ISBN 978-82-326-2874-2 (printed ver.)
ISBN 978-82-326-2875-9 (electronic ver.)
ISSN 1503-8181

NTNU
Norwegian University of
Science and Technology

Petr Pokorny

Doctoral thesis

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NTNU
Norwegian University of Science and Technology
Thesis for the Degree of
Philosophiae Doctor
Faculty of Engineering
Department of Civil and Environmental
Engineering

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Printed by NTNU Grafisk senter

Acknowledgements

I would like to express my gratitude to all the people working at the Department of Civil and Environmental Engineering at NTNU. I particularly would like to thank Carl Christian Thodesen, Kjerstina Røhme and Trude Tørset, who run the department in such a positive way that it has been a great pleasure to spend a part of my life there. I have appreciated the opportunities to attend awesome social activities and outstanding conferences and seminars, both in Norway and abroad. Furthermore, I would like to thank María Díez Gutiérrez, Albert Lau and Ray Pritchard, my friends and colleagues, for all those moments we have spent together discussing our research, fishing and exploring the beauty of Norway.

I would also like to thank Eirin Ryeng (NTNU) for chairing the PhD committee and Anne Goodchild (University of Washington) and Aliaksei Laureshyn (Lund University) for their efforts in evaluating my work. My very special thanks goes to my supervisor Kelly Pitera, who developed the initial project idea and offered me the PhD position. She provided me with absolute freedom and trust, which motivated me even more to give my all when doing the research.

I would like to express my thanks to my co-supervisor Thomas Jonsson (NTNU) for his advices, Axel Wilke (ViaStrada) who guided me to the topic of cyclists' safety and Josef Mikulík (CDV), who was my mentor when I first started working in the field of traffic safety research in 2002. I would also like to thank Jonas Austli and Tore Skaldebø for their friendship and the great times we spent together brewing beer and climbing.

Finally, my deepest gratitude goes to my parents, who have always supported me in my move abroad. And naturally, I would like to thank my wife Belma for her infinite love and patience. As she herself is an excellent researcher, she has been providing me with many inspirational ideas and helped me a lot during my PhD research.

Trondheim, January 2018

Petr "Pøk" Pokorný

Abstract

Currently, the numbers of cyclists are increasing in many cities worldwide. People are encouraged and motivated to cycle, as it improves their health, reduces the negative effect of car traffic and creates more liveable and vibrant cities. At the same time, current economic development, customers' requirements and shippers' strategies are contributing to the growth of truck traffic in urban areas. Trucks and cyclists must share the constrained urban space, and their routes often overlap. Experiencing an accident with a truck presents one of the most serious encounters imaginable for a cyclist, and just the presence of trucks on the roads may deter some people from cycling. Therefore, finding more out about safety between trucks and cyclists has been recently recognised as an important topic requiring extensive research.

To get more comprehensive knowledge about the topic, several methods have been applied within a Norwegian context in this PhD project. These methods included the literature review, analysis of accident records from the national database and review of in-depth investigation reports of fatal accidents, nationwide survey of cyclists regarding their conflicts with trucks, face-to-face interviews with trucking industry employees and behavioural and conflict analysis using long-term video recordings of traffic on several sites. In particular, the infrastructure-related risk factors were of research interest. Most truck-bicycle encounters occur in urban areas; thus, focus has been directed towards urban environments. Trucks over 3.5 tonnes (excluding vans) have been considered in this research. The main conclusions from each method are summarised below.

The literature review found that the current understanding of truck-bicycle safety is based on accident analysis, and that particularly technological tools to detect the cyclists in the trucks' blind spots are in the centre of research attention. Accidents between trucks and cyclists (particularly involving right turning trucks) have been recognised as severe road safety problem in urban areas since 1990's. They are not frequent, but typically have very severe consequences for involved cyclists. Additionally, several knowledge gaps were identified within the review, such the lack of an explanation for the overrepresentation of female cyclists in accidents with trucks, lack of effort to identify risk factors from higher levels of the transport system or lack of safety analysis of less severe encounters in traffic (e.g. conflicts).

The analysis of the accident records from police databases revealed that the percentage of cyclists killed in accidents with trucks among all cyclists' fatalities in Norway is one of the highest in Europe. Residential areas were the most frequent environment for truck-bicycle accidents, with intersections and crossings being the most common locations. Right-turning

accidents were recorded as those that happened most often. In addition, female cyclists were found to be overrepresented in serious and fatal accidents with trucks.

The review of the in-depth investigation reports of fatal truck-bicycle accidents clarified the characteristics of the truck drivers and their vehicles involved in the accidents with bicycles. Most of the trucks were relatively modern, having the required safety equipment and being driven by experienced drivers. Moreover, the review provided deeper insight into the development of the accidents themselves. The combination of various risk factors was found to contribute to each accident's occurrence.

The nationwide questionnaire survey of cyclists identified recurring types of conflicts with trucks. Over 60% of respondents reported at least one conflict with a truck over the past 12 months. Surprisingly, overtaking conflicts were reported as being the most frequent. It appears that the distribution of conflict types is significantly different within Norwegian cities, a finding which might be partially explained by the cities' different infrastructure layouts.

The face-to-face interviews with truck drivers and managers from the companies operating their trucks in Trondheim provided valuable information about the risky locations existing in that city. Furthermore, the route planning procedures within the companies were discussed, and it was found that cyclists' needs are not considered during route planning.

