Safety-in-numbers and other risks associated with traffic composition

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Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides *a quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1. Summary

Hesjevoll, I.S., August 2016

1.1 COLOUR CODE: RED (VRU)

As the share of cyclists and/or pedestrians in the traffic flow increases, accident numbers increase. However, the increase in the number of crashes is found to be less than would be expected for the proportional increase in traffic volume, indicating a lower risk for each road user at higher volumes.

COLOUR CODE: GREY (HGV)

The effect of the share of heavy goods vehicles on road safety is unclear; the few studies identified show mixed results.

1.2 KEYWORDS

Cyclist; Pedestrian; Traffic composition; Safety-in-numbers; Meta-analysis; HGVs; Traffic flow

1.3 ABSTRACT

Traffic composition refers to the share of different groups of road users in traffic (e.g. cars, pedestrians, cyclists, heavy goods vehicles, powered two wheelers). An increase in the volume of cyclists and pedestrians is associated with a net increase in crashes (between cyclists/ pedestrians and motor vehicles), but this increase is less than would be expected for the proportional increase in volume, corresponding to lower risk for each road user. A meta-analysis estimated that a doubling of the volumes of pedestrians or cyclists would correspond to a 41 % increase in crashes (across road types and areas). This is in accordance with a "Safety-in-numbers" effect (more cyclists/ pedestrian corresponds to a lower crash risk for each cyclist/pedestrian), but it remains unclear if the lower risk is *caused* by the higher numbers of pedestrians/cyclists. The effect of the share of heavy goods vehicles on road safety is unclear (few studies with mixed results), and no studies were found on the share of powered two wheelers or public transport.

1.4 BACKGROUND

1.1.1 What is traffic composition?

Traffic composition refers to the share of different groups of road users (e.g. cars, pedestrians, cyclists, heavy goods vehicles (HGVs), powered two wheelers (PTWs)). Thus, a stream of traffic consisting of 10 % heavy vehicles, 80 % light vehicles and 10 % pedestrians or cyclists has a different composition from a traffic stream consisting of 5 % heavy vehicles, 75 % light vehicles and 20 % pedestrians or cyclists. Traffic composition differs between rural and urban roads and also between types of road. As an example, pedestrians and cyclists are not allowed to use motorways, but can make up more than 50 % of traffic in city centres.

1.1.2 How does traffic composition affect road safety?

The relationship between the share of pedestrians or cyclists and crash risk has been described as a "Safety-in-numbers" effect, i.e. that an increase in the volumes of cyclists/pedestrians is associated with a lower risk for each cyclist/pedestrian. It is not clear what mechanism is responsible for this association, but several have been proposed (here exemplified by cyclists): It might be that a higher number of cyclists causes the reduced risk, by make drivers more aware of cyclists or because increases in interactions between cyclists and motor vehicles improves the quality of these interactions or lowers the speed. Alternatively, the characteristics of the cyclist population could change as more cyclists enter the traffic (individuals who join the cyclist population at a later point in time could be more cautious than other cyclists, reducing the average risk for cyclists). Another possibility is that the mechanism goes in the opposite direction: more people walk and cycle where it is safe to do so. It may also be that the observed association is a result of some other (spurious) variable affecting both road user shares and crash frequency, for instance that the quality of the infrastructure available for cyclist affects both the road user share and crash risk.

Regarding HGV-share, both the effect on road safety and the mechanism by which this occurs is unclear, due to a small amount of studies reporting mixed results.

1.1.3 What road safety outcomes are affected by traffic composition?

The studies reviewed for the effect of traffic composition on road safety are all concerned with crash frequency; none focused on crash severity.

1.1.4 How is the effect of traffic composition on road safety studied?

Two main groups of studies are reviewed. The first group of studies address the volumes of cyclists/pedestrians and motor vehicles, and the Safety-in-numbers effect. Among these studies is one meta-analysis, covering studies from various settings (urban, rural), countries (mostly Northern Europe and North America) and levels of analysis (from cities to crossings).

The second group of studies in concerned with the share of heavy goods vehicles (in relation to cars/other motorized vehicles). The three studies are from Spain, Sweden and the United States, and they investigate different types of roads.

All studies are cross-sectional, using multivariate crash prediction models to explain variations in crash numbers.

