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The safety of physically separated cycle tracks compared to marked cycle lanes and mixed traffic conditions in Amsterdam

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Bicycle infrastructure is utilised to improve cycling safety and encourage bicycle use as a sustainable and healthy transport mode. This study sets out to assess whether providing physically separated cycle tracks along distributor roads, as prescribed in Dutch design guidelines and the Sustainable Safety vision, yields the expected safety benefits for cyclists. Therefore the safety of physically separated cycle tracks is compared to marked or painted cycle lanes and to mixed traffic conditions at distributor roads with a speed limit of 50 km/h in Amsterdam in the Netherlands. The study also includes the presence of the risk factors curbside parking and trams. Since police records are known to underreport single bicycle crashes and other crashes without a motor vehicle involved, ambulance records are used in this study instead. Also, both motor vehicle volumes as well as cyclists counts are taken into account in the crash analysis. By doing so, this study aims to address two weaknesses of previous research, i.e. the lack of control for exposure of cyclists and the use of police recorded crashes which miss the majority of bicycle crashes without motor vehicles. Results show that, controlled for kilometres travelled by bicycle and by motor vehicle, 50-60% less bicycle crashes occur on distributor roads with cycle tracks compared to those with cycle lanes. Curbside parking and trams are related to an increased

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likelihood of bicycle crashes, a difference of a factor 2 and 1.7-2 respectively. The authors therefore recommend to favour physically separated cycle tracks over cycle lanes and to take out curbside parking from the cross section as this presents the possibility to introduce cycle tracks in existing cross sections and mitigate an important risk factor concurrently.

***Keywords**: cycling safety, road safety, bicycle crashes, bicycle infrastructure, bicycle tracks, cycle tracks, cycleway, bike track, bike lane, cycle lanes, risk factors, curbside parking, tramway, the Netherlands, Amsterdam.*

1. Introduction

Many governments are promoting cycling to increase physical activity, reduce emissions, and to decrease congestion (Khreis et al., 2016, Shaheen et al., 2010), but more cycling contributes to more injuries and deaths among cyclists due to traffic crashes (Stipdonk and Reurings, 2012). Road safety measures aimed at improving cycling safety are required to reduce the significant health burden resulting from bicycle crashes (European Commission, 2010). Combining cycling friendly policies with road safety policies can help to promote cycling, as a perceived lack of safety is a deterrent to start cycling (Fishman et al., 2012, Horton et al., 2007). Cycle tracks to physically separate cyclists from high-speed motor vehicle traffic is a key part of the Dutch Sustainable Safety approach and have been part of policies to encourage cycling and improve cycling safety (Wegman et al., 2012, Buehler and Pucher, 2012). However, literature on the safety impact of cycle tracks is inconclusive as studies suffer from a number of weaknesses such as lack of control for exposure (Elvik et al., 2009a, Mulvaney et al., 2015, Reynolds et al., 2009, Høye et al., 2015). Therefore this study sets out to test the hypothesis that physically separated cycle tracks are safer than marked or painted cycle lanes on the roadway and roads with mixed traffic conditions, while controlling for cycling exposure on the full network of distributor roads in Amsterdam, the Dutch capital city. Several risk factors are examined on their relation with bicycle crashes additionally to further increase knowledge on the safety of cycling infrastructure.

2. Literature

In this section we describe literature on physically separated cycle tracks and road safety. Section 2.1 addresses cycle tracks within the Safe Systems Approach, in particular Sustainable Safety, the key vision in Dutch road safety policy over the past decades (Section 2.1). Section 2.2 describes to what degree cycle tracks have been found to affect volumes of cyclists to explore the importance of controlling for exposure. Section 2.3 and 2.4 describe international literature, respectively Dutch literature on the impact of cycle tracks on cycling safety. Section 2.5 summarizes the research gabs.

2.1 Cycle tracks within the Safe Systems Approach

Dutch road safety policy is founded on the Sustainable Safety vision which was introduced at the beginning of the nineties (Koornstra et al., 1992, Wegman et al., 2008). Two of its key principles are Homogeneity and Functionality. Functionality refers to classification of roads in a hierarchical road network. Homogeneity implies that differences in speed, direction, and mass should not be too large. Physically separated cycle tracks along roads with speed limits of 50 km/h or higher are needed to prevent speed and mass differences between cyclists and heavy motorised vehicles that may cause fatal injuries in the event of a crash. Agreement on implementation of the vision was reached in 1998, resulting in the development of a hierarchical road classification by which Dutch roads are classified as *access* roads, *distributor* roads, or *through* roads (Weijermars and Wegman, 2011). Table 1 lists the speed limits and the location of cyclists for the three classes of road. Parking on or along the carriageway is the standard for access roads. This solution is not preferable at higher speeds because of the speed difference with other traffic but Dutch guidelines do not strictly advise against application on 50 km/h roads.

Table 1. Road classification and speed limits in the Netherlands

Road classes	Speed limits in urban areas	Location of cyclists
Access roads	30 km/h	Mixed with other traffic
Distributor roads	50 or 70 km/h	Physically separated from motorised traffic by cycle tracks or visually by cycle lanes if the former is not feasible
Through roads	100 or 120 km/h	Cycling not allowed

2.2 Impact of cycle tracks on the amount of cycling

Knowledge of the impact of bicycle infrastructure is needed to examine whether changes in crash frequency after installing physically separated cycle tracks or marked or painted cycle lanes are due altered volumes of cyclists and/or changed crash risk. Both modal choice (cycling participation) and route choice may change by changing the infrastructure. Review studies on the impact of cycling infrastructure on cycling participation show a lack of before and after evaluations (Heinen et al., 2010, Pucher et al., 2010, Scheepers et al., 2014). A well conducted evaluation by Barnes and Thompson (2006) suggests an increased bicycle mode share in areas where on-street cycle lanes and standalone cycle tracks (of about an equal length) were installed. A US correlational study showed each additional mile of cycle lane per square mile to be associated with an increase of approximately one percentage point bicycle modal share (Dill and Carr, 2003, Pucher et al., 2010). In a study in Copenhagen (an area with a high bicycle modal share) it was found that average daily cycle traffic on streets equipped with cycle tracks increased by around 19%, while motorised traffic decreased by 10% (Jensen, 2006). These results suggest that cycle tracks affected both modal choice and route choice. Revealed preference research on route choice including Dutch research (Gommers and Bovy, 1987) show a preference for routes along roads with cycle lanes and separated cycle tracks, although their contribution to decision making is less important than distance and time (Broach et al., 2012, Gommers and Bovy, 1987, Howard and Burns, 2001, Menghini et al., 2010). Therefore we can conclude that before-after and correlational studies on the road safety impact of cycle tracks and lanes need to control for potentially changed amounts of cycling to yield reliable results.

