Observations of truck-bicycle encounters: A case study of conflicts and behaviour in Trondheim, Norway

Petr Pokorny*; Kelly Pitera

NTNU - the Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering, Trondheim, Norway

*Corresponding author

NTNU, Faculty of Engineering, Department of Civil and Environmental Engineering

Høgskoleringen 7A

7034 Trondheim, Norway

Email: petr.pokorny@ntnu..no

Tel: +47 981 60 530

1 Introduction

The current growth of both bicycle and truck traffic in many urban areas raises, among other things, the question of safety challenges with regard to their coexistence (Conway et al., 2016). Despite effort made to segregate cyclists from trucks and control the movement of urban freight, these two road user groups still share the same space and meet one other, particularly at crossings, intersections and specific locations (e.g. near construction sites or loading areas). These elementary traffic events – when road users meet one another at a given location at the same time – are called encounters (Fyhri et al., 2017). Encounters lead to different safety outcomes ranging from smooth, undisturbed events to severe, sometimes fatal accidents, although the most serious encounters are fortunately the least frequent.

The presence of trucks creates a significant accident risk factor to cyclists (Allen–Munley and Daniel, 2006). This is mainly due to the trucks' visibility limitations. Particularly during truck turning manoeuvres, cyclists can be placed in areas where the truck driver cannot directly see them (so called blind spots) (Niewoehner and Berg, 2005), (Kockum et al., 2017). If a truck–bicycle accident occurs, its consequences are often very severe because of the significant size and weight differences between bicycles and trucks and cyclists' vulnerability (Kim et al., 2007).

According to the EU accident database CARE, 283 cyclists were killed in accidents involving trucks in 2015, which represents 13.7% of all cyclists' fatalities in that year (EC, 2017). Indeed, this percentage share is usually higher in urban areas. For example, cyclists killed in truck–bicycle accidents in urban areas in Norway represented 35% of all urban cyclists' fatalities during the period of 2000–2014 (Pokorny et al., 2017), while in London this percentage rose to 43% during the period of 1992–2006 (Morgan et al., 2010). The number of truck–bicycle accidents is relatively low compared to other types of bicycle accidents, however the cyclists' fatality rate is typically very high. For example, truck–bicycle accidents represented 2% of bicycle accidents in Norway in period 2000-2014, while their fatality rate was 10 times higher than in any other accidents involving cyclists (Pokorny et al., 2017).

Besides accidents, less severe traffic encounters have negative consequences as well. Experiencing a conflict with a truck can be very frightening for cyclists and may even deter other people from bicycling (Sanders, 2015). According to a recent Norwegian survey, cyclists are experiencing these conflicts often (Pokorny et al., 2018).

Given the diversity of the operations and behaviours of bicycle and truck traffic within a complex transport system, developing a comprehensive understanding of their safety presents a multidisciplinary challenge (Raftery et al., 2013). The existing knowledge is founded on police accident record analyses as well as in–depth analyses of severe and fatal accidents. Nevertheless, accident analysis suffer from well–known limitations. Road accidents, particularly truck–bicycle accidents, are rare events, for instance there were only 271 of these accidents recorded in Norway during the period of 2000–2014 (Pokorny et al., 2017). Furthermore, the reporting level of bicycle accidents is typically low, even if a higher reporting level is to be expected for truck–bicycle accidents than for other types of bicycle accidents (Bjørnskau, 2005). In addition, the quality of accident data collected by police is sometimes questionable, and a certain amount of data may be completely missing. To overcome these limitations, less severe but more frequent traffic encounters (i.e. conflicts) and behaviour may be studied for the purpose of identifying safety issues (Johnsson et al., 2018). Additionally, thinking towards the future, deeper knowledge of cyclist behaviour can be used to inform automated systems which attempt to further improve the safety of cyclists within traffic (Twaddle and Busch, 2019).

There are limited non–accident studies that relate specifically to truck–bicycle coexistence. Studies from the US have examined truck drivers' parking behaviour on bicycle–friendly streets using spatial analysis and observation (Conway et al., 2016), as well as truck–bicycle conflicts on several bicycle and parking lane configurations (Conway et al., 2013). A recent US study has explored cyclists' perceived level of comfort when riding adjacent to truck loading zones by asking them to state their preferences to different configurations in an online survey (Abadi and Hurwitz, 2018). Additionally, studies from the UK have studied cyclists' behaviour at signalised intersection when equipped with external blind spot mirrors (FDS International, 2010). They have also studied cyclists' risk perception in proximity of trucks with respect to gender differences (Frings et al., 2012). Using an online survey, a recent Norwegian study analysed self–reported conflicts between trucks and cyclists (Pokorny et al., 2018).

The study presented in this article aims at exploring the behaviour and conflicts surrounding truck–bicycle encounters using long term traffic recordings at several potentially risky locations as a way to better understand such encounters. The study focuses on the city of Trondheim (population 191,000), which has a reputation of being one of the best "cycling cities" in Norway, having a bicycle modal share of around 9% (Hjorthol et al., 2014). The existing bicycle infrastructure in Trondheim is characterised by a relatively well connected network, particularly outside the city centre. This network consists of separate bicycle paths and bicycle lanes; moreover, cyclists can legally ride on the sidewalks in Norway. The municipality plans to significantly increase the amount of dedicated bicycle infrastructure in the near future (Miljøpakke Trondheim, 2016) thus the bicycle modal share is expected to grow. At the same time, increased truck activity is evident in the city, and safety concerns related to truck–bicycle encounters are growing to an urgent level.

2 Methodology

The study is exploratory in nature. The research approach may be described as inductive, as no preconceived hypothesis was tested. Seven sites (four signalised intersections, two zebra crossings within roundabouts and one bicycle crossing within a T–intersection) have been selected for the initial analysis based on following criteria:

- Potential for risky manoeuvres that was indicated in a previous accident analysis (Pokorny et al., 2017).
- Sufficient bicycle and truck volumes moving in desired directions.
- Sites perceived as risky by cyclists and truck drivers, as found within the survey that preceded this study (Pokorny et al., 2018).
- Possibility of installing the recording unit safely.

Each site was recorded using a portable Scout video collection unit during morning and afternoon peak hours over a period of 5–10 days during the workweek. Video was recorded in 720x480 resolution, with a frame rate of 30 fps. The quality of the recording did not allow for recognition of sensitive personal details (e.g. license plate or gender), which simplified obtaining the approval to record in public places. The recordings were manually reviewed to identify times when both a truck and a cyclist were present and engaged in “encounters of interest” (i.e. events when their behaviour was assumed to be influenced by the other). The truck was defined as a large road vehicle (over 3.5t) used for carrying or hauling goods or materials. Traffic volume counts were completed for one observation day (assumed as an average 8–hour observation day, typically Tuesday), while truck–bicycle encounters were identified over the entire observation period. Encounters were extracted from the recordings and categorised into several types according truck and cyclist’s manoeuvres. Sites with low number of recorded encounters (N<100) were not considered in the analysis.