1.5 OVERVIEW OF RESULTS

1.5.1 Main results

One meta-analysis based on 15 original studies, as well as two additional original studies, confirm a safety-in-numbers effect for both pedestrians and cyclists: as the volumes of pedestrians and cyclists increases, crash risk (for crashes involving pedestrians/cyclists and motor vehicles) declines. According to the meta-analysis, a doubling of the volumes of pedestrians or cyclists is only expected to increase crashes by 41 %.

Regarding the share of heavy goods vehicles, results are mixed. One study indicates that the impact of HGVs on crash frequency may vary depending on the road type (high or low capacity), one indicates that the percentage of HGVs is not related to crash frequency and the third indicates that crash numbers decrease as the number of HGVs increase, holding car volume constant.

1.5.2 Transferability

With similar results from studies from a variety of countries and several levels of measurement units, the results from the meta-analysis on the safety-in-numbers effect appears to be similar for western countries, and for both urban and rural areas. The available evidence for shares of other road users is limited, with studied on the share of HGVs reaching very different conclusions. Since studies differ with regard to countries, road types, measurement of HGVs and analysis, it remains unclear what is the main source of result differences.

1.5.3 Notes on analysis methods

While the SIN effect is reported across studies and contexts, the studies do not say if this association is due to a) more cyclists *causing* lower risk, b) lower risk causing more cyclists, or c) some other factor, such as infrastructure quality, affecting both cyclist share and risk. More research is needed on the share of HGVs and PTWs to establish how this relates to road safety.
In studies of SIN one can see an improvement in quality over time. Recent studies include more variables and are based on more extensive statistical analyses than the oldest studies. These studies can be regarded as methodologically sound. The picture is less clear as far as HGV studies are concerned.

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2. Scientific overview

2.1 LITERATURE REVIEW

2.1.1 On the investigation of safety-in-numbers.

The SIN effect is generally estimated from multivariate crash prediction models including volumes for motor vehicles and pedestrian or cyclists, as well as any additional independent variables (such as type of crossing and speed limit). The resulting estimated regression coefficients indicate the change in crashes associated traffic volume increases, holding other variables in the model constant. If the estimated coefficients for both motor vehicle- and pedestrian (or cyclist) volume are less than one, it is generally concluded that there is a safety-in-numbers effect.

As noted in the summary, it is not clear whether the association identified between the volumes of cyclist, pedestrians and cars and crashes is causal, or if it is explained by confounders such as selective recruitment of road users or infrastructure quality. A number of potential issues related to the investigation and interpretation of the SIN effect ought to be mentioned.

Elvik (2013) argues for a distinction between a complete and a partial safety-in-numbers effect: As mentioned, a coefficient below one is generally interpreted as in accordance with a SIN effect. But if the sum of the coefficients for motor vehicle flow and the flow of cyclists/pedestrians is larger than 1, it may be characterized as a partial SIN, or potentially hazard in numbers. In such instances, the increase in crashes associated with an increase in pedestrian flow could be less than proportional to the volume increase *if the volume of motor vehicles is held constant*. However, if the volumes of cyclists/pedestrians and motor vehicles are positively correlated, there might not be an overall safety-in-numbers effect: When the coefficients sum to more than one, crashes would more than double when the sum of pedestrian and motor vehicle volume doubles (Elvik, 2013).

Several authors have raised the issue that some studies employ a model of the relationship between traffic volume and crashes which give rise to a negative relationship that appears to be a safety-in-numbers effect but may be a statistical artefact (see e.g. Elvik & Bjørnskau, 2015; Elvik, 2013; Knowles et al., 2009). This applies to studies that define risk as (injury/km travelled) and exposure as (km travelled/number of inhabitants), which by definition produces a negative association between exposure and risk that will appear to be a SIN effect. No such studies are included in this synthesis, nor in the meta-analysis of Elvik and Bjørnskau.

Another potential issue is that all models, both in the meta-analysis and two additional studies, specify a monotonic functional relationship for the relationship between traffic volumes and crash frequency. It is, however, possible that such an effect has a limit or a turning point (Elvik, 2009), but this has not been investigated in any of the identified studies.