The long-term video recordings of eight sites in Trondheim provided unique data about truck-bicycle encounters and behaviour in actual traffic situations. In total, during 619 hours of observations, there were 993 encounters recorded, 34 of them resulted in a conflict defined by an evasive action. Encounters between right-turning trucks and straight riding cyclists were evaluated as most risky, and several examples of risk awareness behavioural patterns were observed.

The applied multi-method strengthened the benefits and reduced the shortcomings of each method. It enabled the exploration of the truck-bicycle safety phenomenon from different perspectives and therefore provided a more comprehensive overview about the research topic. Each method identified different risk factors from different levels of road transport system. The knowledge of risk factors was further applied on evaluation of the common cycle infrastructure layouts.

Dissertation overview

This dissertation has been submitted to the Norwegian University of Science and Technology (NTNU) in October 2017. The PhD project was carried out between October 2014 and September 2017 at the Department of Civil and Environmental Engineering, which also provided funding for the project.

The advisors during the PhD project have been Associate Professor Kelly Pitera, main supervisor, and Professor Thomas Jonsson, co-supervisor, both employed at the Department of Civil and Environmental Engineering at NTNU.

The dissertation is structured in the following manner. Chapter 1 introduces the motivation for the presented research and its objectives. Chapter 2 summarises the methodological approach utilised to achieve those objectives. Chapter 3 delivers the list and the bibliographic data of the papers written during the PhD project. The papers' full texts are contained in the appendix. Chapter 4 provides an overview of the role, specifications and safety of truck and bicycle traffic in the urban road transport system. Chapter 5, focusing on the results and discussion, describes the synopsis of results that have been fully presented in the papers as well as additional results which have not be published. Moreover, it includes a summary of infrastructure risk factors and safety evaluation of common cycle infrastructure layouts. Chapter 6 provides evaluation of the research methodology as the whole. Chapter 7 concludes the dissertation, as it recapitulates the contribution of the PhD project to current knowledge in the field, summarises lessons learned and presents the list of identified knowledge gaps.

The photographs appearing in the dissertation were taken by the author (unless otherwise indicated in their captions).

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1 MOTIVATION AND OBJECTIVES

"…as there is an overarching goal in Norwegian transport policies that the traffic growth inside major urban areas should be taken by walking, cycling or public transport, we expect to see increasing numbers of fatal and serious injuries among vulnerable road users if we do not take specific actions."

Ketil Solvik-Olsen, Norwegian Minister of Transport and Communications (PIN report, ETSC, 2016)

As cycling is being promoted as one of the preferable modes of urban travel, an adequate level of safety must be ensured for cyclists. It is therefore necessary to create an optimal environment in which people are not afraid to cycle and where both the accident and injury risk factors are reduced to minimum. Thus, it is essential to gather knowledge about the risk factors associated with cycling.

At the same time, recent trends in land use and urban planning, economic development, and consumer demand are all factors increasing the numbers of trucks within urban transport systems. Trucks present one of the most important risk factors for cyclists, and their presence alone has the potential to deter people from cycling (Kröyer, 2015; Jachyra et al., 2015; Sanders, 2015). Trucks have been involved in more than 30% of urban cyclists' fatalities in Norway over the past 15 years, which is one of the highest rates in Europe (Pokorny et al., 2017; Evgenikos et al., 2016). Since truck-bicycle accidents are typically very severe, they usually attract a lot of media attention and public concern (see Figure 1).

Figure 1 – Examples of several articles from Norwegian newspapers. From the left – "A girl died on her way to school after having been hit by reversing truck"; "A cyclist hit by 3-ton truck"; "A young girl seriously injured in traffic accident"

The increasing numbers of cyclists and trucks and severe consequences of their encounters highlight the need for truck-bicycle safety research and the implementation of knowledge-based safety measures. The current knowledge about risk factors is predominantly founded on accident analysis (both of accident databases and in-depth investigations of fatal accidents). The research efforts are focusing on technology used to detect cyclists who are in close proximity to trucks. Only a few studies have looked at less severe encounters between trucks and bicycles and the effects of infrastructure layouts on the occurrence of these encounters. Even though several infrastructure risk factors have been identified in recent studies, their broader understanding is still lacking (Gelino et al., 2012).

To date, a comprehensive research of truck-bicycle safety has not been conducted in Norway. Although a certain amount of knowledge gained from foreign studies is transferrable, using a local context is essential in order to get a better understanding of the risk factors. Thus, this research project's objective has been to explore the truck-bicycle safety in Norway's urban areas, looking not only at accidents but also at less severe truck-bicycle encounters. Risk factors related to the urban road infrastructure were of particular interest, with a focus on cyclists.

Given the diversity in the nature and use of trucks, combined with cycle traffic, which itself is very diverse, studying truck–bicycle safety within complex urban road transport system presents a challenging multidisciplinary assignment. Therefore, the multi-method approach has been applied, consisting of the following methods: accident database analysis, review of in-depth investigation reports of fatal accidents, online questionnaire survey of cyclists, face-to-face interviews with employees of truck companies, and conflict and behavioural analysis using long-term traffic recordings, in sum attempting to answer the following questions:

- What are the characteristics of truck-bicycle accidents?
- What risk factors influence the occurrence and consequences of truck-bicycle accidents?
- What types of truck-bicycle conflicts are reported by cyclists?
- Is it possible to apply the conflict technique to observe and analyse the truck-bicycle encounters in real traffic?
- Does the presence of trucks influence the behaviour of cyclists and vice versa?
- What encounters are typical for common infrastructure layouts?
- What infrastructure risk factors influence the truck-bicycle safety?
- What are the benefits and limitations of the methods applied within the research?
- What are the knowledge gaps?