2.3 International literature on the effects of cycle tracks

This section describes international literature on paved cycle tracks physically separated from the carriageway for motor vehicles. We exclude studies on facilities shared by pedestrians and bicyclists or studies combining cycle tracks and visually marked cycle lanes (e.g. Rodgers, 1997). Elvik et al. (2009a) suggest that a decrease of crashes along roads sections could be offset by an increase of crashes at junctions. They found it hard to draw final conclusions however on the net safety impact of cycle tracks because "most studies have not controlled for the number of cyclists". Reynolds et al. (2009) reviewed studies published in scientific journals. The authors conclude that literature on transportation infrastructure and cyclist safety is limited by the incomplete range of facilities studied and difficulties in controlling for exposure to risk. Track

The review by Thomas and DeRobertis (2013) focused specifically on the safety of urban cycle tracks and also included grey literature based on studies that controlled for exposure. They identified two Canadian studies in Montreal and Toronto (Lusk et al., 2011, Teschke et al., 2012) which reported a reduced risks of 0.11 to 0.72. From their review study, Thomas and DeRobertis (2013) conclude that, when effective intersection treatments are employed, constructing cycle tracks on busy streets reduces collisions and injuries. The outcomes also indicate that one-way cycle tracks are generally safer at intersections than two-way tracks (see also Methorst et al., 2017) and that providing a speed hump, to lower vehicle turning speeds reduces the risk of collisions and injury severity (Gårder et al., 1998, see also Schepers et al., 2011).

The Cochrane review by Mulvaney et al. (2015) on cycling infrastructure included two studies on cycle tracks that met their inclusion criteria such as a controlled before-after research design (Agerholm et al., 2008, Gårder et al., 1998). A non-significant increase of cyclist injury collisions after installing cycle tracks was found by Agerholm et al. (2008) but this Danish study did not control for exposure. Gårder et al. (1998) examined the safety effects of raised cycle crossings that cross minor roads. Accounting for an increase over 50% of the number of cyclists at the treated locations the authors conclude that “the most likely effect of raising the cycle crossing is a risk reduction of 30%” (Gårder et al., 1998). The results of the latter indicate the safety benefits of speed reduction rather than the overall impact of cycle tracks. In a before-after study in Toronto, Ling et al. (2020) recently found 2.1 times more police recorded bicycle-motor vehicle crashes after cycle tracks were installed while the volume of cyclists rose by a factor of 2.6.

2.4 Dutch literature on the effects of cycle tracks within urban areas

Welleman and Dijkstra (1988) studied 145 road segments between crossings of distributor roads, i.e. between 290 major junctions. These road segments had an average annual daily traffic of some 10,000 motor vehicles and contained over 700 crossings with minor roads. The study controlled for the number of cyclists, mopeds and motor vehicles and analysed the association with number of police reported injury crashes between 1973 and 1977 per passing cyclist (for intersections) or per kilometre cycled (for road sections). As shown in Figure 1, stretches of road including intersections with minor (access) roads, had the lowest crash rate when physically separated cycle tracks were present, while at major intersections those with cycle tracks had the highest crash rate. Furthermore, road segments with cycle tracks had lower crash rates than cycle lanes at both road sections (excluding minor intersections) and at minor intersections, where minor intersection in the Netherlands commonly entail unsignalised intersections between distributor and access roads with priority for traffic on the distributor roads. The results for those intersections were substantiated in a more recent study on police reported bicycle-motor vehicle crashes by Schepers et al. (2011) who also controlled for volumes of cyclists and motor vehicles. Owing to physical separation at road sections it is highly likely that the safety benefits of cycle tracks along road sections reported by Welleman and Dijkstra (1988) are still valid.

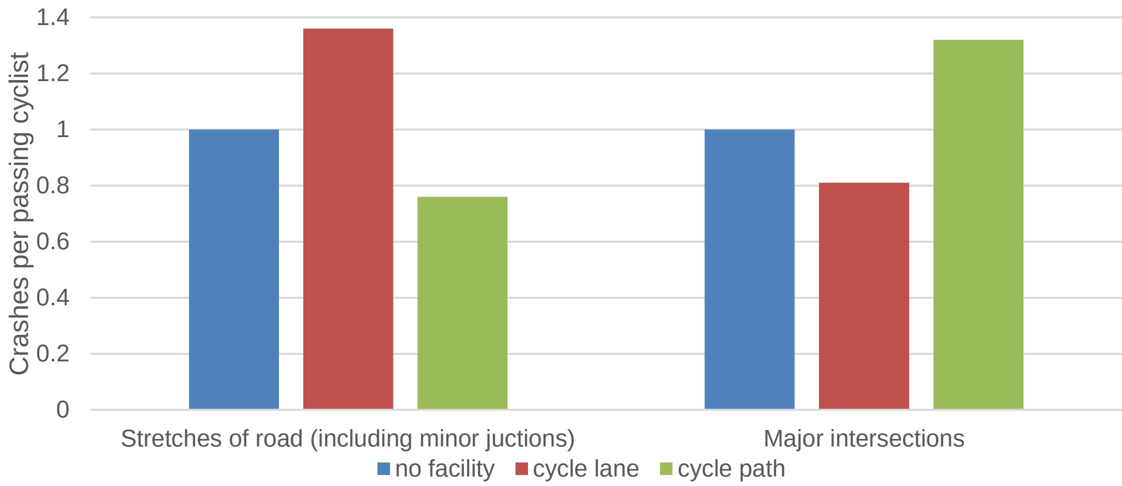

Figure 1. Crashes per passing cyclist at Dutch distributor roads according to (Welleman and Dijkstra, 1988)

Intersections of distributor roads In the 1970’s –the study period of the Welleman and Dijkstra study– were mostly signalised and to a lesser extend unsignalised. Signalised intersections and roundabouts are the most common solutions for crossings of distributor roads in current Dutch practice. Dijkstra (2004) summarised Dutch research on roundabouts. While the results of international research on cycling safety at roundabouts is inconsistent (see e.g. Brüde and Larsson, 2000, Daniels et al., 2009, Sakshaug et al., 2010), the results of Dutch studies suggest converting intersections to roundabouts reduces crashes with cyclists and mopeds by some 60% (Van Minnen, 1990). Roundabouts with higher volumes of motor vehicles (over 4,000 passing motor vehicles per day) are substantially safer with cycle tracks compared to cycle lanes, i.e. a threefold lower crash rate (Van Minnen, 1995). The study did not address roundabouts with mixed traffic. The conversion of major intersections to roundabouts over the past decades (Weijermars and Wegman, 2011) may have improved the average level of safety at crossings of distributor roads compared to the study period of the Welleman and Dijkstra (1988) study.

To put the results for intersection crashes in perspective, a study by Schepers and Voorham (2010) suggests the following distribution of bicycle - motor vehicle crashes at intersections of distributor roads within urban areas: 70% at priority intersection (mostly minor junctions), 23% at signalised intersections, and 7% at roundabouts (the latter two categories being mainly crossings of distributor roads).

2.5 Research gaps and goals of the current study

The largest Dutch study by Welleman and Dijkstra (1988) may be outdated. The 1973-1977 study period of the Welleman and Dijkstra (1988) study preceded measures introduced to implement the Sustainable Safety vision over the past decades leading for instance to conversion of major intersections to roundabouts (Weijermars and Wegman, 2011) and the measure to move mopeds (with a legal speed limit of 45 km/h) from the cycle track to the roadway. This study aims to assess whether the standard of providing separated cycle tracks along distributor roads in Dutch guidelines and the Sustainable Safety vision yielded the expected safety benefits for cyclists. This study aims to answer this question while addressing two weaknesses of previous research, i.e. the lack of control for exposure and the use of police recorded crashes which miss the majority of bicycle crashes without motor vehicles which are causing most serious injuries among cyclists (Mulvaney et al., 2015, Schepers et al., 2015, Weijermars et al., 2016).