2.1.2 How could HGV share affect road safety?

The results on the share of HGVs on crash frequencies are mixed, leaving uncertainty regarding how this would affect road safety. In the reviewed studies, several possible mechanisms are proposed: It may be that larger shares of HGVs in some cases reduce the average speed, which in turn affects road safety. On the other hand, HGVs driving slower than light vehicles could increase the speed differences, resulting in a detrimental effect on road safety. It could also be that a higher share of light vehicles corresponds to increases in overtaking manoeuvres using the oncoming lane, producing more possible conflict scenarios and increasing crash risk. Or it could be that the number of HGVs on the road coincides with other factors that affect the crash frequency, such as good road conditions or times of the day when experienced drivers are driving (Hiselius, 2004; Ramirez et al., 2009).

2.2 DESCRIPTION OF STUDIES

Six studies are reviewed, including one meta-analysis. All studies are concerned with crash frequency, and three focus on the shares of HGVs and cars, while the remaining three, including the meta-analysis, investigates the Safety-in-numbers effect related to shares of pedestrians, cyclists and motor vehicles.

2.2.1 How is traffic composition measured?

All models in the meta-analysis, as well as the two original studies coded on safety-in-numbers, are similar; multivariate crash prediction models that estimate regression coefficients for how the number of crashes depend on the conflicting flows (see literature review). For the share of HGVs, multivariate crash prediction models including the percentage of heavy goods vehicles in addition to the total traffic volume (and possibly other control variables) are typically used to estimate the effect on road safety. The studies reviewed here focus on the distribution of crash frequencies over time/segments as dependent variable.

Table 1. Description of sampling frames of coded studies.

Author(s), year, country	Sample, context	Crashes	Road users	Design, analysis
Pedestrians, cyclists and motor vehicles				
Elvik & Bjørnskau, 2015, several	Based on 15 studies investigating the SIN effect on micro (e.g. crossings), meso (e.g. road networks) and macro (e.g. cities) levels, from which 25 coefficients were meta-analysed	Involving both cars and either pedestrians or cyclists	Pedestrians Cyclists Motor vehicles	Inverse-variance meta-analysis with both fixed and random effects
Elvik, 2016, Norway	Police-reported crashes occurring in 239 pedestrian crossings in the larger Oslo area.	Police-reported crashes: collisions between motor vehicle and pedestrian or cyclist	Pedestrians Cyclists Motor vehicles	Negative binomial with log link function.
Kröyer, 2016, Sweden	113 intersections in middle-sized cities in Sweden, with 5 years of accident data (2008-2012), traffic counts	From police- and hospital databases, collisions between motor vehicle and pedestrian or cyclist*	Pedestrians Cyclists Motor vehicles	Negative binomial
Heavy goods vehicles and cars				
Daniel & Maina, 2011, USA	998 freeway segments from New Jersey, one year (2008) of crash- and traffic data.	All crashes.	Cars HGVs	Negative binomial
Hiselius, 2004, Sweden	83 rural road sections, hourly traffic flow per car/lorry from 1989 to the middle of 1995, separated into four road types with different road widths and speed limits	Injury crashes, approximately 160 and 600 crashes for the road type with least and most crashes, respectively	Cars HGVs	Poisson regression

Ramirez et al., 2009, Spain	2541 road segments on interurban roads. AADT per vehicle type. 1 year (2001) of traffic and crash data for model development, validated with 2 more years of crash data.	Injury crashes, police-reported.	Cars HGVs	Negative binomial with log link function

Note: *The study also contains estimates for single bicycle accidents and single pedestrian accidents, which are not relevant for traffic composition (nor SIN, according to Elvik & Bjørnskau, 2015) and will not be addressed here.

Table 1 outlines the sampling frames and methodologies of the coded studies, grouped by road users investigated. All studies use crash frequency as outcome variable, and all original studies are cross-sectional. An overview of control variables can be found in the supporting document.

2.2.2 How well has the effect of traffic composition been studied?

The safety in numbers effect has been investigated by a large number of studies from different countries and on different levels: The meta-analysis found homogeneous results from studies from Canada, United States, Great Britain, Denmark, Sweden, Netherlands, Norway and New Zealand, and similar estimates for study units on a micro-level (e.g. junctions or pedestrian crossings), meso-level (typically street networks or urban traffic zones), and macro-level (municipalities, cities or states), and covered both urban and rural areas. The number of locations covered in the primary studies varies from 105 to 1000, and the numbers of crashes from 27 to 5349. Elvik and Bjørnskau (2015) found no evidence for publication bias. Still, evidence on the mechanisms explaining this association is lacking, although some mechanisms have been suggested. These include changes in expectations and/or the quality of the interactions between the groups of road users.

