they have developed the skills and capabilities to anticipate hazards fairly well. Furthermore, those who continue to cycle frequently throughout their lives will maintain their cycling skills. In addition, the experience of being a cyclist may help drivers anticipate cyclists. A study by Maas [54] indicated that, after statistically controlling for motor vehicle kilometres and age, motorists who cycle frequently are less likely to collide with cyclists. However, because of the small sample size these relationships were not statistically significant. We are not aware of any larger studies on this issue, but as it is often suggested that experience plays a role in drivers' hazard perception and anticipation [55], it is conceivable that this factor plays a role.

Education and training
A road safety education programme targeting primary school children has been in place since 1932, and became obligatory in 1959 [56]. Schools can take part in a theoretical examination that focuses on traffic rules, and also in a practical test of children's cycling skills on public roads. Currently, about half of the schools participate in the practical examination [57]. However, of the traffic education programmes that have been evaluated, the results show only minor positive effects [18]. Motorist training and examination is rather intensive in the Netherlands [13]. However, international reviews of evaluation studies suggest that formal basic driver training and examination is not related to drivers' crash rate after licensing [55, 58]. From this we are unable to conclude that education and training offer a valid explanation for the high level of cycling safety.

Legal liability
In the Netherlands, the legal liability of motorists involved in collisions with cyclists differs from that of many other countries [15]. Under a Dutch law introduced 1 January 1994, a motorist is held responsible for any collisions in which a child, a cyclist, or a pedestrian is injured. According to article 185, the driver is still liable for 50% of the damage if an adult non-motorised road user was at fault [59]. It has been stipulated that this law may have affected drivers' awareness and attitude towards cyclists [4]. As the law has not been evaluated for road safety, we fitted a linear regression line on the number of bicycle fatalities per billion bicycle kilometres (see Figure 3) with year (for the year by year risk decrease) and a dummy variable (equalling 0 between 1983 and 1993 and 1 between 1994 and 2003) to test the effect of the law. The model fit is good, indicated by an R^2 of 0.93. The standardised beta for the average year by year risk decrease is significant (Beta = -1.17;

p<0.001). However, the dummy variable for the introduction of the law indicates a higher rather than a lower risk (the rise was not statistically significant; Beta = 0.25; p = 0.07). Thus, the new liability law does not seem to be related to cycling safety, although this analysis is possibly too simplistic to draw firm conclusions.

Safety measures to reduce risky behaviour
Safety measures to combat deliberate risky behaviour, such as deterring alcohol use among cyclists or promoting the use of helmets, may play a role in greater cycling safety. Bicycle helmets seem to provide a small protective effect when the risk of injury to head, face or neck is viewed as a whole Elvik [60]. However, this does not explain the high level of cycling safety as Dutch cyclists are not obliged to wear helmets and rarely do so [61]. Alcohol use has a negative effect on both cyclists and drivers and increases the likelihood of crashes [62, 63]. Although forbidden, the Netherlands do not enforce the ban on alcohol use by cyclists [64]. Policies focused on driver behaviour such as campaigns and enforcement to reduce driving under the influence of alcohol and drugs are important. However, these measures do not differ much from those in other countries and do not explain differences between cycling safety in the Netherlands and other developed countries.

4.2.2 Road infrastructure

Bicycle paths
Over 80% of all police-reported fatal and severe BMV crashes in built-up areas occur on distributor roads where exposure to high-speed motor vehicles is greatest [24]. The *Homogeneity* principle, already mentioned in Section 4.1.1, suggests that cyclists should be separated from motorised traffic along distributor roads because speeds exceed 30 km/h. SWOV mentioned the *Homogeneity* principle as an explanation for the desirability of separated bicycle paths as early as the 1960s [65]. By 1965 the country had approximately 66,000 of paved roads and 6,000 km of bicycle paths [65, 66]. Since the 1960s the kilometres of roadway has doubled, however bicycle paths have increased six-fold, to 35,000 km in 2013 [67]. In Figure 6, the right-hand picture shows a physically separated bicycle path, the preferred option along distributor roads, while the left-hand picture shows bicycle lanes, the option that can be applied if space for a bicycle path is lacking [68]. Distributor roads without bicycle infrastructure are rare in the Netherlands.