Furthermore this study includes the presence of parking on or along the carriageway. Previous research suggests that on-street parking appears to be a hazard to cyclists due to the potential of having a car door open directly in a cyclist's path (DiGioia et al., 2017). Also, parking manoeuvres can be dangerous for cyclist directly as the parking car will cross the cyclists trajectory and indirectly due to an evasive manoeuvre from a cyclist for a car leaving the parking lot, which may lead the cyclist onto a car trajectory on the roadway. Furthermore, parked cars may cause sight obstructions of cyclists on cycle tracks. The distance between the carriageway and cycle track moves the cyclist further away from the centre of the driver’s field of view and a cyclist being visually covered by parked cars near intersections would add to the risk of being noticed too late. The impact of on-street parking has not been widely researched however (Reynolds et al., 2009). Finally, the presence of tramways is included in this study, as the research is carried out in Amsterdam, where the presence of tramways has a major impact on the layout of the street and the use of the street. A bicycle wheel may be caught in the flangeway at tramway crossings causing loss of control, for instance when cyclists approach a tramrails crossing at a low angle (Shah et al., 2020, Ling et al., 2017). Pedestrian activity around tram stops may increase the risk of bicycle-pedestrian crashes (Vandenbulcke et al., 2014). An indirect effect may be that adding tram rails reduces the space for sufficiently wide bicycle infrastructure.

3. Data

As the Sustainable Safety vision and Dutch guidelines favour application of physically separated cycle tracks along distributor roads, this study is focused on roads with a 50 km/h speed limit. This speed limit is most common for distributor roads within built-up (urban) areas. This study includes all distributor roads with a speed limit of 50 km/h and a length of at least 100 m, except those that did not meet criteria described in the remaining sections. Crash data, traffic volumes and road characteristics were collected for these roads in Amsterdam. For the analysis all data were aggregated to street level. The following three sections describe each data type.

3.1 Crash data

Bicycle crashes without motor vehicles are underreported by the police (Langley et al., 2003, Schepers et al., 2017). To assess the impact of infrastructure on both bicycle crashes with and without motor vehicles this study used crashes recorded by ambulance services. In the years 2009 through 2012 ambulances registered a total of 9840 traffic crashes on the 622 municipal roads of Amsterdam with a speed limit of 50 km/h. The level of precision for which the location of the crashes were registered differed amongst the crash records and included address, zip code and street names. As street names could be derived as a common location registration for most crashes, streets were used as the study units.

3.2 Traffic volumes

Traffic volume estimates were used for motor vehicles and cyclists on 50 km/h roads. The municipality of Amsterdam supplied 2010 average annual daily traffic (AADT) estimates per road section based on their traffic model 'Traffic Monitoring Amsterdam'. Volumes per section were averaged to estimate the AADT per street. The results of the 2015 and 2016 "Bicycle count week" ("Fietstelweek") (The Urban Future, 2020) were used to estimate volumes of cyclists per street . A consortium of companies and NGO's recruited cyclists to install an app on their Smart phone and track their routes. The number of Amsterdam participants amounted to 2,508 in 2015 and 2,244 in 2016, yielding a total of 65,656 bicycle rides covering a distance of 241,182 km. From the Bicycle count week (BCW) the total number of rides per street for both periods was determined.

To check the validity of cyclist counts by the Bicycle count week as a representative exposure variable, correlation tests have been performed on manual counts, counts from detector loops and Bicycle week counts. On 108 locations, four 7 min (on average) manual counts were conducted during rush hour (morning and evening) within a 5-6 week period. Detector loop counts were acquired from these locations for full rush hour periods (7:00-9:00, 16:00-18:00). Spearman rank correlations between manual counts and detector loop counts were as high as 0.9 (Wijlhuizen et al., 2016). Further analyses showed a Pearson correlation of 0.78 between manual counts and the Bicycle count week.

A portion of the streets included in the dataset contained 0 counts for motor vehicles and cyclists. As true zeros are not expected to exist in reality and the regression model is not able to cope with these zero's, motor vehicles were set to a minimum of 30 and cyclist counts to a minimum of 3.

3.3 Road characteristics of 50 km/h roads

Road characteristics were collected by trained assessors using Cyclomedia images recorded in the years 2015 and 2016 (CycloMedia, 2020), see Figure 2 for a typical example of such an image.

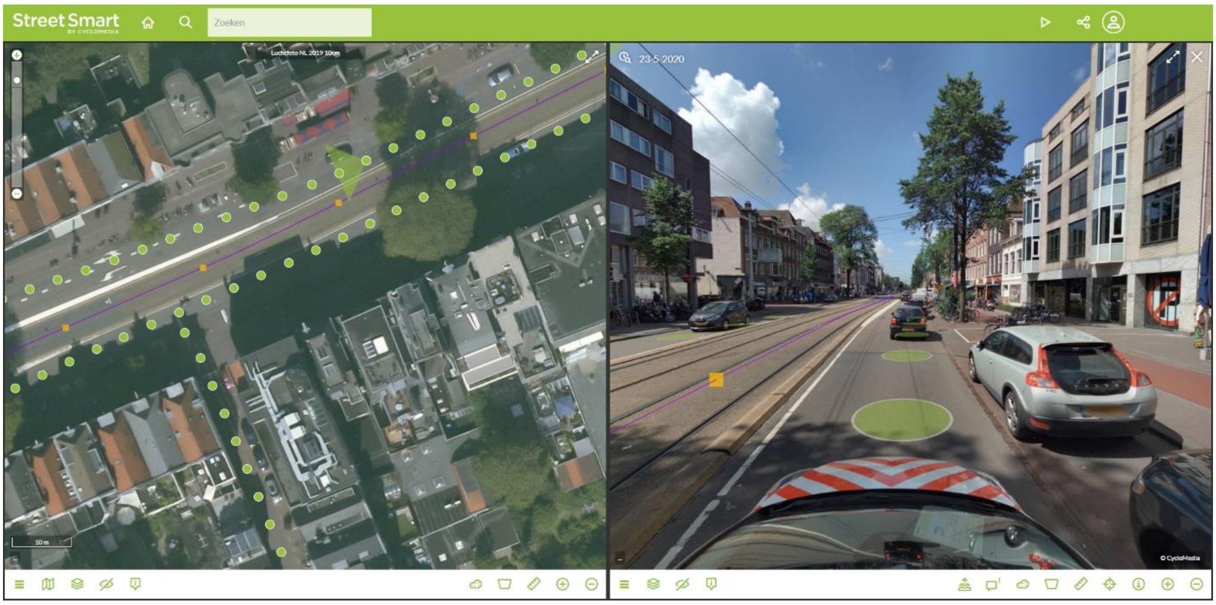

Figure 2. Road imagery example available to assessors (source: Cyclomedia - Street Smart)