2 THE METHODOLOGY

Since the explorative nature of the PhD project (explorative in two ways – first, to understand the problem within a Norwegian context and second, to understand how the phenomenon could be best studied in general) and the complexity of the studied topic, multiple research methods have been applied, on both the national and city levels. Table 1 provides an overview of the methods, data and their sources, methods of data analysis and the objectives of each method.

Table 1 - Overview of the methods, data and their sources, analytical methods and objectives

Method	**Data**	**Data source**	**Analytical method**	**Objective**
Literature review	Journal papers and reports	Web of Science and Scopus databases	Exploratory review	Summarise the current knowledge
Accidents analysis	Accident data	Police database	Review of data Descriptive statistics and regression analysis	Create typology of accidents Recognition of long-term trends Identify accident characteristics and risk factors
	Reports on fatal accidents	In-depth investigation reports on fatal accidents	Descriptive statistics	Deeper understanding of accidents' development and risk factors
Interviews with truck-industry stakeholders	Personal opinions and experience of truck drivers and managers	Face-to-face interviews	Descriptive summary	Deeper understanding of truck-related aspects Identify potentially risky sites
Conflict analysis	Self-reported conflicts	Retrospective online survey of cyclists	Descriptive statistics and regression analysis	Identify frequent conflict types and risky locations
	Recorded truck-bicycle encounters	Long-term video recordings	Behavioural and conflict analysis	Observe behaviour Identify conflicts Identify risk factors Compare infrastructure layouts

Throughout the entire research project, the relevant literature (research articles, reports, policy documents) has been studied. This review was formalised at the end of the project in order to summarise and formally document the state-of-the-art in the field of truck-bicycle safety.

The obvious start to the research project was analysing the existing accident data, as those present the direct safety indicator, are “readily” available and provide information about long-term trends, types of accidents and characteristics of involved road users. All truck-bicycle accident (hereafter referred to as TCA) recorded in the Norwegian national accident database (which is based on police recorded accidents) were reviewed using Google maps and detailed accident descriptions. This review enabled a better understanding of the manoeuvres of both trucks and cyclists and identified the more accurate infrastructure, environmental and land use characteristics of the accident locations. The knowledge from the review enabled to draw basic accident diagrams and suggest the TCA typology. The reviewed accident data were analysed using descriptive statistics and binary logistic regression. The regression model was applied to identify the variables significant for the TCA consequences (fatal/non-fatal). In addition, the in - depth investigation reports of fatal TCA (prepared by the Norwegian Public Road Administration’s investigation teams) were revised in order to obtain specific knowledge concerning the trucks involved in TCA as well as risk factors that contributed to the fatal accidents occurrence.

In the second phase of the research, several unique types of data have been collected and analysed. First, the data regarding the cyclists’ involvement in conflicts with trucks were of interest, particularly the types and frequencies of experienced conflicts. Regarding the data collection, the online retrospective survey of cyclists was disseminated nationwide through several internet channels. The obtained data were analysed using the descriptive statistics and the binary and multinomial logistic regressions. The regression analysis estimated the associations between the probability of experiencing a conflict and the explanatory variables (age, gender, education, experience and city), and between the types of conflicts and the same explanatory variables. Second, in order to better understand the trucks’ route planning and safety procedures within the truck companies themselves, it was necessary to gather input from the truck drivers and company managers. The truck drivers’ advices with respect to potentially risky sites in Trondheim were also of interest. Given the demographics of and accessibility to truck company employees, face-to-face interviews were conducted in several companies providing different trucking services within the city of Trondheim. Interviews with drivers were conducted in their native language (aided by a Norwegian student’s interpretation - see Fig. 2, left), while interviews with managers were conducted in English. The list of questions was prepared in advance; however, additional questions were allowed, depending on the course of the interview.

Figure 2 – One of the interviews with a driver (left); the camera mounted on a lighting pole (right)

The third (and probably most challenging) task consisted of the behaviour and conflict analysis of eight sites in Trondheim, using long-term video recordings of traffic. The suitable sites have been identified with the knowledge gained from the previously conducted methods. Regarding the data collection, a portable Miovision Scout unit was used. The camera was mounted on a telescopic pole (up to 8 meters high) that can be easily attached to any fixed pole (mostly a lightning pole or a traffic sign – see Figure 2, right). The camera provides a wide dynamic 120° horizontal view. Recorded video is stored on SD cards, in mp4 format, in 720x480 resolution, with a frame rate of 30 fps. The quality of the recording does not allow for recognition of sensitive personal details (e.g. licence plate, face, and gender), which simplified the official approval process needed to record in public places. Each site was recorded during morning and afternoon peak hours (typically between 6:00-10:00 and 14:00-18:00 throughout 10 weekdays), during the spring and autumn of 2016. The recordings were manually reviewed to identify when there was both a truck and cyclist present at the same time and place, engaging in encounters of interest. These encounters were extracted from the recordings and coded using several variables, including truck and cyclist manoeuvres, category of encounter and road user behaviour. A conflict was recognised by the researcher based on the presence of an "obvious" evasive action, typically extensive breaking either of a truck or a cyclist. Conflicts were categorised according the road users' manoeuvres. The share of conflicts in each encounter type enabled to compare the particular encounter types and infrastructure layouts, applying the event-based approach to exposure as described by Elvik (2015). Furthermore, behaviour of trucks and cyclists in specific situations was observed in order to identify any specific behavioral patterns. The knowledge gained from observations enabled to identify the infrastructure risk factors that contribute to the occurrence of conflicts.