Conflicts were identified based on an observable evasive action. As explained by Petzold et al., an evasive action can be described in the following manner: a “clearly visible (re–)action either by cyclist or the conflict partner, e.g. hard braking or sudden swerving manoeuvres. It has to be clear that the (re–action is not simply part of a regular manoeuvre, but rather some form of emergency (re–)action” (Petzoldt et al., 2017). Subsequently, when knowledge was acquired as to the exact numbers of each encounter type and conflict, an event–based approach to exposure, as explained by Elvik (2015), was applied, thereby allowing a comparison of the risk involved in each encounter type and site.

Additionally, behaviour patterns were studied which related to yielding behaviour among cyclists, trucks and personal cars at crossings. Road users' positions within the advanced cycle box at a signalised intersection were also studied.

3 Results

Out of a total of seven observed sites, four were selected for further analysis (marked from A to D), as these four provided a sufficient number of encounters (N>100). The sites' characteristics are summarised in Table 1. The results are described separately for the signalised intersection (site A) and the bicycle/ zebra crossings at the non–signalised intersections (sites B, C and D).

Table 1 - Overview of characteristics of observed sites with >100 encounters

	Site A	**Site B**	**Site C**	**Side D**
Type	Signalised intersection	Zebra crossing - roundabout	Zebra crossing - roundabout	Cycle crossing – T-intersection
GPS	63.433083, 10.403722	63.413556, 10.412028	63.439583, 10.405139	63.408639, 10.397306
Cycle infrastructure	Bicycle lane, advanced box	Bicycle path, zebra crossing	Bicycle path, zebra crossing	Bicycle path, separated bicycle crossing
Speed limit	30 km/h	50 km/h	30 km/h	30 km/h
Road category/ Land use	Collector/City centre	Collector/Mixed-residential+university	Exit from harbour area/Industrial	Local/Residential
Analysed encounters	Right-turning trucks vs. straight and right-turning cyclists	Cyclist crossing vs. trucks entering and exiting the roundabout	Cyclist crossing vs. trucks entering and exiting the roundabout	Cyclist crossing minor road vs. trucks entering and exiting the minor road
Cycle volume (8 hours)*	456 straight, 242 right turning	917 using zebra crossing (45/55 direction ratio)	877 using zebra crossing (53/47 direction ratio)	600 using cycle crossing (60/40 direction ratio)
Truck volume (8 hours)*	43 right turning	164 driving over crossing (59/41 direction ratio)	468 driving over crossing (53/47 direction ratio)	89 driving over crossing (55/45 direction ratio)
Total observation time (hours)	112	104	64	60

**The volume shows the traffic count obtained from the video during a typical working day during the observation period. All cyclists and trucks performing manoeuvres of interest during one day of recording were counted.*

3.1 Signalised intersection (site A)

Site A is the four–arm signalised intersection in the city centre. The observed approach has two traffic lanes (with one designated as right–turn only) and a red painted bicycle lane with an advanced bicycle box. The encounters between right–turning trucks and cyclists riding in the bicycle lane on the trucks' right side were of interest (see Figure 1).

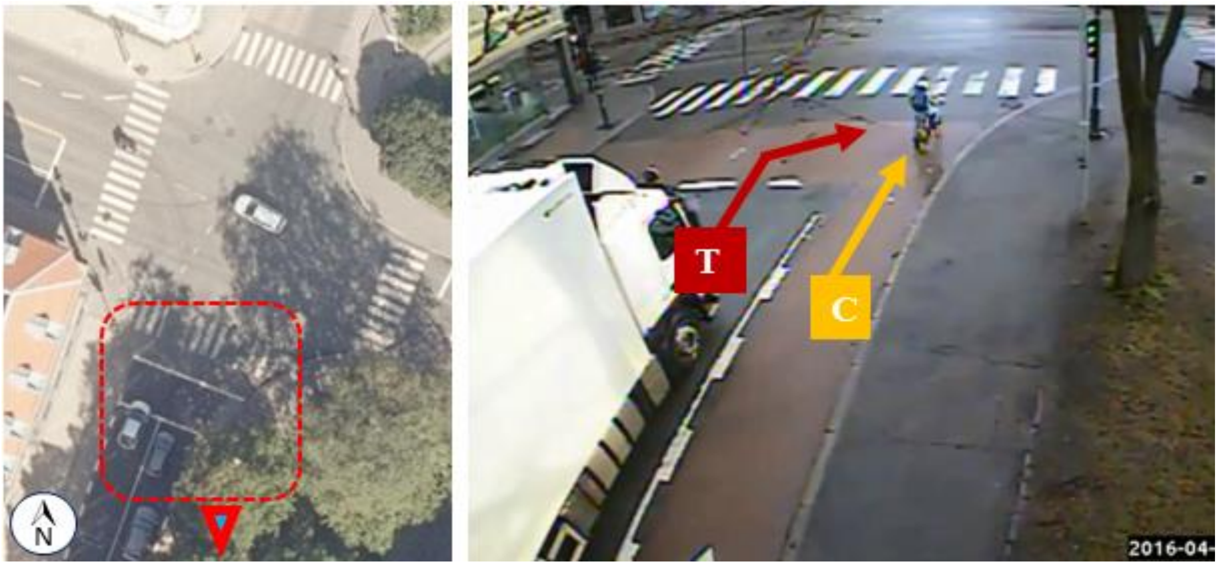

Figure 1: Site A. Left – Aerial photo of the entire intersection with the camera position marked by a triangle symbol and area of interest marked by a red line. Right – Camera view with the manoeuvres of interest (C=cyclist, T=truck)

In total, 197 encounters between right–turning trucks and cyclists riding straight ahead were recorded. Static and moving encounters were distinguished. Their definitions are provided in Table 2.

Table 2 – Types of encounters

Static encounter (N=148)	**Moving encounter (N=49)**
Both trucks and cyclists are stopped at the red phase. When the signal turns green, they both start to move.	Both trucks and cyclists approach and manoeuvre through the intersection during the green phase. This includes situations when a truck accelerates after stopping and a cyclist approaches the intersection and vice versa. Three scenarios have been recorded: ▪ #1 – the cyclist rides and stays behind the truck during the truck's complete turning manoeuvre ▪ #2 – the cyclist tries to overtake the truck along its right (inner) side ▪ #3 – the cyclist rides in front of the truck during the truck's complete turning manoeuvre

3.1.1 Static encounters

Static encounters were the most common at site A (75% of all encounters). No conflicts were observed during these encounters, as cyclists accelerated faster than trucks when the green cycle began, thus "escaping" the trucks' proximity. When observing behaviour during these static encounters, it was obvious that cyclists' waiting positions varied with different other road users present at the intersection when the cyclist arrived. Therefore, the chi–square test was applied to determine, if there was a significant difference in the cyclists' positions. Based on the expected visibility between the cyclists and drivers, four cyclists' waiting areas were recognised, (area A being considered the safest and area D the most risky – see Figure 2). Three scenarios were compared: a) no motorized vehicle present,

b) a previously waiting truck, and c) a previously waiting personal car. Each scenario involved 90 observations of a cyclist arriving at the intersection (note: “the cyclist” meaning the first to arrive and thus being unaffected by the presence of any other cyclists). According to the results of the chi-square test, there was a statistically significant difference (p–value < 0.00001) between the cyclists’ various chosen positions in the three scenarios. Cyclists selected most visible positions when trucks were present (see Figure 2).