Streets were divided in 25m segments. For each 25m segment the assessors recorded over 50 road characteristics, among which cycling infrastructure, parking facilities, intersections and tram rails. This extensive data collection effort was part of the development of NSI (Network Safety Index) in Amsterdam (Wijlhuizen et al., 2017) and CycleRAP (Wijlhuizen et al., 2014), an extended version of the bicycle module within the European Road Assessment Programme, EuroRAP (EuroRAP, 2020). The following classification of road characteristics for each 25m segment were used in the current study:

- The presence of bicycle infrastructure, for examples see Figure 3:
  - Physically separated cycle track along one or both sides of the road. This category includes both unidirectional and bidirectional cycle tracks.
  - Visually marked cycle lane along one or both sides of the road. This infrastructure category comprises visually marked lanes without legal status, so called advisory cycle lanes, and mandatory visually marked lanes with a legal status (Parkin, 2018). Mandatory cycles lanes in the Netherlands are marked by a bicycle symbol on the cycle lane surface.
  - Combination of a cycle track on one side of the road and a cycle lane on the opposite side of the road.
  - Mixed traffic conditions: cyclists mix with motorised traffic on the roadway.
- The presence of kerbside parking such as shown in Figure 2 and 3.
- The presence of tram rails (often on the carriageway in Amsterdam) such as in Figure 2.
- The presence and type of intersections
  - Intersection with a distributor road (both streets have a 50 km/h speed limit)
  - Intersection with a collector road (side street is a collector road with a 15 or 30 km/h speed limit)

Figure 3. *Cycling infrastructure facilities examples, showing situations with and without curbside parking (source: Cyclomedia - Street Smart)*

Aggregation of road data
Since the crash data is aggregated to the number of crashes per street, the road characteristics data also needs to be aggregated to the street level. Curbside parking is aggregated to the streetlevel as "present" if curbside parking is present somewhere in the street. Tramways are aggregated to the streetlevel as "present" if trams are present somewhere in the street. Intersections are aggregated to densities; number of intersection divided by street length. Bicycle infrastructure is aggregated to street level as follows:

- Cycle track: At least 80% of the 25m segments have cycle tracks along one or both sides
- Cycle lane: At least 80% of the 25m segments have cycle lanes along one or both sides

- Combined facilities: At least 80% of the 25m segments have a combination of cycle tracks and cycle lanes
- Mixed traffic conditions (cyclist on the roadway): At least 80% has no facilities for cyclist and cyclist mix with other traffic on the roadway
- Mixed facilities: Mix of facilities; none of the other categories scores 80% or higher

3.4 Subsets based on traffic volumes

The speed limit of 50 km/h was the main criterium for road selection. The speed limit of 50 km/h is the standard for distributor roads that have a function to distribute traffic from higher ranked through roads to lower ranked access roads, i.e. 'minor roads'. One would therefore expect these roads to carry relatively high volumes of motor vehicles. However, our results indicated the presence of 50 km/h roads with fairly low amounts of motor traffic. As the relationship between road characteristics and crash likelihood may depend on whether a road carries a substantial amount of motor traffic we conduct analyses for both all 50 km/h roads in our sample and for 50 km/h roads carrying over 3,000 motor vehicles per day and where cyclists were observed in the Bicycle count week. For instance, we expect mixing cyclists and motor vehicles on the carriageway is more common on low volume roads than on high volume roads and this type of road design may also have a different impact on low versus high volume roads.

3.5 Further street selection criteria

Some distributor roads have parallel access roads with a speed limit of 30 km/h. If so, cyclists are obligated to use the parallel access roads where they will mix with motorised traffic, or if present use a cycle track. Because of the limited amount of streets with this configuration and difficulties with crash data allocation on these streets, this configuration is excluded from this study. Also, distributor roads with closed access for cyclists, multiple speed limits and missing data are excluded from this study.

4. Methodology

4.1 Model framework

To assess the contribution to bicycle crash risk of different cycling infrastructure types, parking facilities, intersection densities and tramways, crash prediction models were fitted by the application of negative binomial regression models with a log link function (for details, see Hilbe, 2011), using the SPSS 25 GENLIN procedure. Negative Binomial (NB) regression models serve as statistical approximations to crash processes and are able to handle the common issue of overdispersion, i.e. the variance exceeding the mean (Lord et al., 2005). Using NB regression this study related crashes to traffic volumes and afore mentioned road characteristics, while street length was added as an offset variable. The models can be specified as followed:

$$E(Y) = \alpha Q_{mv}^{\beta_1} Q_c^{\beta_2} L^{\gamma} e^{\Sigma \delta_j x_j} \quad (1)$$

where:
$E(Y)$: expected number of crashes, or expected crash frequency
α: constant (exponent of the intercept)
Q_{mv}: annual average daily traffic flow (AADT) of motor vehicles
Q_c: cyclist counts (from the 'Fietstelweek')
L: Street length with γ = 1
x_j (1,2,…, n): risk factors cycling and parking facilities
β , γ, δ_j: model parameters of the different variables

According to a review by Elvik and Bjørnskau (2017) this equation is the most commonly applied form for bicycle crash models comprising variables for the volume of both cycle and motor vehicle traffic.

Akaike information criterion (AICc) was used to compare the quality between different models on the same dataset. Exposure variables and risk factors were added in two steps to check if the model improved from the null model (only intercept), to a model only containing the exposure variables, to the full model containing both exposure variables and risk factors.

The presence of tramways is added as an additional risk factor to the model as tramways have a significant impact on the layout of the street, the use of the street and are expected to have a significant impact on crash risk in streets. To correct for the differences between streets with and without tramways, tramways are included in the model as a risk factor.

4.2 Sensitivity to interactions

In the full model, all variables are assumed to be independent. Some possible crash mechanisms may however cause interactions between the independent variables and cycling crashes. For instance, the risk of cyclist crashes at two roads with a similar flow of cyclists could differ if the one carries few motor vehicles while the other carries a heavy traffic flow of motor vehicles. Also, crash mechanisms may differ for curbside parking along different cycling infrastructure types. To test if these interactions play an important role in the crash likelihood of cyclists and may increase the model performance, these interactions are tested in separate regression analysis. As interactions in regression models can lead to collinearity (Bijleveld and Commandeur, 2012), all continues variables were centred to their means to counter collinearity due to interactions before running the regression analysis on the possible interactions.

5. Results

5.1 Main results

Based on criteria described in chapter 0, two datasets were compiled for the analyses. The dataset for model 1 contained 256 streets, from which a subset was taken containing 151 streets for model 2 (over 3,000 motor vehicles per day). Descriptive statistics for both datasets are presented in Table 2.