Regarding heavy goods vehicles, few studies were identified, and more research is needed to disentangle the effects of road types, time periods and other potentially relevant moderators, as well as differences between countries.

2.2.3 Transferability

The SIN effect is confirmed in all studies. Since studies of the SIN effect have been reported from the 1970s until now, and in many countries, this suggests that the effect can be expected to be found at least in Western, highly motorised countries. Whether it applies to low-income countries is less clear.

2.3 OVERVIEW OF RESULTS

2.3.1 Pedestrians, cyclists and motor vehicles

One meta-analysis and two original studies investigating the relationship between flows of pedestrians, cyclists and motor vehicles were coded. All studies use crash prediction models where the outcomes are regression coefficients for the change in crash frequency expected for an increase in conflicting flows. A coefficient below 1 is generally taken to indicate a safety-in-numbers effect. The results are presented in Table 2. All results are in accordance with a safety-in-numbers effect, i.e. the coefficients are lower than 1. Again, this means that the total number of crashes is expected to increase with volume increases, but less than proportional to the volume increase.

The meta-analysis, based 15 studies and a total of 51 coefficients (25 from car volume, 15 for pedestrian volume and 11 for cycle volume), finds consistent results between studies. The summary estimates are close to 0.5 for all traffic volumes which, converted to elasticities, mean that a doubling in the volume of pedestrians or cyclist is expected to increase the number of crashes by 41

% (Elvik & Bjørnskau, 2015). While the coefficients for both studies indicate a SIN effect, this is far greater in the study of Elvik than in the Kröyer study. The bicyclist model of Kröyer (2016) indicates a partial SIN-effect.

Table 2. Results (regression coefficients) from safety-in-numbers studies.

Author, year, country	Level of analysis	Coefficients			Effect (crashes)	Effect (risk)
		Ped	Cyc	MV		
Meta-analysis						
Elvik & Bjørnskau, 2015, several	All	0.499	0.432	0.511	↗	↘
	Micro (e.g. crossings)	0.563	0.479	0.491	↗	↘
	Meso (e.g. road networks)	0.640	0.514	0.428	↗	↘
	Macro (e.g. cities)	0.566	0.369	*	↗	↘
Original studies						
Kröyer, 2016, Sweden	Micro	0.3		0.64	↗	↘
	Micro		0.36	0.71	↗	↘
Elvik, 2016, Norway	Micro	0.066	0.12	0.048	↗	↘

Note: * no results

2.3.2 Heavy goods vehicles and cars

Three coded studies investigated how the share of heavy goods vehicles relates to crash frequency, all are cross-sectional. Two studies use average traffic data (AADT) and address the percentage of heavy goods vehicles (Ramirez et al., 2009; Daniel & Maina, 2011), while Hiselius (2004) analyse hourly traffic volume data with separate indicators for car volume and lorry volume. The main results are displayed in Table 3.

Table 3. Main results of studies addressing share of heavy goods vehicles.

Author, year, country	Analysis	Measure of HGV share	Effect on crash frequency	Explanation	Control variables
Ramirez et al., 2009, Spain	Negative binomial, log link function	ln (% HGV)	↗ ↘	Increased % of HGVs is related to higher crash frequencies on high-capacity roads, and lower crash frequencies on lower capacity roads	Road type; ln(AADT); ln(%HGV); ln(%HGV) per road type
Hiselius, 2004, Sweden	Poisson regression	Ln (hourly HGV volume)	↘	An increasing number of lorries is related to a lower crash frequency independent of the volume of cars. This is found for all crashes, single vehicle crashes and multiple vehicle crashes.	Exposure (number of hours and km each section is studies); volume of cars

Daniel & Maina, 2011, USA	Negative binomial	% HGV	-	A higher percentage of trucks is found to be associated with a higher number of crashes, but the result is not statistically significant.	section length; AADT; speed limit; number of lanes; lane width; shoulder width; ramp density

Due to differences in measurement and model architecture, as well as the fact that one study found opposite effects for different road types and it was not evident how these roadtypes were best compared to those investigated in other studies, a meta-analysis was not feasible.