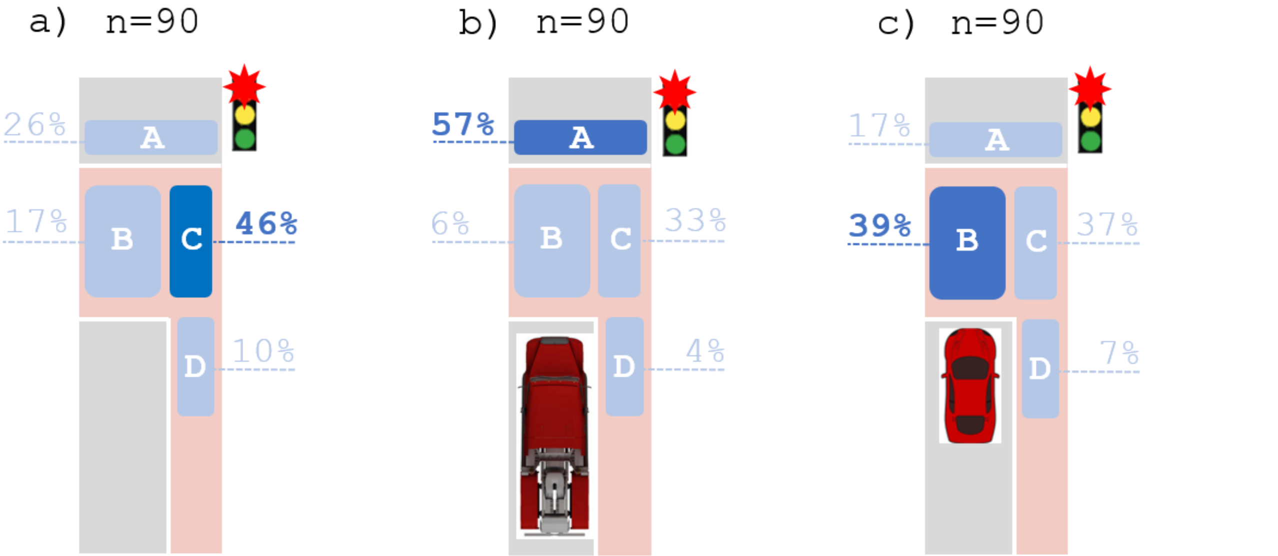

Figure 2: Positions of cyclists (a) without a vehicle, (b) with a truck present, and (c) with a personal car present. The dark blue areas show cyclists’ most frequently chosen positions in each scenario

Furthermore, the stopping positions of both trucks and personal cars were compared regarding two scenarios: a) no cyclist waiting in the advanced cycle box, and b) a cyclist already waiting in the advanced cycle box. Ninety events were evaluated for each scenario. The majority of truck drivers (78%) selected “safer” positions farther back from the stop line (distance > 1 m) when a cyclist was present, thus gaining a better overall view of the area. However, personal car drivers did not display this behaviour as frequently (44% stopping farther back from the stop line). According to the results of the chi-square test, this difference is statistically significant (p–value < 0.00001). When cyclists were not present, there was no statistically significant difference (p-value = 0.257) in the behaviour of truck drivers and car drivers, as 34% and 27% respectively stopped at a position farther away from the stop line.

3.1.2 Moving encounters

The recordings captured 49 moving encounters where both trucks and cyclists approach and manoeuvre through the intersection during the green signal phase. Twenty encounters were type #1 (cyclist staying a certain distance behind the turning truck during the truck’s complete turning manoeuvre), 21 encounters were type #2 (cyclist trying to overtake the truck along its right side) and 8 encounters were type #3 (cyclist staying in front of the turning truck).

There were no conflicts observed within encounters #1 and #3, where the cyclist stayed either directly behind or in front of the truck. In several encounters of both types, either cyclists or truck drivers slowed down slightly, so that the other road user could manoeuvre through the intersection. In seven encounters #1, cyclists rode in the traffic lane behind the turning truck instead of in the bicycle lane. In three encounters #1, cyclists overtook the turning truck along the trucks' left side during the truck–turning manoeuvre.

In moving encounters #2, the cyclists rode parallel to the turning trucks (note that a truck driver who is turning right should yield to a cyclist who is riding parallel in the cycle lane). In 11 cases of these encounters, cyclists overtook the truck and travelled through the intersection ahead of the truck, in some cases after a certain amount of negotiation. However, in 10 of the encounters, the truck turned first despite the cyclist's presence. In the latter encounters the involved cyclists were forced to stop (or "balance" at a very low speed), and 6 conflicts were identified.

T–Analyst software[1] provided more details regarding the mutual speeds of both trucks and cyclists in moving encounter #2. Interestingly, in all 21 of the encounters, the cyclist was travelling faster than the truck in their approach to the intersection. Two typical examples of speed profiles and behaviour of trucks and cyclists in these encounters are shown in Figure 3.