Table 2. Descriptive statistics for the selection of roads for the datasets of model 1 (all roads) and 2 (streets with minimum traffic flows of Qv > 3000 and Qc > 0)

Variable	Dataset Model	N	min*	max*	mean *	median	IQR	st.dev.*
Length [m] (offset)	1	256	100 (4.6)	2375 (7.8)	462 (5.8)	325 (5.8)	400 (1.2)	422 (0.8)
	2	151	100 (4.6)	2375 (7.8)	525 (6)	375	400	450 (0.8)
Qmv (motor vehicles AADT)	1	256	30 (3.4)	31906 (10.4)	5644 (7.4)	4321 (8.4)	8034 (2.4)	5919 (2.2)
	2	151	2986 (8)	31906 (10.37)	9064 (9)	8229	6433	5505 (0.5)
Qc (Bicycle count week cyclist count)	1	256	3 (1.1)	635 (6.5)	80 (3.4)	41 (3.7)	113 (3.0)	100 (1.6)
	2	151	3 (1.1)	635 (6.5)	124 (4.4)	104	137	108 (1.1)
Access road intersection density	1	256	0.0000	0.0242	0.0041	0.0027	0.0061	0.0047
	2	151	0.0000	0.2200	0.0053	0.0047	0.0061	0.0044
Distributor road intersection density	1	256	0.0000	0.0146	0.0039	0.0032	0.0030	0.0027
	2	151	0.0000	0.0150	0.0034	0.0031	0.0023	0.0024
Mixed facilities	1	22 (9%)						
	2	17 (11%)						
Mixed traffic conditions	1	98 (38%)						
	2	21 (14%)						
Combined facilities	1	3 (1%)						
	2	3 (2%)						
Cycle lane	1	31 (12%)						
	2	22 (15%)						
Cycle track (reference)	1	102 (40%)						
	2	88 (58%)						
Curbside parking	1	181 (70%)						
	2	109 (68%)						
No curbside parking (reference)	1	75 (30%)						
	2	42 (32%)						
Tramway	1	53 (21%)						
	2	48 (32%)						
No Tramway (reference)	1	203 (79%)						
	2	103 (68%)						

* values between brackets are descriptives from log transformed data

The descriptive statistics from the two datasets show that besides the difference in the distribution of traffic flows, there is a clear differences in the share of bicycle infrastructure types. A decrease in the share of mixed traffic conditions and an increase in the share of physically separated cycle tracks can be observed, showing that traffic volumes and the presence cycling infrastructure facilities are related.

The stepwise approach to the regression analysis showed that model fit, as shown by the AICc, improved by adding the exposure variables and adding the risk factors and accordingly this full model is used in the remainder of this section. Results from model 1 on the full dataset are shown in Table 3.

Table 3. NB regression analysis on bicycle crashes: Results model 1 on the complete selection of 50 km/h 256 streets

Parameter	β*	Std. Error	95% Profile Likelihood Confidence Interval		
			Lower	Upper	Sig.
(Intercept)	-11.223	0.6363	-12.522	-10.018	0.000
Length (offset)	1	-	-	-	-
Qv (motor vehicle aadt)	0.359	0.0736	0.219	0.508	**0.000**
Qc (bicycle week cyclist count)	0.664	0.0783	0.510	0.819	**0.000**
Mixed facilities	0.295	0.2434	-0.170	0.792	0.226
Mixed traffic conditions	0.258	0.2318	-0.191	0.722	0.266
Combined facilities	0.267	0.5702	-0.757	1.553	0.640
Cycle lane	0.627 (1.87)	0.2255	0.192	1.083	**0.005**
Cycle track (reference)	0[a]				
Curbside parking	0.674 (1.96)	0.2008	0.277	1.068	**0.001**
No curbside parking (reference)	0[a]				
Access road intersection density	24.720	19.9820	-14.708	64.195	0.216
Distributor road intersection density	52.622	33.7387	-13.211	119.863	0.119
Tramway	0.549 (1.73)	0.1796	0.195	0.905	**0.002**
No Tramway (reference)	0[a]				
(Negative binomial)	0.765	0.1042	0.585	1.002	

* exponents are shown between brackets for significant model parameters for nominal variables

The results show that cycle lanes incur a higher risk on cyclist crashes compared to cycle tracks by a factor 1.9 on street level (intersections and road sections included). The results also show that both traffic flow variables significantly contribute to crash likelihood. This suggests that separate cycle tracks clearly contribute to cyclist safety and are a safer option than cycle lanes.

Further results are that both the presence of tramways and curbside parking are associated with an increased risk of cyclist crashes of a factor 1.7 and 2.0 compared to streets without tramways and parking.

The absence of cycling facilities, or mixed traffic conditions, did not show statistically significant results from the full model on all 256 streets. It was hypothesised that this could be due to different use of streets with low traffic flow and a relatively high share of streets with mixed traffic conditions amongst streets with low traffic flow, compared to the rest of the population of 50 km/h roads. Therefore a subset of streets carrying at least 3,000 motor vehicles per day was created, see Table 2. The full model results for the subset of 151 streets are shown in Table 4.

It should be noted that these results are correlations and do not necessarily reflect causation, which is the nature of a comparative regression analysis with GLM techniques.

Table 4. NB regression analysis on bicycle crashes: Results model 2 on a subset of 151 50 km/h streets with minimum traffic flows of Qv > 3000 and Qc > 0

Parameter	β*	Std. Error	95% Profile Likelihood Confidence Interval Lower	Upper	Sig.
(Intercept)	-11.849	1.6611	-15.154	-8.589	0.000
Length (offset)	1	-	-	-	-
Qv (motor vehicle aadt)	0.442	0.1878	0.074	0.816	**0.018**
Qc (bicycle week cyclist count)	0.611	0.0994	0.412	0.805	**0.000**
Mixed facilities	0.301	0.2573	-0.190	0.830	0.243
Mixed traffic conditions	0.495 (1.64)	0.2873	-0.058	1.077	*0.085*
Combined facilities	0.388	0.5810	-0.662	1.688	0.504
Cycle lane	0.485 (1.62)	0.2418	0.019	0.976	**0.045**
Cycle track (reference)	0				
Curbside parking	0.678 (1.97)	0.2279	0.228	1.127	**0.003**
No curbside parking (reference)	0				
Access road instersection density	17.155	23.1813	-28.599	63.018	0.459
Distribitor road intersection density	71.073	41.8936	-9.238	156.526	*0.090*
Tramway	0.686 (1.98)	0.1963	0.301	1.078	0.000
No Tramway (reference)	0				
(Negative binomial)	0.752	0.1092	0.566	1.004	

* exponents are shown between brackets for significant model parameters for nominal variables

The results tentatively indicate (p-value .09) an increased crash risk on streets with mixed traffic conditions of a factor 1.64 compared to streets with cycle tracks. This again suggests that cycle tracks contribute to the safety of cyclists. However, these results are not as robust as they don't comply to the generally accepted rule of 5% uncertainty ($p < 0.05$). The risk factor for cycle lanes is somewhat lower with a factor of 1.6 compared to the full model 1 results. There does not seem to be a difference in crash risk between cycle lanes and no cycling facilities.

It should again be noted that these results are correlations and do not necessarily reflect causation, which is the nature of a comparative regression analysis with GLM techniques.