Figure 6: Example of a bicycle path (right) and bicycle lane (left)

Although there are still problems at intersections, the overall safety effect of one-way bicycle paths on busy streets is positive [43, 69, 70]. This is not the case for the frequently implemented two-way bicycle paths, which, compared to one-way bicycle paths, have a two-fold elevated risk of BMV crashes at intersections. [43]. This is due to, in the case of right-hand driving, drivers coming from minor roads not expecting cyclists from the right [53]. Similarly, two-way bicycle paths increase the risk of BMV crashes at roundabouts [71], and of crashes with lorries [20]. The positive effects of two-way cycle paths compared to cycle lanes or no provision along distributor roads is offset by this problem. However, as around three-quarters of all cycle tracks are one-way tracks, we can still conclude that separated bicycle paths do contribute to the high level of cycling safety in the Netherlands.

Intersection treatments
Intersections are important because the majority of BMV crashes along distributor roads are concentrated at intersections [43, 70]. Speed reduction and a clearance between 2 and 5 m between the bicycle path and the carriageway improve cycling safety, see for example Figure 7 [43]. The latter is also important in the prevention of very severe crashes with right-turning trucks by keeping cyclists out of the blind spot on the trucks' passenger side [19, 20]. Similarly, speed reduction is associated with reduced injury severity [72]. To indicate the importance of these measures, it was estimated that speed-reducing measures that have been implemented at unsignalized intersections in the Netherlands have prevented some 2.5% of the total number of cyclist fatalities [24, 73].

Figure 7: Example of an intersection treatment: a speed hump and clearance of 5m between the bicycle path and distributor road [43]

Measures taken to prevent crashes at signalized intersections include advance stop lines, bike boxes and a pre-start for cycle traffic (where there are separate signals for cyclists) to make cyclists more visible [19, 20, 74], see Figure 8.

Figure 8: Example of a bike box (left) and a pre-start for cyclists, i.e. through cyclists have a green light while the light for right turning motor vehicles is still red (right)

4.2.3 Vehicles

The range of motor vehicle brands used in the Netherlands are roughly comparable to those used in other countries. The country does not have its own car manufacturing industry and most vehicle requirements are set at the European level. We expect that measures such as the close proximity mirror (mandatory since the 1980s) and open side underrun protection (mandatory for new lorries since 1995) improve cycling safety [20], but that they do not contribute to differences in cycling safety with other countries.

The basic design of bicycles have changed little over time and it is unlikely that differences between countries in this respect contribute to different fatality rates [75]. However, more specific characteristics like conspicuity measures may have an effect on the likelihood of BMV crashes. White front lights became obligatory in 1906; red rear lights in 1927; and rear, pedal and side reflectors in the 1970s and 1980s [66, 76, 77]. Use of bicycle lights is still being promoted and enforced [78], but with only about three-quarters of all cyclists using front lights, usage is at about the same level as in the 1970s [79, 80]. Small positive effects have been found for some of these visibility measures [76, 77], but the risk of a collision with a motor vehicle is still much higher in darkness than in daylight [64]. Also, the use does not seem very different from other countries.

To summarise, the most important risk factors contributing to the high level of cycling safety in the Netherlands are a low cycling speed, (one-way) bicycle paths and intersection treatments such as speed-reducing measures. The available data and research do not allow for quantitative assessment of these factors. The length of cycling experience may be an additional contributing factor, but this would need to be substantiated in future research.

5 DISCUSSION

This paper, structured according to a conceptual framework for road safety, explored the high level of cycling safety in the Netherlands. In line with the conceptual framework, we have found both travel behaviour and exposure (the upper part of the model) and risk factors (the lower part of the model) to contribute to the low cyclist fatality rate in the Netherlands and the country's impressive cycling safety improvement since the 1970s. The most critical factor related to travel behaviour and exposure to risk (to high speed motor vehicles) is 'network level separation'. Large traffic-calmed areas and a heavily used freeway network have reduced cyclists' exposure to high-speed motor vehicles. The high incidence of cycling is also beneficial to cycling safety. Important risk reducing factors are a low cycling speed, (one-way) bicycle paths and intersection treatments that reduce speed and increase visibility.