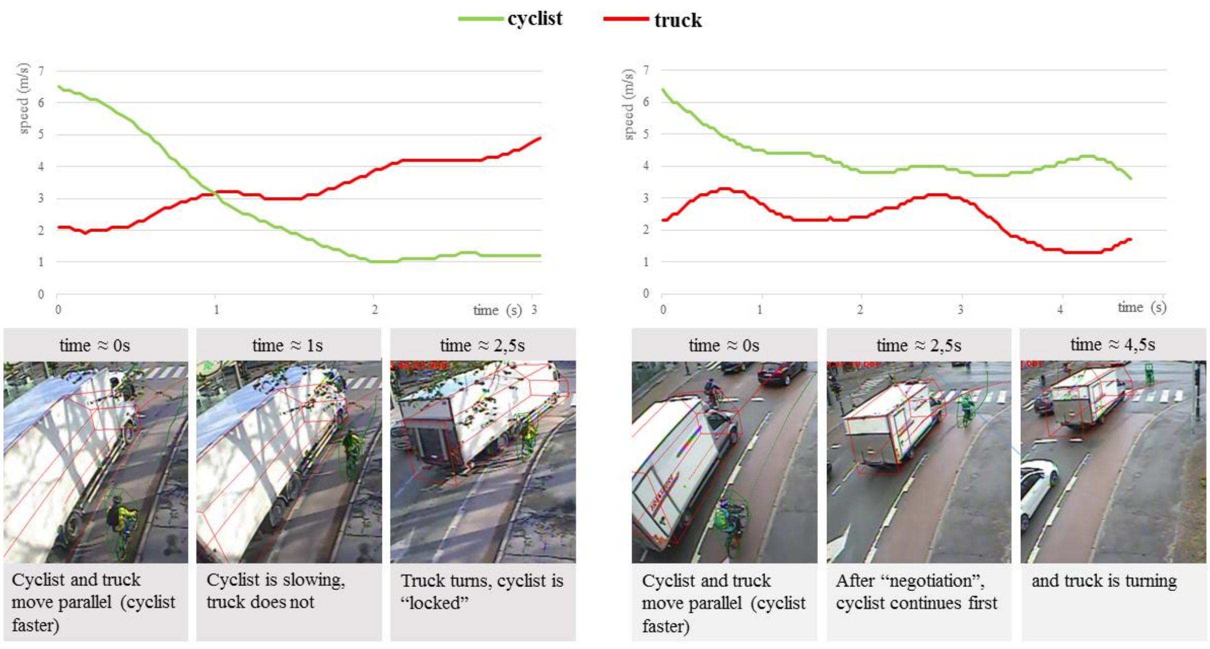

Figure 3: Speed profiles in moving encounter #2. Cyclist being locked by turning truck (left). Cyclist goes first after a negotiation (right)

Additionally, encounters involving right–turning cyclists were of interest, as these encounters can be dangerous for cyclists because of the turning trucks' potential cut–in trajectory. The majority

---

[1] *A semi-automated tool for processing videos and managing detected situations of interest, developed by the Department of Technology and Society at the Faculty of Engineering, Lund University*

of the right–turning cyclists rode on the sidewalk. Nevertheless, 11 encounters were noted when a cyclist was turning right while using bicycle lane and simultaneously a right–turning truck was present. In all of the observed encounters, cyclists rode relatively fast (up to 10 m/s) while adjacent to the trucks, without giving any indication that they might undertake a turning manoeuvre. In three encounters, truck drivers lowered their speed to an almost complete stop as they approached the intersection. None of these encounters were considered conflicts.

3.2 Zebra crossings and cycle crossings at non-signalised intersections (sites B, C, D)

Three crossing sites were analysed. There were different yielding rules at sites B and C (zebra crossing) compared to site D (bicycle crossing). In the case of zebra crossings, cyclists must yield to vehicular road traffic (while vehicles must yield to pedestrians). Typically, cyclists have three options: a) yielding to drivers, b) riding over the zebra crossing while hoping drivers will yield or c) forcing drivers to yield by dismounting and walking over the zebra crossing. However, should a cyclist stay on his/her bicycle, approaching drivers have two choices: either a) driving on as the law suggests or b) yielding to the cyclists. Yet, because of a designated bicycle crossing at site D, cyclists have the right of way over vehicular traffic.

Site B is a four–arm roundabout in a mixed land use environment (university, football stadium, residences). The observed zebra crossing overlays two traffic lanes on the approach and one traffic lane on the exit (see Figure 4). The exit and approach are divided by a raised traffic refuge island. There is a sidewalk on the southern end of the crossing and a bidirectional bicycle path on its northern end.

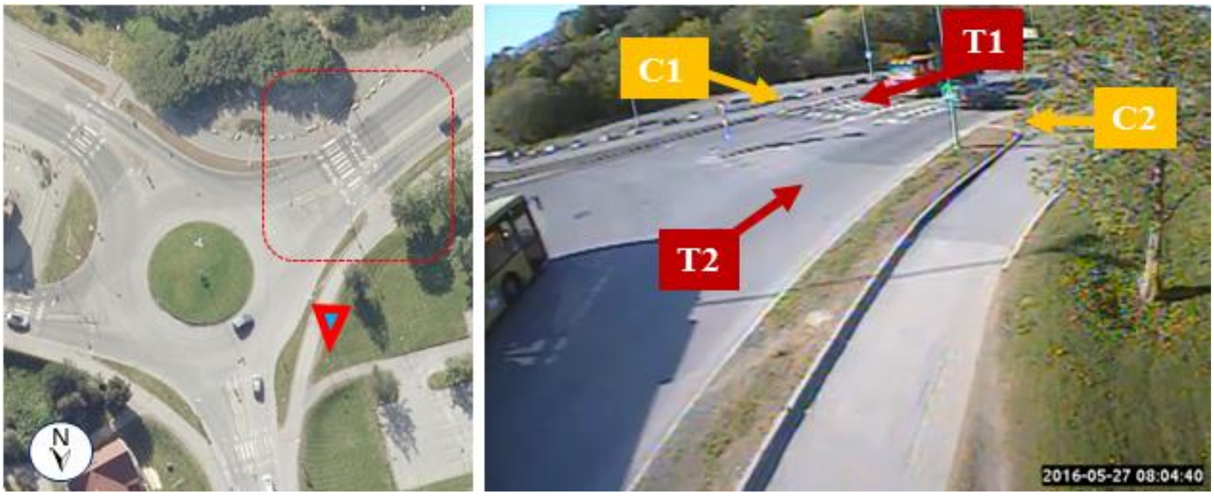

Figure 4: Site B. Left – Aerial photo of the entire intersection with the camera's position marked by a triangle and area of interest marked by a red line. Right – Camera view with the manoeuvres of interest (C=cyclist, T=truck)

Regarding this particular site, 191 encounters were observed during cyclists' crossing manoeuvres (86 C1T1, 34 C1T2, 41 C2T1 and 30 C2T2). Fifteen conflicts were identified in total. Twelve conflicts occurred between one truck and one cyclist (with the trucks yielding to the cyclists); however, the evasive action was not intense. The remaining three conflicts related to the approach's two–lane configuration, when a vehicle (truck or car) in one lane yielded to a cyclist while simultaneously reducing the visibility between this cyclist and a truck approaching in the adjacent lane.

Site C is a four–arm roundabout near the industrial port. The observed zebra crossing on the eastern leg crosses one traffic lane on the approach and one traffic lane on the exit. The exit and approach are divided by a raised traffic refuge island. There is a sidewalk and bidirectional bicycle path on both ends of the crossing (see Figure 5).