5.2 Sensitivity analysis results
Several possible interactions were tested between exposure variables, cycling infrastructure types and curbside parking, as presented in section 4.2. None of the tested interactions proved to contribute to the model performance. Of main interest was the interaction curbside parking to cycling infrastructure types. Also no significant correlations were found between these variables. This suggests that curbside parking increases the risk of cyclist crashes along different cycling infrastructure types, for instance both along roads with cycle tracks as along those with marked cycle lanes.

6. Discussion

6.1 Discussion of results
Previous research was inconclusive on the safety effects of physically separated cycle tracks (see for instance Elvik et al., 2009b, Mulvaney et al., 2015, Usami and Ammari, 2017, Høye et al., 2015), while measures are needed to reduce the substantial health burden resulting from road crashes among cyclists. A major limitation in current international literature leading to this uncertainty is

the lack of control for the exposure of cyclists and use of police records that exclude bicycle crashes without motor vehicles. This study aims to increase our understanding of the effectiveness of cycle tracks by effectively controlling for the exposure of cyclists and by the use of ambulance records which in the Netherlands contain a better registration of cyclist crashes than police records.

This study shows cycle tracks to be an effective measure against bicycle crashes compared to cycle lanes, by the identified correlations from our model results. This is in accordance with earlier Dutch research by Welleman and Dijkstra (1988) and a more recent study of Schepers et al. (2011) about unsignalised intersections. Furthermore the results seem to suggest that there is no benefit for cycle lanes over mixed traffic, in terms of crash likelihood, which is in line with the results of Welleman and Dijkstra (1988). Results also tentatively indicate cycle tracks to be safer than mixed traffic conditions along roads with an AADT over 3,000 on a street level (including major intersections). This result is not statistically significant as the significance test only reached a p-value of 0.09. However, Welleman and Dijkstra (1988) found similar results on road sections between major intersections (including minor intersections). Combined with the model results and previous findings, the improvement in model 2 over model 1 on a 40% smaller subset of streets suggest the exclusion of streets with very low traffic volumes to be justifiable and that a lack of statistical significance might be attributed to a small sample set. We recommend to conduct further research to compare mixed traffic conditions with cycle tracks and cycle lanes to gain more certainty over the safety differences and the size of the impact. Furthermore, we recommend for further analysis to exclude streets with very low traffic flows.

Another point of uncertainty about the effects of cycle tracks on cycling crashes, in both Dutch and international literature, is how the crash likelihood between road sections and intersections balance out. As this study analysed the effects on a street level, including intersections with both access and distributor roads, the effects can be interpreted as a nett effect. In other words, even though cycle tracks may locally adversely affect the crash likelihood at (major) intersections, the overall effect of cycle tracks is still found to be positive.

Furthermore this study shows curbside parking to be an important risk factor, as twice as many crashes are expected on streets with curbside parking compared to streets without curbside parking. It was examined by including interaction terms in the model if the safety effects differed for curbside parking along different cycling infrastructure types. No differences could however be found as the interaction terms were not statistically significant, suggesting a general effect of parking along distributor roads for streets with cycle tracks, cycle lanes and mixed traffic conditions alike. Still it is expected that crash mechanisms for cycle tracks, cycle lanes and mixed traffic conditions with respect to curbside parking differ. While dooring and parking manoeuvres are expected to contribute to a higher crash likelihood on streets with mixed traffic conditions and cycle lanes, sight obstructions due to parked cars near intersections and extra pedestrian crossings are expected to affect crash risks on streets with cycle tracks. Further research is recommended to study the safety effects and mechanisms of crashes at locations with parking along streets. Crash mechanisms and possible mitigating measures are less obvious for different combinations of cycling infrastructure types and parking facilities.

6.2 Transferability of results

As this study was conducted in the city of Amsterdam only, the results may not be transferable to other cities, especially those with lower volumes of cyclists. It is recommended to extend the analysis to other cities to check whether results can be replicated and conclusions can be strengthened. Similarly, such research is needed to examine whether the results are transferable to other countries because both the Netherlands and Amsterdam are known for their high levels of cycling participation (Gemeente Amsterdam, 2017).

Important to mention is that this study reflects on the effects to bicycle crashes. Riding speeds and crash risk hardly differ between e-bikes and classic bicycles (Schepers et al., 2020), but riding speeds on light-mopeds exceed those on e-bikes and bicycles by more than 10 km/h while mopeds ride even faster than light-mopeds (Dufec, 2015). The likelihood of moped and light-moped riders to get involved in severe or fatal crashes is markedly higher than likelihood among cyclists (SWOV, 2017). The effects of cycle tracks may also differ for moped and light-moped riders. Research by Welleman and Dijkstra (1988) and Agerholm et al. (2008) suggest that for mopeds, the use of cycle track poses a high safety risk, especially on intersections. Moving mopeds from cycle tracks to the roadway to mix with other motor vehicles proved to strongly decrease crashes in the Netherlands (van Loon et al., 2001). The same could be true for speed pedelecs (electric motor supported bicycles with pedal assistance up to 45km/h in Europe), because speed-pedelec riders exceed the speeds of cyclists to a similar degree as moped riders (Stelling et al., 2017). This means that the impact on road safety is likely to be less favourable in case mopeds and speed-pedelecs are allowed to use cycle tracks.

6.3 Policy recommendations
Investing in road safety measures can help decrease the health burden resulting from crashes among cyclists and at the same time help to promote cycling. Separating cyclists from motor vehicles by implementing separate cycle tracks has been the standard on distributor roads in the Netherlands, driven by the Dutch Sustainable Safety approach The results of this study suggests that this policy has helped to improve road safety for cyclists. The authors recommend to favour physically separate cycle tracks over cycle lanes, as cycle tracks are related to a lower likelihood of cyclist crashes and as no benefit can be found for cycle lanes over mixed traffic conditions. Furthermore, curbside parking along cycling facilities may cause cycling crashes due to dooring and sight obstruction of cyclists on cycle tracks close to intersections. As parking facilities along cycling facilities are indeed found to increase the likelihood of cycling crashes, both cycle tracks and cycle lanes, removing parking facilities seems to be a good strategy to create space in the cross section for cycle tracks and at the same time significantly decrease the likelihood on bicycle crashes.

7. Conclusion

By effectively correcting for exposure of both motor vehicles and cyclists, this study suggests a clear overall safety benefit to cyclists of physically separated cycle tracks as 50 – 60 % less cycling crashes are expected on streets (including intersections) with physically separated cycle tracks compared to streets with marked or painted cycle lanes. Also, no benefit for cycle lanes over mixed traffic conditions could be found. Furthermore, curbside parking was found to be an important risk factor as it was found that twice as many crashes were found on streets with curbside parking compared to streets without curbside parking. This was found to be a general effect for streets with curbside parking alongside both physically separated cycle tracks and cycle lanes and with mixed traffic conditions. It is hypothesised that curbside parking may contribute to an increased likelihood of cycling crashes due to dooring and sight obstructions of cyclists near intersections. Further research is recommended on how parking affects these different cycling infrastructure types. Finally, the presence of tramways were found to be associated with a strongly increased likelihood of cycling crashes, a difference of a factor 1.7-2.

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References

Agerholm, N., Caspersen, S. & Lahrmann, H. 2008. Traffic safety on bicycle paths - results from a new large scale Danish study. *In:* Archer, J., ed. ICTCT, 2008 Melbourne. Monash University, 1-11.