The results are mixed. In the Spanish study, the effect of HGV share on road safety varies by road type. The Swedish study investigated several road types jointly, and the U.S. study found the effect of HGV share not to be significantly related to crash frequency. With the number of studies being low, it is not possible to say for certain if these differences reflect differences between countries, road types, time periods or the design or analysis of the data.

CONCLUSION

One meta-analysis and five original studies investigating the impact of traffic composition on crash occurrence have been coded summarized. Studies on shares of pedestrians, cyclists and cars, including one meta-analysis, consistently find a safety-in-numbers effect: as the volumes of cyclists/pedestrian increases, crashes increase less than proportional to the volume increase. However, this might not always hold if the volume of motor vehicles increases too, and the cause of the association is not known with certainty. The effect of HGV share on road safety is unclear, and more research is needed on this topic.

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3. Supporting document

3.1 METHODOLOGY

3.1.1 Literature Search strategy

The literature search was conducted in Science Direct, TRID, Springer Link and Taylor & Francis. Additionally, Google Scholar was searched for relevant articles published after the meta-analysis identified. The search was limited to journal articles and reports published after 1999 in the English language. Preliminary searches indicated that search terms such as "traffic composition" returned irrelevant and unmanageable numbers of hits in most databases. Thus, safety in numbers was used as a key search term.

Database: Science Direct **Date:** 16th of March 2016

search no.	search terms / operators / combined queries	hits
#1	TITLE-ABSTR-KEY("safety in numbers") AND (accident* OR crash* OR risk OR safety) AND (pedestrian* OR cyclist* OR bicycl* OR vehicl*)	33
#2	"vehicle mix" AND (accident* OR crash* Or risk OR safety OR injur*)	241

Database: Google Scholar **Date:** 17th of March 2016

search no.	search terms / operators / combined queries	hits
#1	"safety in numbers" AND "accident* OR crash* OR injur* OR risk OR safety) AND (pedestrian* OR vehicle* OR PTW OR cyclist* OR bicycl*)	1020
#2	"safety in numbers" AND (accident* OR safety OR risk OR injur* OR crash*) [years 2015-2016; after meta-analysis]	366

Database: Taylor & Francis **Date:** 16th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("safety in numbers") AND (accident* OR crash* OR risk OR safety) AND (road OR traffic OR transport* OR travel) AND (pedestrian* OR cyclist* OR bicycl* OR vehicl*) NOT(nurse OR patient* OR nursing OR -nursing OR medication*)	125

Database: TRID **Date:** 16th of March 2016

search no.	search terms / operators / combined queries	hits
#1	Keywords: "traffic composition" AND (risk OR accident* OR crash* OR safety)	439

Database: Springer Link **Date:** 11th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("safety in numbers") AND (accident* OR crash* OR risk OR safety) AND (road OR traffic OR transport* OR travel) AND (pedestrian* OR cyclist* OR bicycl* OR vehicl*) NOT(nurse OR patient* OR nursing OR -nursing OR medication*)	136

3.1.2 Results of literature search, screening and prioritizing

After screening titles and abstracts of the search hits, 17 studies were retrieved and screened full-text.
The following elimination criteria were applied:

- Included in the meta-analysis identified
- Result may be statistical artefact (risk is defined as (injury/km travelled) and exposure as (km travelled/number of inhabitants), see literature review section for explanation)
- Share of road users not reported
- Results are not based on accidents/incidents
- Not peer-reviewed

Additionally, since single vehicle crashes are generally not considered to be affected by SIN, results for single vehicle crashes, as well as analyses based on both cyclist/motor vehicle and single crashes were excluded. Such studies were only retained if analyses on crashes that were not single crashes were reported. Furthermore, when multiple studies were based on (mostly) the same data, the study with the larger sampling frame was given priority.

In prioritizing remaining studies, those not compatible with coding (e.g. unusual analyses, insufficient reporting of detail) were given a lower priority. As were studies mostly concerned with different types of road design for mixed traffic.

This left 6 studies to code, including the meta-analysis, which is based on 15 studies (with 8 additional studies excluded).