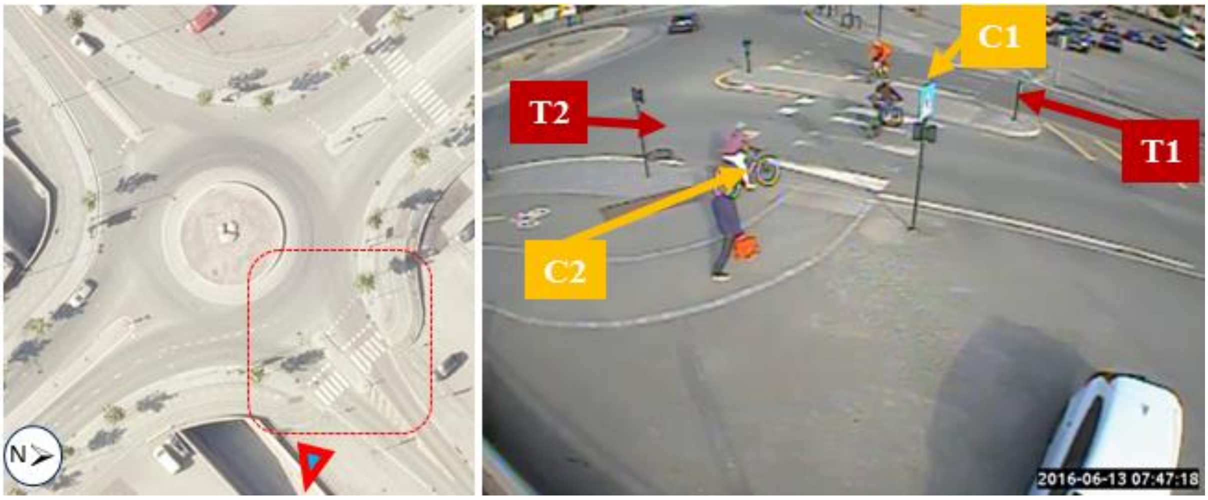

Figure 5 Site C. Left – Aerial photo of the entire intersection with the camera's position marked by a triangle and area of interest marked by a red line. Right – Camera view with the manoeuvres of interest (C=cyclist, T=truck)

A total of 370 crossing encounters were observed at this site (125 C1T1, 44 C1T2, 149 C2T1 and 52 C2T2). Seven conflicts were identified, with trucks stopping suddenly for crossing cyclists in every situation. One specific conflict was captured during the pilot recording at this site, when the camera was placed in a different position than later in the study (the pilot position of the camera was determined to be insufficient to cover the desired area). This conflict is not included in the analysis; nevertheless, as it demonstrates a cyclist's unexpected risky manoeuvre, it is described here. The conflict was observed within a C1T1 encounter. The short distance between the bicycle crossing and the roundabout's entrance, combined with a high number of long trucks entering the roundabout, contribute to situations where trucks block the crossing while waiting for a suitable moment to enter the roundabout. This blockage forces cyclists to either wait or make a potentially unsafe manoeuvre around the waiting truck. A total of 109 similar "blocking" situations were observed during the "official" recording and several of them lasted for more than 1 minute. Typically, the cyclists waited or went around the rear of the truck. However, during the pilot recording, one cyclist decided to ride in front of a truck, using the roundabout in contra-flow. At the same time, the truck started to move. The truck driver had to brake hard in order to avoid a collision when noticed the cyclist.

Site D is a three–arm T–intersection in a residential area. The observed red painted raised bicycle crossing (combined with zebra crossing) crosses one traffic lane on the approach and one traffic lane on the exit (see Figure 6). There is a sidewalk and bidirectional bicycle path on both ends of the crossing.

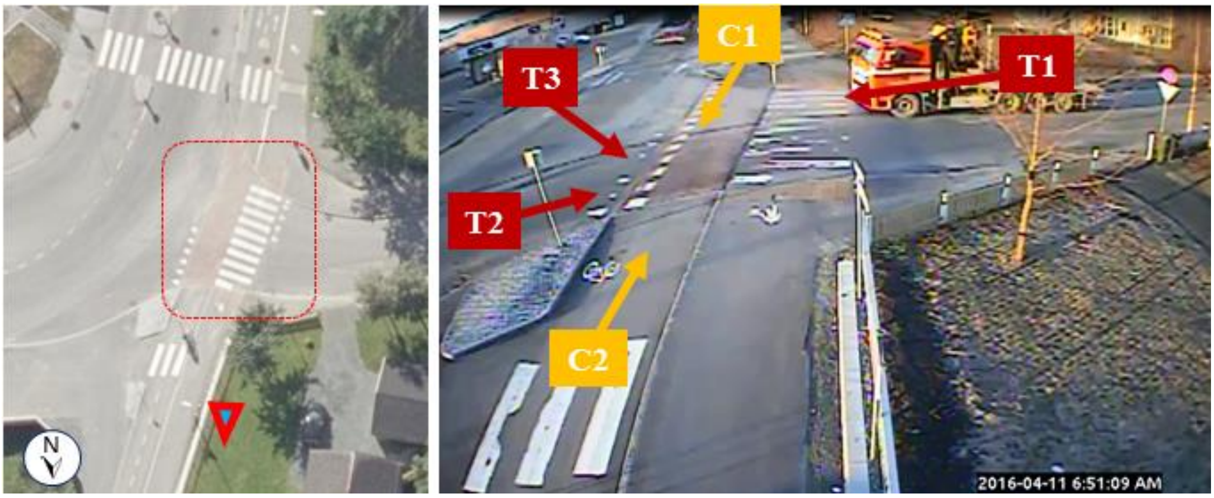

Figure 6 Site D. Left – Aerial photo of the entire intersection with the camera's position marked by a triangle and area of interest marked by a red line. Right – Camera view with the manoeuvres of interest (C=cyclist, T=truck)

A total of 161 encounters were observed at this site (93 C1T1, 18 C1T2, 33 C2T1, 6 C2T2, 10 C1T3 and 1 C2T3). During the entire observation period, three conflicts were identified, all involving trucks from T1 direction. In two of the conflicts, a truck performed a slightly evasive (braking) manoeuvre, and in the other one, a cyclist braked in a controlled manner.

3.2.1 Crossing behaviour of cyclists

The cyclists' crossing behaviour in encounters with trucks and personal cars was compared at all three sites, particularly the percentages of cyclists who dismounted from their bicycle and those who stayed on their bicycle while crossing. Only encounters uninfluenced by the presence of other road users were compared (112 encounters at site B, 158 encounters at site C and 59 encounters at site D). As previously stated, the yielding rules vary at the crossing sites – at sites B and C, cyclists are to behave like pedestrians (dismount and walk their bicycle) in order to maintain the right–of–a–way over vehicles, while at site D, cyclists have priority when staying on their bicycles.