Barnes, G. R. & Thompson, K. B. 2006. A longitudinal analysis of the effect of bicycle facilities on commute mode share. *Transportation Research Board 85th Annual Meeting.* Washington D.C.: Transportation Research Board.

Bijleveld, C. C. J. H. & Commandeur, J. J. F. 2012. *Multivariate analyse: een inleiding voor criminologen en andere sociale wetenschappers*, Uitgeverij Lemma b.v.

Broach, J., Dill, J. & Gliebe, J. 2012. Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transportation Research Part A,* 46**,** 1730-1740.

Brüde, U. & Larsson, J. 2000. What roundabout design provides the highest possible safety? *Nordic Road and Transport Research,* 12**,** 17-21.

Buehler, R. & Pucher, J. 2012. Walking and cycling in Western Europe and the United States: trends, policies, and lessons. *Tr News*.

CycloMedia. 2020. *Street Smart Imagery* [Online]. Zaltbommel: CycloMedia Technology. Available: https://www.cyclomedia.com/ [Accessed 2 January 2020].

Daniels, S., Brijs, T., Nuyts, E. & Wets, G. 2009. Injury crashes with bicyclists at roundabouts: influence of some location characteristics and the design of cycle facilities. *Journal of Safety Research,* 40**,** 141-148.

DiGioia, J., Watkins, K. E., Xu, Y., Rodgers, M. & Guensler, R. 2017. Safety impacts of bicycle infrastructure: A critical review. *Journal of Safety Research,* 61**,** 105-119.

Dijkstra, A. 2004. Rotondes met Vrijliggende Fietspaden ook Veilig voor Fietsers (Are Roundabouts with Separate Cycle Tracks also Safe for Cyclists)? Leidschendam.: Institute for Road Safety Research.

Dill, J. & Carr, T. 2003. Bicycle commuting and facilities in major U.S. cities: if you build them, commuters will use them. *Transportation Research Record,* 1828**,** 116-123.

Dufec 2015. Monitoring Snelheid Brom- en Snorscooters Amsterdam (Monitoring Moped and Light-moped Speed in Amsterdam). Tilburg: Dufec.

Elvik, R. & Bjørnskau, T. 2017. Safety-in-numbers: a systematic review and meta-analysis of evidence. *Safety Science,* 92**,** 274–282.

Elvik, R., Høye, A., Vaa, T. & Sørensen, M. 2009a. *The Handbook of Road Safety Measures,* Bingley, Emerald.

Elvik, R., Hoye, E., Vaa, T. & Sorensen, M. 2009b. *The Handbook of road safety Measures, 2nd edition,* Bingley, UK, Emerald Publishing.

European Commission 2010. Towards a European Road Safety Area: Policy Orientations on Road Safety 2011-2020 (COM(2010) 389). Brussels.

EuroRAP. 2020. *Making cyclists safer* [Online]. Brussels: EuroRAP. Available: https://www.eurorap.org/making-cyclists-safer/ [Accessed 2 January 2020].

Fishman, E., Washington, S. & Haworth, N. 2012. Understanding the fear of bicycle riding in Australia. *Journal of the Australasian College of Road Safety,* 23**,** 19-27.

Gårder, P., Leden, L. & Pulkkinen, U. 1998. Measuring the safety effect of raised bicycle crossings using a new research methodology. *Transportation Research Record,* 1636**,** 64-70.

Gemeente Amsterdam 2017. Meerjarenplan Fiets 2017-2022; Voor fietsers en een gezonde en bereikbare stad. Amsterdam: Gemeente Amsterdam.

Gommers, M. J. P. F. & Bovy, P. H. L. 1987. Routekeuzegedrag en Netwerkgebruik (Route Choice and Network Use). Delft: Delft University of Technology.

Heinen, E., Maat, K. & Van Wee, G. P. 2010. Day-to-day choice to commute or not by bicycle. *Transportation Research Record,* 2230**,** 9-18.

Hilbe, J. M. 2011. *Negative binomial regression*, Cambridge University Press.

Horton, D., Rosen, P. & Cox, P. 2007. *Cycling and Society,* Farnham, Ashgate.

Howard, C. & Burns, E. K. 2001. Cycling to work in Phoenix: Route choice, travel behavior, and commuter characteristics. *Transportation Research Record,* 1773**,** 39-46.

Høye, A., Sørensen, M. W. J. & de Jong, T. 2015. Separate bicycle facilities in urban areas. Effects on safety, mobility, perceived risk and modal share. *Separate sykkelanlegg i by: Effekter på sikkerhet, fremkommelighet, trygghetsfølelse og sykkelbruk.* Institute of Transport Economics (TØI).

Khreis, H., Warsow, K. M., Verlinghieri, E., Guzman, A., Pellecuer, L., Ferreira, A., Jones, I., Heinen, E., Rojas-Rueda, D., Mueller, N., Schepers, P., Lucas, K. & Nieuwenhuijsen, M. 2016. The health impacts of traffic-related exposures in urban areas: Understanding real effects, underlying driving forces and co-producing future directions. *Journal of Transport and Health,* 3**,** 249-267.

Koornstra, M. J., Mathijssen, M. P. M., Mulder, J. A., Roszbach, R. & Wegman, F. C. M. 1992. Naar een Duurzaam Veilig Wegverkeer (Towards Sustainably Safe Road Traffic). Leidschendam: Institute for Road Safety Research.

Langley, J. D., Dow, N., Stephenson, S. & Kypri, K. 2003. Missing cyclists. *Injury Prevention,* 9**,** 376-379.

Ling, R., Rothman, L., Cloutier, M.-S., Macarthur, C. & Howard, A. 2020. Cyclist-motor vehicle collisions before and after implementation of cycle tracks in Toronto, Canada. *Accident Analysis and Prevention,* 135**,** 105360.

Ling, Z., Cherry, C. R. & Dhakal, N. 2017. Factors influencing single-bicycle crashes at skewed railroad grade crossings. *Journal of Transport and Health,* 7**,** 54-63.

Lord, D., Washington, S. P. & Ivan, J. N. 2005. Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory. *Accident Analysis and Prevention,* 37**,** 35-46.

Lusk, A. C., Furth, P. G., Morency, P., Miranda-Moreno, L. F., Willett, W. C. & Dennerlein, J. T. 2011. Risk of injury for bicycling on cycle tracks versus in the street. *Injury Prevention,* 17**,** 131-135.

Menghini, G., Carrasco, N., Schüssler, N. & Axhausen, K. W. 2010. Route choice of cyclists in Zurich. *Transportation research part A,* 44**,** 754-765.

Methorst, R., Schepers, P., Kamminga, J., Zeegers, T. & Fishman, E. 2017. Can cycling safety be improved by opening all unidirectional cycle paths for cycle traffic in both directions? A theoretical examination of available literature and data. *Accident Analysis and Prevention,* 105**,** 38-43.

Mulvaney, C. A., Smith, S., Watson, M. C., Parkin, J., Coupland, C., Miller, P., Kendrick, D. & McClintock, H. 2015. Cycling infrastructure for reducing cycling injuries in cyclists. *Cochrane database of systematic reviews*.