At the final stage of the project, the experience gained throughout the research enabled to evaluate safety of the common cycle infrastructure layouts, contained in Norwegian Cycle Handbook. The risk factors connected to the particular design layouts were identified, and the recommendations were provided to eliminate those risk factors. In addition, the suitability and limitations of each method and of the multi-method approach were evaluated and the knowledge gaps were identified.

3 THE LIST OF PAPERS

The results of the research carried out during the PhD project have been discussed in the five papers included in the dissertation’s appendix. The papers are numbered I to V according to their content order.

Paper I: Pokorny, P., Pitera, K., *Truck-bicycle safety: an exploratory literature review*. This paper was written in 2017 and submitted to the Transport Reviews journal in August 2017.

Contribution of each author: Petr Pokorny wrote the article and conducted the review; Kelly Pitera edited the text and provided comments to the methodology.

Paper II: Pokorny, P., Drescher, J., Jonsson, T., Pitera, K., *Accidents between freight vehicles and bicycles, with a focus on urban areas*. This paper was written in 2015 and presented at the World Conference on Transport Research (WCTR 2016, Shanghai, China). The paper was published in Transportation Research Procedia, Vol. 25, 2017. https://doi.org/10.1016/j.trpro.2017.05.474

Contribution of each author: Petr Pokorny wrote the article and conducted the analysis; Thomas Jonsson provided feedback on the statistical methods used in the data analysis part; Kelly Pitera edited the text and provided comments to the methodology; Jerome Drescher provided the accident data and their GPS positions.

Paper III: Pokorny, P., Pritchard, R., Pitera, K., *Conflicts between bikes and trucks in urban areas – a survey of Norwegian cyclists*. The paper was written in 2016-2017 and will be published in Case Studies on Transport Policy journal in 2018. The paper has been available online from December 2017. https://doi.org/10.1016/j.cstp.2017.11.010

Contribution of each author: Petr Pokorny wrote the article and conducted the analysis; Ray Pritchard prepared the data regarding the local cycling policies, investments and infrastructure; Kelly Pitera edited the text and provided comments to the methodology.

Paper IV: Pitera, K., Pokorny, P., Kristensen, T., Bjørgen. A., *The complexity of planning a shared urban space: a case study involving cyclists and goods delivery*. The paper was written in 2016 and presented as the poster at VREF Conference on Urban Freight 2016, Gothenburg, Sweden. It was published in European Transport Research Review, Vol. 9:46, 2017. DOI 10.1007/s12544-017-0262-8

Contribution of each author: Petr Pokorny conducted the safety analysis, wrote the relevant part of the article and provided comments to the rest of the text; Kelly Pitera wrote the majority of the article; Terje Kristensen and Astrid Bjørgen were responsible for the analysis of decision-making and planning processes and wrote the relevant part of the article.

Paper V: Pokorny, P., Pitera, K., *Application of several methods to study truck-bicycle encounters in urban areas*. The paper was written in 2017 and presented at the Road Safety and Simulation Conference (RSS2017) in Hague, The Netherlands in October 2017. The included paper contains several minor changes compared to the version originally submitted to the RSS2017 conference. The reason for the difference is the effort to correct the issues identified after the paper's acceptance to the conference. The paper has been selected for consideration to be published in the RSS2017 Special Issue of Accident Analysis and Prevention.

Contribution of each author: Petr Pokorny wrote the article and conducted the analysis; Kelly Pitera edited the text and provided comments to the methodology.

4 BACKGROUND

The presented research concerns the safety of truck and cycle traffic within urban road transport system. Therefore, this chapter provides a brief overview of the features of road transport system, discusses the characteristics and safety of truck and cycle traffic in Norway and describes the types of traffic encounters and the methods to study their safety.

4.1 Complexity of road transport system

A common sense definition recognises a system as "a set of interacting units or elements that form an integrated whole intended to perform some function" (Skyttner, 2005). In case of road transport system, all the elements interact with each other in order to ensure the accessibility and mobility for people and transport of goods (Larsson et al., 2010a). The road transport system can be understood as the hierarchy of levels, with each level being more complex than the one below it (Leveson, 2011). Each level contains several elements. The elements and the levels can be integrated both vertically and horizontally. A simplified graphical illustration of such hierarchical system is demonstrated in Figure 3.

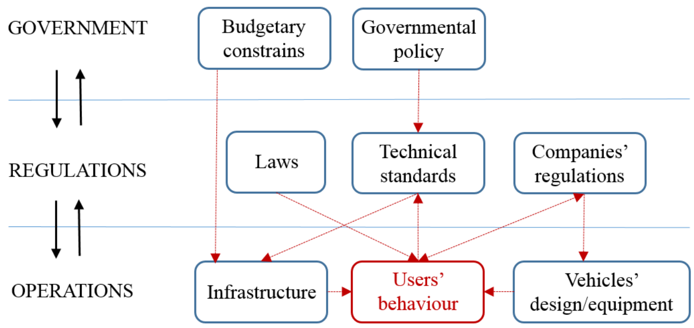


Figure 3 – Simplified graphical illustration of hierarchical road transport system

The elements located in the lowest level are related to the infrastructure, vehicles and road users, while the upper levels contain elements related to regulations and government. As an example, the red lines demonstrate the connections between the elements affecting road users' behaviour. The behaviour is influenced by elements from the same level (e.g. road conditions), and simultaneously by the elements from upper levels (note, that these are further affected by other elements). At the same time, road users' behaviour can affect elements from upper levels as well (e.g. certain behaviour can stimulate an upgrade of technical standards).