At site D, 100% of cyclists rode (stayed on) their bicycles while crossing. This fact is unsurprising given that they have priority here, thus, there is no "advantage" to dismounting. However, there was a significant difference (p–value < 0.00001) between sites B and C even though the same traffic rule applies to both sites. At site B, cyclists dismounted from their bicycles in 44% of crossing encounters with trucks (behaving as a pedestrian and thus having the right–of–way), while at site C only 4% did so. Furthermore, there was a significant difference (p–value < 0.00001) observed between cyclists' behaviour in encounters with trucks and personal cars at site B. Significantly more cyclists dismounted from their bicycles in crossing encounters with trucks than with personal cars (44% vs. 14%). No such difference was observed at site C.

3.2.2 Yielding behaviour of motorised vehicles

Upon consideration of the observations at all three crossing sites, it was possible to compare the yielding behaviour of trucks and personal cars in encounters when cyclists approached the crossing and stayed on their bicycles. Only encounters uninfluenced by other road users were analysed. Table 3 shows the results for all three sites. The values printed in bold type present the incorrect behaviour as defined by traffic rules. Generally, regardless of the traffic rules, motor vehicles yielded to cyclists.

Table 3 – Yielding behaviour of truck and car drivers, while cyclists are on their bicycles

	Truck		**Personal cars**	
	did not yield	**yielded**	**did not yield**	**yielded**
Site B (N=62)	27%	**73%**	13%	**87%**
Site C (N=152)	30%	**70%**	11%	**89%**
Site D (N=59)	**5%**	95%	**0%**	100%

Over 70% of truck–bicycle encounters at sites B and C proceeded against the traffic rule (the truck yielding to the cyclist despite having the right–of–way), while in the case of personal cars, this share rose to nearly 90%. This difference is significantly different ($p = 0.04395$ for site B and $p = 0.00007$ for site C). In contrast, at site D there was no significant difference in the behaviour of truck and personal car drivers, as almost all encounters were processed as defined by traffic rules and all vehicles yielded to cyclists. This is expected given the layout of site D, which priorities cyclists.

3.3 Risk comparison of sites and encounter types

To estimate and compare the risk related to each site and encounter type, the event–based approach to measuring the exposure as described by Elvik (2015) was applied. Regarding each site, the percentage of conflicts in total number of relevant encounters were calculated (see Table 4). Site B (zebra crossing on two–lane approach/one–lane exit to/from roundabout) scored as having the highest share of conflicts.

Table 4 – Comparison of observed sites

Site	**A**	**B**	**C**	**D**
Nr. of observation hours	112	104	64	60
Nr. of encounters	210	191	370	161
Nr. of conflicts	6	15	7	3
Percentage of conflicts	3%	8%	2%	2%

To compare the particular encounter types, the risk of each encounter type was calculated as the share of conflicts in each encounter type (see Table 5). The moving encounter #2 at site A (the cyclists riding along the inner side of the right–indicating trucks) was ranked as being the riskiest encounter. Encounter types C1T2 and C2T1 at site B were the riskiest crossing encounters, both occurring on the crossing's outer edge (from the cyclist's point of view).

Table 5 – Number of encounters, conflicts and share of conflicts in each encounter type for each site (only non-zero values of conflicts shown)

Site	Type of encounter	Nr. of encounters	Nr. of conflicts	Percentage of conflicts
A	Moving #2	21	6	29%
B	C1T1	86	6	7%
	C1T2	34	4	12%
	C2T1	41	5	12%
C	C2T1	149	3	2%
	C1T1	125	4	3%
D	C1T1	93	1	1%
	C2T1	33	2	6%

4 Discussion

The discussion considers conflicts, behaviour and risk awareness as well as consideration of the methodology.

4.1 Conflicts

The video recordings were analysed for conflicts in specific encounters at each site. The highest share of conflicts was seen in the right–turning encounters, more specifically when the cyclists rode along the inner side of the right–indicating trucks. This observation indicates that a certain number of cyclists choose to overtake right–turning trucks on the right, thus placing themselves in potential blind spots. While this type of manoeuvre is legal given that the cyclist has the right–of–way, there is a great potential for conflicts to develop due to limited visibility. This finding correlates to a certain degree with the results of several accident studies which indicate that a similar type of accident occurs frequently (Kaplan and Prato, 2013), (Seiniger et al., 2015). However, as no such accident was recorded at the observed site, it is not possible to validate this finding. In five of the six recorded conflicts of this type, cyclists had to perform an evasive action (i.e. almost stop) due to them being cut–off by the turning trucks. The observations were not able to reveal whether truck drivers were aware of cyclists or not. The existence of bicycle lanes and a simultaneous green signal phase for right–turning trucks and straight riding cyclists could contribute to the occurrence of these situations. Also at this site, encounters that involved right–turning cyclists and right–turning trucks appeared confusing for the truck drivers as cyclists rode relatively fast next to the trucks without giving any indication that they would make the turning manoeuvre. Therefore, the truck drivers might have been uncertain about the cyclists' intentions and consequently slowed down or stopped their vehicle as seen in several encounters.

Regarding the crossing sites (B–D), the identified conflicts were characterised by only slightly evasive actions and could thereby easily be considered as a standard yielding. Both cyclists and trucks reduced their speeds before cyclists typically crossed in front of trucks, seeming to be aware of each other or at least the potential for an encounter. The conflicts with more intense evasive action were rare and were related to “unexpected” scenarios (i.e. cyclists trying to go around trucks blocking the crossing).

Site B (zebra crossing on two-lane approach/one-lane exit to/from roundabout) scored as having the highest share of conflicts for any site studies. At this location, the existence of two–lane traffic on the approach (which impacted visibility), and poor road marking of the crossing could have contributed to conflicts (see Figure 7, left).

4.2 Behaviour and risk awareness

In addition to the previously described risky behaviour at site A, several forms of risk awareness were observed. For instance, the observation of road users’ positions while waiting for the green signal revealed that the majority of observed cyclists and truck drivers seemed to be aware of the potential risks related to limited visibility and adjusted their behaviour accordingly, placing themselves in positions which allowed for greater visibility more frequently when compared to encounters with personal cars. As the visibility limitations connected to personal cars are not as critical as to trucks, it seems that cyclists differentiate the risk between trucks and cars.

Another form of risk awareness was observed during the encounters when cyclists rode in the traffic lane behind the right–turning truck. Motivation for such behaviour could be that the cyclists wanted to avoid any encounter with turning trucks. This type of manoeuvring requires a certain level of cycling experience as these cyclists were comfortable enough to ride in the middle of traffic. Alternatively, when cyclists rode in front of the trucks, truck drivers usually slowed down to a slight degree, which would let them maintain their visibility of the cyclists.

Several encounters involved visible negotiations between cyclists and truck drivers to make it clear who was to go first. However, these actions were detectable only from the cyclists’ perspective. They typically ended with cyclists waving their arm to thank the truck drivers. This type of communication shows an awareness of the situation that while traffic rules may dictate who has the right–of–way, there can be both uncertainty regarding specific behaviours, as well as a certain amount of compromise between road users.