Parkin, J. 2018. *Designing for Cycle Traffic: International Principles and Practice,* Westminster, London, ICE Publishing.

Pucher, J., Dill, J. & Handy, S. 2010. Infrastructure, programs, and policies to increase bicycling: an international review. *Preventive Medicine,* 50**,** S106-25.

Reynolds, C. C., Harris, M. A., Teschke, K., Cripton, P. A. & Winters, M. 2009. The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. *Environmental Health,* 8**,** 47.

Rodgers, G. B. 1997. Factors associated with the crash risk of adult bicyclists. *Journal of Safety Research,* 28**,** 233-241.

Sakshaug, L., Laureshyn, A., Svensson, Å. & Hydén, C. 2010. Cyclists in roundabouts—Different design solutions. *Accident Analysis and Prevention,* 42**,** 1338-1351.

Scheepers, C., Wendel-Vos, G., Den Broeder, J., Van Kempen, E., Van Wesemael, P. & Schuit, A. 2014. Shifting from car to active transport: a systematic review of the effectiveness of interventions. *Transportation research part A,* 70**,** 264-280.

Schepers, J. P., Kroeze, P. A., Sweers, W. & Wust, J. C. 2011. Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections. *Accident Analysis and Prevention,* 43**,** 853-61.

Schepers, J. P. & Voorham, J. 2010. Oversteekongevallen met Fietsers (Crossing Accidents with Cyclists). Delft: Rijkswaterstaat.

Schepers, P., Agerholm, N., Amoros, E., Benington, R., Bjørnskau, T., Dhondt, S., de Geus, B., Hagemeister, C., Loo, B. P. Y. & Niska, A. 2015. An international review of the frequency of single-bicycle crashes (SBCs) and their relation to bicycle modal share. *Injury prevention,* 21**,** e138-e143.

Schepers, P., Stipdonk, H., Methorst, R. & Olivier, J. 2017. Bicycle fatalities: trends in crashes with and without motor vehicles in The Netherlands. *Transportation research part F,* 46**,** 491-499.

Schepers, P., Wolt, K. K., Helbich, M. & Fishman, E. 2020. Safety of e-bikes compared to conventional bicycles: What role does cyclists' health condition play? *Journal of Transport and Health,* 19**,** 100961.

Shah, N., Buckner, I. & Cherry, C. R. 2020. A jughandle design will virtually eliminate single bicycle crashes at a railway crossing. *Journal of Transport and Health,* 19**,** 100962.

Shaheen, S. A., Guzman, S. & Zhang, H. 2010. Bikesharing in Europe, the Americas, and Asia: past, present, and future. *Transportation Research Record,* 2143**,** 159-167.

Stelling, A., Mesken, J., Vlakveld, W. P. & Wesseling, S. 2017. Speed-pedelec op de rijbaan; Eerste praktijkonderzoek naar gedragseffecten (Speed-pedelec on the carriageway; First pilot research into behavioural effects). The Hague: SWOV Institute for Road Safety Research.

Stipdonk, H. & Reurings, M. 2012. The effect on road safety of a modal shift from car to bicycle. *Traffic Injury Prevention,* 13**,** 412-21.

SWOV 2017. Moped and light-moped riders. *SWOV-factsheet.* The Hague: SWOV Institute for Road Safety Research.

Teschke, K., Harris, M. A., Reynolds, C. C., Winters, M., Babul, S., Chipman, M., Cusimano, M. D., Brubacher, J. R., Hunte, G., Friedman, S. M., Monro, M., Shen, H., Vernich, L. & Cripton, P. A. 2012. Route infrastructure and the risk of injuries to bicyclists: a case-crossover study. *American journal of public health,* 102**,** 2336-43.

The Urban Future. 2020. *Dutch Bicycle Count Week* [Online]. Breda: Breda University of Applied Sciences, The Urban Future. Available: https://theurbanfuture.com/project/ [Accessed 2 January 2020].

Thomas, B. & DeRobertis, M. 2013. The safety of urban cycle tracks: A review of the literature. *Accident Analysis and Prevention,* 52**,** 219-227.

Usami, D. S. & Ammari, A. 2017. *Cycle lane treatments; cycle path treatments* [Online]. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Available: https://www.roadsafety-dss.eu/#/references?topic=COUNTERMEASURE&taxonomy=5897 [Accessed 09-12-2020].

van Loon, A. A. P. M., de Baan, D. L. & Buningh, S. J. 2001. Evalusatie verkeersveiligheidseffecten 'Bromfiets op de rijbaan'.

Van Minnen, J. 1990. Ongevallen op Rotondes (Crashes at Roundabouts). Leidschendam: Institute for Road Safety Research.

Van Minnen, J. 1995. Rotondes en Voorrangsregelingen. R-95-58 (Roundabouts and Priority Rules). Leidschendam: SWOV Institute for Road Safety Research.

Vandenbulcke, G., Thomas, I. & Panis, L. I. 2014. Predicting cycling accident risk in Brussels: A spatial case–control approach. *Accident Analysis and Prevention,* 62**,** 341-357.

Wegman, F. C. M., Aarts, L. T. & Bax, C. 2008. Advancing sustainable safety: national road safety outlook for the Netherlands for 2005–2020. *Safety Science,* 46**,** 323-343.

Wegman, F. C. M., Zhang, F. & Dijkstra, A. 2012. How to make more cycling good for road safety? *Accident Analysis and Prevention,* 44**,** 19-29.

Weijermars, W., Bos, N. & Stipdonk, H. L. 2016. Serious road injuries in the Netherlands dissected. *Traffic injury prevention,* 17**,** 73-79.

Weijermars, W. A. M. & Wegman, F. C. M. 2011. Ten years of Sustainable Safety in the Netherlands. *Transportation Research Record,* 2213**,** 1-6.

Welleman, A. G. & Dijkstra, A. 1988. Veiligheidsaspecten van Stedelijke Fietspaden (The safety of Urban Bicycle Tracks). Leidschendam: Institute for Road Safety Research.

Wijlhuizen, G. J., Dijkstra, A. & Van Petegem, J. W. H. 2014. Safe Cycling Network : developing a system for assessing the safety of cycling infrastructure. Report on behalf of the Royal Dutch Touring Club ANWB. The Hague: SWOV Institute for Road Safety Research.

Wijlhuizen, G. J., Van Petegem, J. W. H., Goldenbeld, C., Van Gent, P., De Bruin, J., Commandeur, J. J. F. & Kars, V. 2016. Doorontwikkeling CycleRAP-instrument voor veiligheidsbeoordeling fietsinfrastructuur. Doelmatigheid handmatige intensiteitsmetingen, betrouwbaarheid beoordelingen infrastructuur en validiteit van het CycleRAPinstrument. Den Haag: SWOV.

Wijlhuizen, G. J., Van Petegem, J. W. H., Schermers, G., De Bruin, J., Commandeur, J. J. F. & Kars, V. 2017. Ontwikkeling Netwerk Safety Index gemeente Amsterdam. Den Haag: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.