As the road transport system comprises technical, psychological and social elements, it can be further considered to be a socio-technical complex system (Larsson et al., 2010b). The system's complexity is multiplied in the urban environment, as more actors and influences are presented in urban rather than rural areas. Naturally, freight truck and cycle traffic create the inevitable parts of the system, as both personal and goods mobility is vital in urban environments (see Figure 4).

Figure 4 – Delivery truck and a cyclist riding with a child encounter one another on a summer morning in the centre of Amsterdam (left); Busy urban roundabout in Zwolle (right)

4.2 Freight truck traffic

The majority of inland freight transport in Europe is performed by trucks. For example, in Norway 87 % of total inland freight transport tonne-kilometres was carried by trucks in 2015 (Eurostat, 2017). Goods movement represented 20.6% of kilometres driven in the whole country in 2016, with vans and small trucks accounting for 16.2% and heavy trucks for 4.4% (Statistics Norway, 2017a). More than 90% of the road freight volume is transported over short distances and is related to construction work and local distribution (NTP, 2015).

Truck traffic presents a large, diverse and complex field. When combined with road users, infrastructure and vehicle elements, it may be considered to be another basic element of the road transport system (Pattinson and Thompson, 2014). Focusing on urban environment, truck traffic includes all deliveries and collections of supplies, materials, parts, consumables or mail services, involving private trucks, waste removal and maintenance trucks as well as long-distance through traffic (trucks passing through a city to reach another destination). The exact volume of truck traffic in cities is often unknown; however, it is estimated that movement of goods represents between 20% and 30% of vehicle kilometres driven in a city and that a city generates about 300-400 truck trips per 1,000 people per day and 30-50 tons of goods per person per year (Dablanc, 2007; Macharis and Melo, 2011).

Trucks are associated with several negative externalities that affect the quality and liveability of urban areas. For instance, they contribute to poor air quality, congestion and road safety problems, they increase the level of noise and dust, and contribute to visual intrusion and the loss of green fields and open spaces (e.g. Anderson et al., 2005). The fact, that trucks used in cities tend to be older than the general fleet of the truck industry contributes significantly to a certain number of these externalities (Dablanc, 2007).

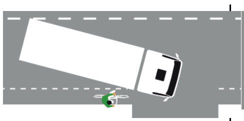
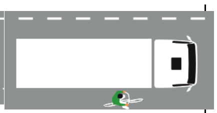
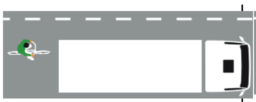
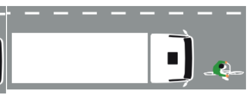
Thus, even though trucks are an inevitable part of the current economy, most cities view them as something that ought to be banned or, at the very least, strictly regulated (Dablanc, 2007). So in order to deal with the negative externalities, cities have been introducing policies to regulate truck traffic in certain periods and areas, including route restrictions, parking regulations, time-of-day restrictions, size and weight regulations or emission controls (Plumeau et al., 2012). However, the efficiency of these measures is in many cases questionable (Giuliano et al., 2013). Even though innovative and promising city logistical concepts exist (e.g., urban consolidation centres), the large majority of cities, especially in Europe, have still not found adequate solutions to optimise the urban movement of goods (Behrends et al., 2008). Moreover, with increasing urbanisation, current land use trends of decentralisation and consolidation, and tendencies in consumer behaviour (e.g. e- commerce), it is possible to expect more trucks on roads and streets (Dablanc, 2007; Jaller et al., 2013). More specifically, the number of vehicle kilometres driven by trucks in Norway increased by 5.3% in the period from 2011 to 2016, and further long-term growth is predicted (Statistics Norway, 2017; Hovi et al., 2017).

4.2.1 Truck traffic safety

Trucks are the largest and heaviest vehicles within the road transport system. Their operating characteristics, such as poor acceleration/deceleration, limited visibility, lack of stability and limited manoeuvrability, affect accidents occurrence, types and severity. These operating characteristics determine the infrastructure risk factors, including long/steep downhills, inappropriate crossfalls, lack of friction, overly large curvature, lack of overtaking possibilities, or limited space in urban areas. Typical risk factors related to truck drivers include fatigue, lack of attention and stress. These factors are often connected to risk factors within higher levels of the transport system, from the lack of regulation for retrofitting vehicles to insufficient planning of journeys (Newnam et al., 2017).

The knowledge related to truck safety is founded predominantly on accident analysis. The absence of exposure data and variability in definitions of accident consequences and truck types makes it difficult to compare the safety performance within European states. In total, 3,863 people were killed in accidents involving trucks in the EU in 2014, which is 15% of all road fatalities. Further, 81% of truck accidents' victims were not the truck occupants. The majority of accidents were recorded in rural areas, with personal cars being the most frequent accident opponent. Head-on collisions present the dominant type of fatal accidents, followed by run-off- road accidents (Langeland and Phillips, 2016). Accidents involving vulnerable road users (cyclists, pedestrians, mopeds, motorcyclists) accounted for about 30% of fatalities; more specifically, cyclists represented 8% of the fatalities (Volvo Truck, 2017). The accidents involving cyclists are logically more frequent in urban areas, as it is more probable to encounter each other in this type of setting. The most common accidents involving cyclists are described in Table 2.