3.2 LISTS OF STUDIES CONSIDERED AND CODED

Coded studies:

Daniel, J. R., & Maina, E. (2011). Relating Safety and Capacity on Urban Freeways. Procedia - Social and Behavioral Sciences, 16, 317–328. http://doi.org/10.1016/j.sbspro.2011.04.453

Elvik, R. (2016) Safety-in-numbers: Estimates based on a sample of pedestrian crossings in Norway. Accident Analysis & Prevention, 91, 175–182. http://dx.doi.org/10.1016/j.aap.2016.03.005.

Elvik, R., & Bjørnskau, T. (2017). Safety-in-numbers: A systematic review and meta-analysis of evidence. Safety Science, 92, 274–282, https://doi.org/10.1016/j.ssci.2015.07.017.

Kröyer, H. R. G. (2016) Pedestrian and bicyclist flows in accident modelling at intersections. Influence of the length of the observational period. Safety Science, 82, 315–324 https://doi.org/10.1016/j.ssci.2015.09.015.

Ramírez, B. A., Izquierdo, F. A., Fernández, C. G., & Méndez, A. G. (2009). The influence of heavy goods vehicle traffic on accidents on different types of Spanish interurban roads. Accident Analysis and Prevention, 41(1), 15–24. https://doi.org/10.1016/j.aap.2008.07.016

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Hiselius, L. (2004). Estimating the relationship between accident frequency and homogeneous and inhomogeneous traffic flows. Accident Analysis and Prevention, 36, 985-992. https://doi.org/10.1016/j.aap.2003.11.002

Studies screened and rejected based on abovementioned criteria

Clabaux, N., Fournier, J.-Y., & Michel, J.-E. (2014). Powered two-wheeler drivers' crash risk associated with the use of bus lanes. Accident Analysis and Prevention, 71, 306–10.

Elvik, R. (2013). Can a safety-in-numbers effect and a hazard-in-numbers effect co-exist in the same data? Accident Analysis and Prevention, 60, 57–63.

Murphy, B., & Levinson, D. (2015). Evaluating the "Safety In Numbers" Effect With Estimated Pedestrian Activity.

Strauss, J., Miranda-Moreno, L. F., & Morency, P. (2013). Cyclist activity and injury risk analysis at signalized intersections: A Bayesian modelling approach. Accident Analysis and Prevention, 59, 9–17.

Vlahogianni, E. I. (2007). Some empirical relations between travel speed, traffic volume and traffic composition in urban arterials. IATSS Research, 31(1), 110–119.

Wegman, F., Zhang, F., & Dijkstra, A. (2012). How to make more cycling good for road safety? Accident Analysis & Prevention, 44(1), 19–29.

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Studies not coded based on inclusion in (or exclusion from) meta-analysis:

Included in meta-analysis:

Brüde, U., & Larsson, J., (1993). Models for predicting accidents at junctions where pedestrians and cyclists are involved. How well do they fit? Accident Analysis & Prevention, 25(5), 499-509.

Buch, T. S., & Jensen, S. U., (2013). Trafikksikkerhed i kryds med dobbeltrettede cykelstier. (Rapportudkast). Lyngby: Trafitec.

Elvik, R., Sørensen, M. W. J., & Nævestad, T.-O , (2013). Factors influencing safety in a sample of marked pedestrian crossings selected for safety inspections in the city of Oslo. Accident Analysis & Prevention, 59(0), 64-70.

Geyer, J., Raford, N., Ragland, D., & Pham, T., (2006). The Continuing Debate about Safety in Numbers—Data from Oakland, CA. TRB annual meeting CD-ROM

Hall, R.D., (1986). Accidents at four-arm single carriageway urban traffic signals. Contractor Report 65. Transport and Road Research Laboratory, Crowthorne, Berkshire

Harwood, D. W., Torbid, D. J., Gilmore, D. K., Bokenkroger, C. D., Dunn, J. M., Zegeer, C. C., … Persaud, B. N., (2008). Pedestrian Safety Prediction Methodology. NCHRP Web-only Document 129 Phase III. Washington DC.: Transportation Research Board.