The observation of crossing and yielding behaviour at zebra crossings (sites B and C) revealed that many encounters proceeded against traffic rules. A similar finding was reported in a recent Norwegian study (Bjørnskau, 2017) where a majority of car drivers yielded to cyclists at zebra crossings against traffic rules. Bjørnskau observed three locations and at two of them, around 80% of car drivers yielded to cyclists. This type of behaviour demonstrates a willingness among drivers to share the road space, and act in ways that are mutually beneficial. Nonetheless, within this study it was observed that truck drivers were less willing to stop for cyclists than drivers of personal cars. This unwillingness may be explained by the fact that decelerating and accelerating is more demanding for trucks than for personal cars.

Furthermore, it was observed that cyclists adjusted their crossing behaviour in relation to a site layout and traffic conditions. A majority of cyclists dismounted from their bicycles and behaved as pedestrians at site B where the road was wider and the speed of trucks appeared higher compared to other sites. Additionally, the perception of the crossing seemed to be important. If the crossing looked more like a proper bicycle crossing than a zebra crossing (i.e. site C), cyclists did not dismount from their bicycles as often as they did on the zebra crossing which is not as well marked (i.e. site B, see Figure 7). The presence of a truck also appeared to be an important factor affecting cyclists' crossing behaviour, as was observed at site B.

Figure 7 – The same traffic rule, the different crossing/yielding behaviour at those sites. Site B on the left, site C on the right (source: google maps)

4.3 Methodological aspects

A total of seven sites were nominated for the recordings. These sites were carefully selected based on the researchers' knowledge from previous accident analysis and surveys. Moreover, in order to record a sufficient number of encounters, the recording period was relatively long at each site (on average 81 hours per site). However, only four sites provided a sufficient number of encounters to study. This might be influenced by sites' layout and different traffic volumes and peak travel periods for both cyclists and trucks. The large number of recorded hours resulted in large demands on both equipment and data processing. A total of 569 hours of recording were collected within the confines of this study. A manual analysis of this amount of data was determined to be quite time-consuming. Therefore, a software programme providing computer–based analysis of traffic videos (so–called "watch dog") was applied in order to detect the road users in the recordings and identify the moments when there was a cyclist and truck performing a manoeuvre of interest (i.e. encounter). However, changing environmental conditions such as lighting, in addition to lower recording quality (caused by low resolution of the recordings and significant distance of the camera from certain sites), along with complexity of urban traffic situations and cyclists' characteristics (e.g. a certain level of unpredictability or riding in groups) made automated identification unreliable. Thus, a manual identification of encounters had to be conducted.

The evaluation of recorded encounters presented a certain number of challenges as well, particularly regarding the determination of the threshold between conflicting and non–conflicting encounters. Within the scope of this study, a "conflict" was identified through an obvious evasive action that could be visually recognised by researchers, which involves a certain level of subjectivity. Quantifying the evasive action, e.g. by measuring the deceleration, would increase the objectivity of the conflicts' identification. Although as some accidents occur without any evasive action (Zheng et al., 2014), the same may be true for conflicts. In the case of truck–bicycle encounters, the absence of evasive action from the truck driver could mean that the driver failed to notice a cyclist. Post–encroachment time (PET) could be a useful indicator in such cases, particularly in crossing encounters (Laureshyn et al., 2010). However, the specific characteristics of the truck–bicycle encounters (i.e. very low speeds and the close proximity of concerned road users) makes these types of calculations challenging and they were not undertaken during this study.

The low number of observed conflicts (approximately one conflict per 11 hours of recording) raises the question about the feasibility of the conflict technique for studying truck–bicycle safety. Additionally, the occurrence of relevant truck–bicycle accidents is so rare that making any validation of recorded conflicts is almost impossible. Therefore, complementing the conflict analysis with behavioural observations provided valuable insight into truck–bicycle co–existence. Nevertheless, the manner in which the observed behaviour is linked to the actual accident risk remains unclear, and the assumptions regarding behaviour and risk awareness need to be confirmed. For example, a roadside survey could be conducted to obtain further direct insight into the involved road users' behaviour.

5 Conclusion

Given the expected growth of cyclists and trucks' volumes in urban areas, they – despite all the strategies and measures – will continue to encounter one another in urban areas, particularly at intersections. Experiencing an encounter with a truck can decrease cyclists' comfort and increase their perceived risk (thereby negatively affecting their motivation to cycle). If these encounters were to escalate into an accident, its consequences could often be very severe. In spite of the fact that these accidents do not frequently occur, the current knowledge about truck–bicycle safety is founded on their analysis. Thus, in order to better understand truck–bicycle safety, the less severe encounters from a traffic safety continuum must also be studied, as was done in this study. The analysis of video recordings revealed several conflict types, cyclists' risky behaviour, and both truck drivers and cyclists' levels of risk awareness. The knowledge about the number of encounters and conflicts allowed for the comparison of the risk of specific encounter types and sites.

When interpreting this study's findings, it is necessary to keep in mind that its results may reflect the cultural differences, driving norms, and infrastructure design specific to Norway (e.g. cautious driving behaviour and legal cycling on sidewalks). Additionally, the unique characteristics of each site call for a context–sensitive approach, which considers local conditions. At the same time, this study provides insight into the use of the methodology. The low frequency of recorded conflicts suggests that analysing behaviour could be a complementary approach to evaluating safety at locations with frequent truck-bicycle encounters. While these behaviours might not result in accidents, studying them provides insight into how road users operate with respect to infrastructure in spite of traffic regulations or expected usage. This knowledge may in turn be used to create and improve safe infrastructure designs at locations where trucks and bicycles meet, as well as educate roadway users. Such designs and education are vital not only for existing cyclists, but also for people who are deciding whether to cycle or not.

Acknowledgement

The authors would like to thank the numerous students from NTNU who watched the videos for the purpose of identifying the encounters' presence, Jonas Austli for assisting with camera installations and providing his truck driver perspective, Aliaksei Laureshyn (Lund University) for offering valuable methodological comments, and Martin Lipl (CDV) for his assistance with the speed analysis. The involvement of Martin Lipl was made possible by the financial support provided by the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Programme I, project of Transport R&D Centre (LO1610).

References

Abadi, M. G., Hurwitz, D. S. (2018). Bicyclist's perceived level of comfort in dense urban environments: How do ambient traffic, engineering treatments, and bicyclist characteristics relate? *Sustainable Cities and Society*, *40*, 101-108. doi.org/10.1016/j.scs.2018.04.003

Allen-Munley, C., Daniel, J. (2006). Urban bicycle route safety rating model application in Jersey City, New Jersey. *Journal of Transportation Engineering*, *132 (*6), 499–507.