Table 2 - Most common accident types between trucks and cyclists (source: Volvo Truck, 2017)

			
Turning truck at low speed, hitting the cyclist with truck's front or side	*Collision with cyclists in traffic lane with truck at moderate to high speed, e.g. during lane exit or change, merging or cutting in*	*Cyclist collides with rear or side of a truck ahead (truck at low speed)*	*Truck collides with a cyclist ahead.*

Focusing on Norway, the percentage of fatalities and seriously injured people in accidents involving trucks is about 15% of all fatal and serious accidents. As in the other European countries, most of the accidents are recorded in rural areas and the majority of fatalities are not the truck occupants, but rather occupants of passenger cars. The high rate at which trucks cause injuries to other road users compared to the rate of injuries to truck occupants (so-called external risk) was highlighted by Elvik as a persistent road safety problem (Elvik, 2010b). According to his study, vulnerable road users are injured 56.7 times as often as truck occupants in accidents involving both groups of users.

Cyclists have been particularly involved in 3.7% of the truck accidents in Norway during the period 2000-2014. There is a significant difference according to the environment; in urban areas this percentage was 18.3%, while in rural areas it was only 0.5% (Pokorny et al., 2017).

4.3 Urban cycling

Cycling has been in recent years experiencing a renaissance in many cities worldwide, and a vibrant cycling culture is considered to be an index of health and prosperity (Pucher and Buehler, 2017; Oldenziel et al., 2016). In Norway, there was a decline in cycling at the turn of the twenty-first century, mainly due to the fact that young people were cycling less than they did before (NPRA, 2016). Currently, cycling has been regaining its popularity, although still not reaching the levels seen during the 1990s (see Figure 5).

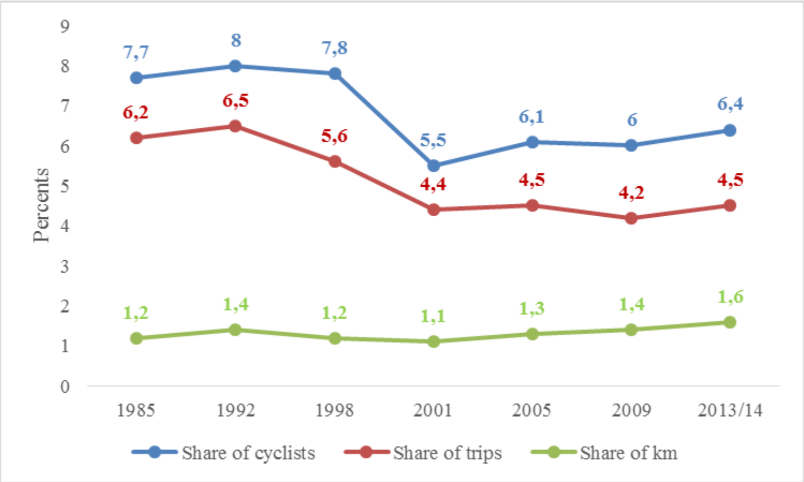


Figure 5 – The amount of cycling in Norway between 1985-2014 (source: Hjorthol, 2014)

The percentage of cycle trips with respect to the total number of trips in major Norwegian cities obviously differs, displaying maximum levels of nearly 10% in Kristiansand and 9% in Trondheim and the lowest level around 3% in Bergen (NPRA, 2014). While diverse climate, geography, demography, tradition and quality of infrastructure contribute to those differences, cycling in Norway may be characterised by the following generalisations, which may vary from other countries:

- An advanced safety culture exists in Norway. The road safety policy is founded on Vision Zero approach. Norway has been ranked as one of the safest countries in Europe for both motor vehicles and cyclists (Adminaite et al., 2016).
- Most of the cycle trips are made to schools and to work places (Hjorthol, 2014).
- The typical Norwegian cyclist is 13-17 years old and has either a low level of education (young people) or university education. There are twice as many males cycling within

the 13-17 age group, while after reaching age 18, the percentage of cycling males and females is nearly the same.

- It is legal to ride a bicycle on sidewalks; however, the cyclist must pass pedestrians at a safe distance and at near walking speed.
- It is legal to cycle over zebra crossings; however, motorists are not obligated to yield to the cyclist in this situation (motorists must yield to pedestrians and cyclists walking their bicycle).
- Cyclists are not obliged to wear a helmet.
- Long winter period characterised by snow, rain and many hours of darkness result in a substantial drop in bicycle volumes during the winter months. According to the National Travel Survey 2013/2014, winter bicycle volumes are less than 30% of the summer volumes with the ratio of bicycle trips in the lowest to the highest month being 1/4.6. The survey also indicates that there has been an overall increase in winter cycling in Norway in recent years, as the share of winter bicycle trips increased from 1.1% in 2009 to 2.1% in 2013/2014 (Hjorthol et al., 2014).
- Recently, efforts have been made to focus on implementing segregated cycling infrastructure, e.g. in Trondheim, the existing cycling infrastructure consists of 18 km of segregated cycle paths, 12 km of cycle lanes and 1 km of cycle streets, and the municipality plans on greatly increasing the amount of segregated cycling infrastructure in the coming years (Miljøpakke Trondheim, 2016).
- There is an increasingly high percentage of e-bikes, having an estimated value over 10% of the total bike market share (www.bike-eu.com).

The Norwegian National Transport Plan 2014-2023 (NTP, 2013) outlines the government's goal of increasing the cycling percentage to at least 8% of all travel in 2023, and that 80% of children and students should walk or cycle to schools. The government has put aside significant annual funding towards implementing these measures for cyclists and pedestrians. Thus, it is possible to expect further growth of cycling in Norwegian cities. The potential for increased cycling is seen primarily in the area of replacing short car trips, as half of all car trips are shorter than 5 km (NPRA, 2003).