Instead of the distinction between exposure and risk according to the model, we could also distinguish between deliberate policies such as infrastructure for cyclists and the effects of the high levels of cycling. The results of our research suggest that since the 1970s, measures such as network level separation, (one-way) bicycle paths and intersection treatments contributed more to the large decrease in cyclists' fatality rate than the amount of bicycle use which grew only by 20% per capita. This would confirm concerns expressed by Bhatia and Wier [81] that policies aiming at increasing bicycle usage without accompanying safety measures may not result in desired cycling safety improvement. However, as the amount of cycling in the Netherlands in the 1970s was, from an international perspective, already high, this may have been at or well beyond the range in which the safety in numbers effect takes hold. Therefore, we cannot draw firm conclusions about the relative impact of different factors.

Other studies on the high level of cycling safety in the Netherlands were based on comparing conditions for cycling to those in other countries [e.g. 4, 14, 15]. Even though only limited attention was being given to the results of the effectiveness of safety measures in these studies, our results confirm several of their outcomes, i.e. the importance of traffic calming, bicycle paths, and intersection treatments [14, 15] as an explanation for the high level of cycling safety. In addition the current study stresses the importance of network design and the Dutch Sustainable Safety principles of Homogeneity and Functionality underlying Dutch practice. A new explanatory factor that has emerged from this study is that of low cycling speeds. This could be typical of countries with high levels of cycling, where utilitarian cycling is dominant. There are also a number of factors deemed important by other researchers which we could not substantiate in this study, i.e. comprehensive traffic education and training of both cyclists and motorists, and traffic regulations that favour cyclist and pedestrians, particularly legal liability. Education may however be important for countries without the long history of cycling that is evident in the Netherlands.

6 STUDY LIMITATIONS

Our study draws heavily on empirical research. The outcomes suggest that there are still research gaps that limit our ability to draw firm conclusions. For instance, it is conceivable the Dutch are more skilled as cyclists because they cycle a lot and learn to cycle at a young age, but empirical research is lacking. There is more support for the behavioural factor of low cycling speeds, but this line of research is still in its infancy. Other limitations are a lack of data, such as about infrastructure. Even if the impact of certain intersection treatments is known and positive, lack of data restricts our ability to aggregate their effects to the national level and quantitatively explain the country's high level of cycling safety.

An important limitation of the study is the exclusion of single-bicycle crashes that cause almost three-quarters of all serious injuries among hospitalised cyclists [25]. Current knowledge allows for some hypotheses such as a role of sufficiently wide and even road surfaces, (winter) maintenance and the visibility of obstacles to prevent of falls and obstacle collisions [82]. Future research could focus on the question of whether such factors explain the low risk of single-bicycle crashes in a country such as the Netherlands.

This study has given only little attention to the implementation of safety measures and the role played by various stakeholders. For instance, the national government enabled demonstration projects of bicycle routes and networks and their evaluation in terms of bicycle use and road safety [83, 84]. Another such initiative was the National Bicycle Master Plan which focussed on both encouraging cycling and improving safety between 1990 and 1996 [85] and led to the funding of many local measures and the publication of the first design manual specifically for bicycle facilities [86]. Nor have we examined the active involvement of NGOs such as associations representing cyclists (ANWB and the Cyclists' Union) or supporting road safety (the Dutch Road Safety Association), and of pressure groups such as "Stop de Kindermoord" ("Stop the Child Murder"). Future research could look at which factors were most important for policy implementation.

7 CONCLUSIONS

Since the 1970s, the Netherlands has achieved an 80% reduction in the number of cyclist fatalities and is now, together with Denmark, the safest country in which to ride a bicycle. Most of this achievement is attributable to road safety policies. The road hierarchy with large traffic-calmed areas where through traffic is kept out, a rough (coarse) distributor road network for motorised traffic, and a heavily used freeway network which shifts away motor vehicles from where cycling levels are high, are key contributing factors. Intersection treatments such as bike boxes are used to reduce the risk at distributor road intersections where encounters and potential conflicts with high-speed motor vehicles are concentrated. Other important behavioural factors are the relatively low speed of Dutch cyclists and the high incidence of bicycle usage and consequential greater awareness among drivers with cycling experience when they encounter cyclists.

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