Bjørnskau, T. (2017). The Zebra crossing game – Using game theory to explain a discrepancy between road user behaviour and traffic rules. *Safety Science*, *92*, 298–301. doi.org/10.1016/j.ssci.2015.10.007

Bjørnskau, T. (2005). Sykkelulykker. Ulykkestyper, skadekonsekvenser og risikofaktorer – Accident types, consequences, and risk factors (in Norwegian). TØI report 793. Institute of Transport Economics, Oslo, Norway. https://www.toi.no/publications/bicycle-accidents-accident-types-consequences-and-risk-factors-article18883-29.html

Conway, A., Tavernier, N., Leal-Tavares, V., Gharamani, N., Chauvet, L., Chiu, M., & Bing Yeap, X. (2016). Freight in a bicycle friendly city. *Transportation Research Record: Journal of the Transportation Research Board*, *2547*, 91–101. doi: 10.3141/2547-13

Conway, A., Thuillier, O., Dornhelm, E., & Lownes, L. (2013). Commercial vehicle-bicycle conflicts: A growing urban challenge. Paper presented at TRB Annual Meeting, Washington, USA.

European Commission (2017). Annual Accident Report. European Commission, Directorate General for Transport.
https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/dacota/asr2017.pdf

Elvik, R. (2015). Some implications of an event-based definition of exposure to the risk of road accident. *Accident Analysis & Prevention*, *76*, 15–24. doi.org/10.1016/j.aap.2014.12.011

FDS International. (2010). Trial of roadside safety mirrors for cycle visibility. Transport for London, London, UK. www.tfl.gov.uk/trial-of-roadside-safety-mirrors-for-cycle-visibility-report.pdf

Fyhri, A., Sundfør, H. B., Bjørnskau, T., & Laureshyn, A. (2017). Safety in Numbers for cyclists – conclusions from a multidisciplinary study of seasonal change in interplay and conflicts. *Accident Analysis & Prevention, 105,* 124–133. doi.org/10.1016/j.aap.2016.04.039

Frings, D., Rose, A., & Ridley, A. M. (2012). Bicyclist fatalities involving heavy goods vehicles: gender differences in risk perception, behavioral choices, and training. *Traffic Injury Prevention*, *13*, 493–498. doi: 10.1080/15389588.2012.664796

Hjorthol, R., Engebretsen, Ø., & Uteng, T. P. (2014). Den nasjonale reisevane undersøkelsen 2013/14 –nøkkelrapport – Norwegian Travel Survey 2013/2014 (in Norwegian). TØI report 1383. Institute of Transport Economics, Oslo, Norway. https://www.toi.no/getfile.php?mmfileid=39511

Ismail, K., Sayed, T., & Saunier, N. (2014). A methodology for precise camera calibration for data collection applications in urban traffic scenes. *Canadian Journal of Civil Engineering, 40*, 57–67. doi.org/10.1139/cjce-2011-0456

Johnsson, C., Laureshyn, A., & De Ceunynck, T. (2018). In search of surrogate safety indicators for vulnerable road users: a review of surrogate safety indicators. *Transport Reviews, 38*. doi:10.1080/01441647.2018.1442888

Kaplan, S., Prato, C. G. (2013). Cyclist-motorist crash patterns in Denmark: a latent class clustering approach. *Traffic Injury Prevention*, *14*, 725–733. doi:10.1080/15389588.2012.759654

Kim, J. K., Kim, S., Ulfarsson, G. F., & Porrello, L. A. (2007). Bicyclist injury severities in bicycle-motor vehicle accidents. *Accident Analysis & Prevention*, *39*, 238–251. doi: 10.1016/j.aap.2006.07.002

Kockum, S., Örtlund, R., Ekfjorden, A., & Wells, P. (2017). European accident research and safety report. Volvo Truck, Sweden. https://www.volvogroup.com/content/dam/volvo/volvo-group/markets/global/en-en/about-us/traffic-safety/Safety-report-170627.pdf

Laureshyn, A., Svensson, Å. & Hydèn, Ch. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. *Accident Analysis & Prevention, 42*, 1637–1646. doi.org/10.1016/j.aap.2010.03.021

Miljøpakke Trondheim (2016). Evaluering av Miljøpakke Trondheim 2016 – Evaluation of Greener Trondheim (in Norwegian). Report 2/2016. Miljøpakke, Trondheim, Norway. https://miljopakken.no/wp-content/uploads/2011/01/Evaluering-Milj%C3%B8pakken-2016.pdf

Morgan, A. S., Dale, H. B., Lee, W. E., & Edwards, P. J. (2010). Deaths of cyclists in London: trends from 1992 to 2006. *BMC Public Health, 10.*

Niewoehner, W., Berg, A. (2005). Endangerment of pedestrians and bicyclists at intersections by right turning trucks. *Statistics*.

Petzoldt, T., Schleinitz, K., Heilmann, S., & Gehlert, T. (2017). Traffic conflicts and their contextual factors when riding conventional vs. electric bicycles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *46*, 477–490. doi.org/10.1016/j.trf.2016.06.010

Pokorny, P., Drescher, J., Pitera, K., & Jonsson, T. (2017). Accidents between freight vehicles and bicycles, with a focus on urban areas. *Transportation Research Procedia, 25,* 999–1007. doi.org/10.1016/j.trpro.2017.05.474

Pokorny, P., Pritchard, R., & Pitera, K. (2018). Conflicts between bikes and trucks in urban areas – A survey of Norwegian cyclists. *Case Studies on Transport Policy, 6,* 147–155. doi:10.1016/j.cstp.2017.11.010

Raftery, S., Woolley J., & Grigo, J. (2013). Heavy Vehicle Safety Data. Austroads Research Report No. R441-13. Austroads Publications Online, Sydney, Australia. https://www.onlinepublications.austroads.com.au/items/AP-R441-13

Sanders, R. L. (2015). Perceived traffic risk for cyclists: The impact of near miss and collision experiences. *Accident Analysis & Prevention*, *75*, 26–34. doi.org/10.1016/j.aap.2014.11.004

Seiniger, P., Gail, J., & Schreck, B. (2015). Development of a Test Procedure for Driver Assist Systems Addressing Accidents Between Right Turning Trucks and Straight Driving Cyclists. The 24th ESV Conference Proceeding. Gothenburg, Sweden.

Twaddle, H., Busch, F. (2019). Binomial and multinomial regression models for predicting the tactical choices of bicyclists at signalised intersections. *Transportation Research Part F: Psychology and Behaviour*, *60*, 47–57. https://doi.org/10.1016/j.trf.2018.10.002

Zheng, L., Ismail, K., & Meng, X. (2014). Traffic conflict techniques for road safety analysis: open questions and some insights. *Canadian Journal of Civil Engineering*, *41*, 633–641. doi.org/10.1139/cjce-2013-0558