4.3.1 Safety of cycle traffic

Cyclists are characterised by vast diversity in their abilities, behaviour, experience, physical conditions and equipment. Some cyclists do not have a driving licence, some follow the traffic rules while others do not. Some cyclists prefer to ride on sidewalks, while others would rather ride on the road. Along with a certain level of behavioural unpredictability, they are not as visible in traffic as other road users. Most importantly, they are very vulnerable to being injured should they become involved in an accident.

Considering accident statistics, there were 164 fatal and 10,840 injury bicycle accidents registered by the Norwegian police during the period of 2000-2016 (in the same period, 2,502 vehicle occupants, 444 pedestrians and 532 motorcyclists were killed). The majority of fatal bicycle accidents was recorded in rural areas, while most injuries occurred in urban environments. Male cyclists were involved in 77% of fatal and 67% of injury accidents. Most of the fatalities were recorded for the age groups 6-15 and 55-64 years, while injury accidents shift slightly to younger age categories. Similar to other European countries (Adminaite et al., 2015), the long-term decrease in roadway fatalities in Norway is significantly smaller for cyclists than for motor vehicle users (see Figure 6), and the same is true for injuries.

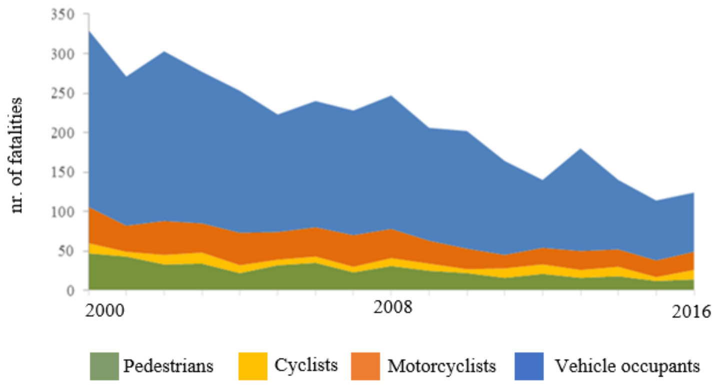


Figure 6 - Reduction of road fatalities since 2000 in Norway (based on data from Statistics Norway, 2017b)

The absolute numbers of cyclists' fatalities and injuries seem to be relatively low compared to other road users. However, in reality, the bicycle accident figures are higher than they appear from official statistics, as a significant number of accidents is typically not reported. This underreporting is usually highest for cyclists (and pedestrians) and lowest for car occupants, with further differences related to the accidents types and consequences. Veisten et al. estimated that official Norwegian accident records include approximately 12% of slight bicycle injuries, 33% of serious injuries, and 71% of severe injuries (Veisten et al., 2007). The underreporting phenomenon is clearly illustrated in Figure 7, comparing the monthly numbers of bicycle injury accidents documented in hospitals in Oslo in 2014 with monthly average for the entire country (based on accidents recorded by the police during the period 2013-2015).

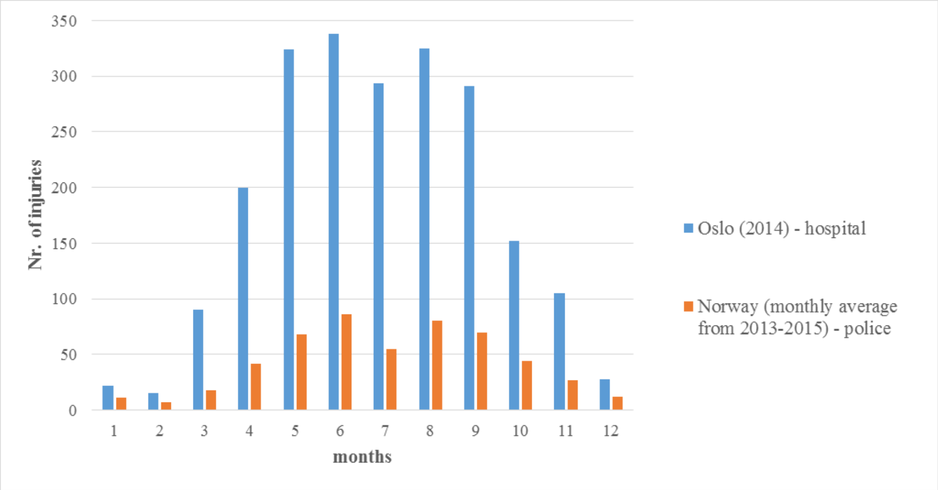


Figure 7 – Numbers of recorded injuries of cyclists in traffic accidents in Norway and Oslo - monthly comparison (source: Statistics Norway, 2017b and Melhuus et al, 2015)

Single bicycle accidents are, in particular, very rarely reported (Elvik and Mysen, 1999). This phenomenon significantly distorts the official accident numbers, as single bicycle accidents have been recently recognised to be the most frequent accident type. Bjørnskau (2005) showed that three out of four bicycle accidents in Norway involve no other road user, and a more recent hospital study (Melhuus et al., 2015) found that 71% of bicycle accidents in Oslo in the year 2014 were single accidents. However, the true amount is probably even greater, since many single accidents do not result in a visit to the hospital (Bergström, 2002).