Inwood, J., Grayson, G.B., (1979). The comparative safety of pedestrian crossings. TRRL Laboratory Report 895. Transport and Road Research Laboratory, Crowthorne, Berkshire

Jonsson, T., (2005). Predictive models for accidents on urban links - A focus on vulnerable road users. PhD, Lund University, Lund. (Bulletin 226)

Leden, L., (2002). Pedestrian risk decrease with pedestrian flow. A case study based on data from signalized intersections in Hamilton, Ontario. Accident Analysis & Prevention, 34(4), 457-464.

Lyon, C., & Persaud, B. N., (2002). Pedestrian Collision Models for Urban Intersections. Transportation Research Record 1818

L.F. Miranda-Moreno, J. Strauss, P. Morency, (2011). Disaggregate exposure measures and injury frequency models of cyclist safety at signalized intersections. Transp. Res. Rec., 2236 (2011), pp. 74–82

Nordback, K., Marshall, W. E., & Janson, B. E., (2013). Bicyclist safety performance functions for a US city. Paper presented at the TRB Annual Meeting, Washington DC

Prato, C.G., Kaplan, S., Rasmussen, T.K., Hels, T., (2014). Infrastructure and spatial effects on the frequency of cyclist-motorist collisions in the Copenhagen region. Artikler fra Trafikdage på Aalborg Universitet. ISSN 1603-9696

Schepers, J. P., & Heinen, E., (2013). How does a modal shift from short car trips to cycling affect road safety? Accident Analysis & Prevention, 50(0), 1118-1127.

J.P. Schepers, P.A. Kroeze, W. Sweers, J.C. Wüst, (2011). Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections. Accid. Anal. Prev., 43 (2011), pp. 853–861

Summersgill, I., Layfield, R.E., (1996). Non-junction accidents on urban single-carriageway roads.

Turner, S. A., Roozenburg, A. P., & Francis, T., (2006). Predicting Accident Rates for Cyclists and Pedestrians. Land Transport New Zealand Research Report 289. Wellington: Land Transport New Zealand

Zegeer, C. V., Stewart, J. R., Huang, H. H., Lagerwey, P. A., Feaganes, J., & Campbell, B. J., (2005). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: final report and recommended guidelines. Washington DC: Federal Highway Administration

Excluded from meta-analysis: Statistical relationship may be an artefact

Jacobsen, P. L., (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Injury Prevention, 9(3), 205-209.

Knowles, J., Adams, S., Cuerden, R., Savill, T., Reid, S., & Tight, M., (2009).

Technical Annex to PPR445 Collisions involving pedal cyclists on Britain's roads: establishing the causes. Wokingham: Transport Research Laboratory

Robinson, D. L., (2005). Safety in numbers in Australia: more walkers and bicyclists, safer walking and cycling. Health Promotion Journal Australia 16(1), 47-51.

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Vandenbulcke, G., Thomas, I., de Geus, B., Degraeuwe, B., Torfs, R., Meeusen, R., & Int Panis, L., (2009). Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transport Policy, 16(2), 77-87

Excluded from meta-analysis: Contains data on cyclist volume only

Bonham, J., Cathcart, S., Petkov, J., & Lumb, P., (2006). Safety in numbers: a strategy for cycling. Australasian Transport Research Forum (ATRF), 29, 9

Leden, L., Gårder, P., Pulkkinen, U., (1998). Measuring the safety of raised bicycle crossings using a new research methodology. Paper presented at the Transportation Research Board Annual Meeting, Washington DC

Schepers, P., (2012). Does more cycling also reduce the risk of single-bicycle crashes? Injury Prev., 18 (2012), pp. 240–245

Excluded from meta-analysis: States coefficient only for cross-product of flows; not for cars and pedestrians

Maycock, G., Hall, R.D., (1984). Accidents at 4-arm roundabouts. TRRL Laboratory Report 1120. Transport and Road Research Laboratory, Crowthorne, Berkshire.

Additional References

Elvik, R., (2009). The non-linearity of risk and the promotion of environmentally sustainable transport. Accident Analysis and Prevention, 41, 849–855

Elvik, R. (2013). Can a safety-in-numbers effect and a hazard-in-numbers effect co-exist in the same data? Accident Analysis and Prevention, 60, 57–63.

Knowles, J., Adams, S., Cuerden, R., Savill, T., Reid, S., Tight, M., (2009). Technical Annex to PPR445 Collisions Involving Pedal Cyclists on Britain's Roads: Establishing the Causes. Transport Research Laboratory, Wokingham.