There is a clear consensus between road safety researchers, this being that the relative accident and injury risk for cyclists is higher compared to other road users. Nonetheless, the values of these estimates differ depending on the methodology used. Bjørnskau and Ingebrigtsen calculated that the risk of injury among cyclists in Oslo is about 50 times as high as for motorists when the exposure measurement is per kilometres, and 16 times as high when the exposure measurement is per unit time in traffic (Bjørnskau and Ingebrigtsen, 2015).

OECD (2013) reports following “broad” factors contributing to a higher risk for cyclists:

- Road transport systems are often not well designed for mixing fast and heavy mass motor vehicles with unprotected, vulnerable and slow road users.
- The specific characteristics of cyclists (e.g. variability, unpredictability, instability, lower visibility, vulnerability) are typically not accounted for in road transport systems.
- Cyclists are often seen as intruders in the road system.

As bicycle accidents are often not reported, the accident databases do not provide complete information. Hence, accidents cannot present the only source of data for safety analysis. The characteristics of less severe encounters in traffic (i.e. conflicts and interactions) can be used as an indirect measure of safety (Laureshyn et al., 2017). These encounters are of "everyday occurrence" for cyclists and are relatively easy to observe (Aldred and Crosweller, 2015). Recently, there have been several studies on such encounters conducted in Norway, e.g. by Phillips et al. (2011), Nævestad et al. (2014) Fyhri et al. (2016), Bjørnskau (2017) and Fyhri et al. (2017), using surveys, observations and video recordings.

4.4 Traffic encounters safety analysis

The elementary events in traffic, when road users meet at a given location at the same time, are called encounters (Fyhri et al., 2017). Encounters lead to different safety outcomes ranging, according to their severity and frequency, from smooth, undisturbed events to fatal accidents, with the most serious encounters being the least frequent. Initially, Hyden demonstrated this concept of the so-called safety continuum by putting forth the well-known "safety pyramid" model, while Svenson later introduced the "severity diamond" model (Hyden, 1987; Svenson, 1998). Although Hyden considered the safest encounters (undisturbed passages) to be the most frequent ones and therefore placed them on the bottom of the pyramid, Svenson suggested that the safest encounters are not the most frequent events (see Figure 8). According to Svenson's research, the most frequent events (those located in the middle of the diamond) contain a certain level of risk that is accepted by the road users in exchange for higher speed and saved time.

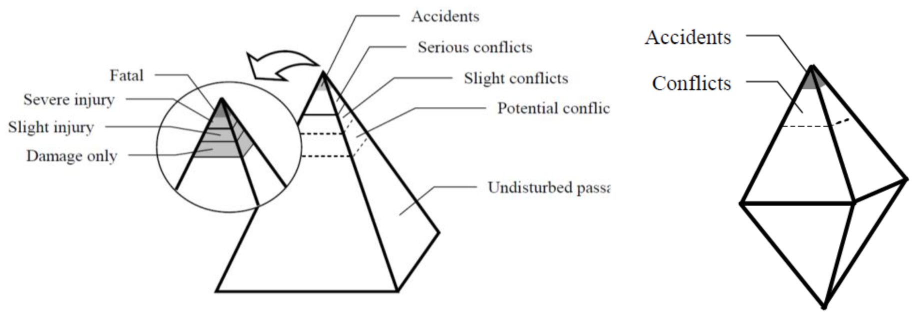


Figure 8 - The models of the safety continuum. Pyramid model on the left, Diamond model on the right (source: InDev, 2016)

The shapes of these models suggest a relationship between the frequencies of different encounters. This type of relationship would make it possible to estimate the number of expected accidents from the number of serious conflicts observed, etc. However, the shape of the distribution (ratio between different encounters) varies according to different types of road layouts, road users involved and performed manoeuvres; beside the point that this shape is often unknown. Therefore, it is typically not possible to simply extrapolate between less and more severe encounters.

Thus, in order to improve safety analysis, the whole safety continuum should be preferably taken into account and not concentrating on only one particular type of encounter. Four types of encounters, according to their severity, are recognised within the PhD project, including accidents, conflicts, interactions and smooth, undisturbed events. The examples of analytical methods to investigate those encounters are briefly described below, with focus on cycling research. Additionally, to better understand the behaviour of cyclists, their attitudes and risk perception are subjects of many safety studies, however those are not discussed here.

Accidents, ranging from fatal injuries to material damage only, are the obvious and most common safety indicator, as they symbolise traffic safety's direct measure. However, they represent only a very minor proportion of traffic encounters. Accidents are typically studied with quantitative methods. Police and hospital databases, in conjunction with in-depth investigations of mostly fatal accidents, provide the data for safety analysis. The type of analysis vary from a simple descriptive statistics to an application of advanced statistical models, depending among others on the purpose of the analysis and quality of the data. The well-known limitations of accident analysis are based on the facts that accidents are rare and random events, not all of which are reported, and if they are reported, a certain data is often missing or inaccurate.

An example of usage of qualitative method to study accidents presents Canadian study that applies in-depth interviews with cyclists in order to explore cycling behavioural change after experiencing the accident (Jachyra et al., 2015).

Conflicts present an indirect safety measure. There are several operational definitions of conflict, which can be grouped into two categories. Those based on evasive action or those based on temporal and/or spatial proximity (Zheng et al., 2014). Elvik provided a "general" definition where a conflict is defined as "any event in which road users arrive at the same place at the same time or within a very short time interval, and which may result in an accident if road users fail to observe each other or take action to prevent an accident" (Elvik, 2010a). Similar to accidents, conflicts can be differentiated according to their severity, which may be determined by the intensity of evasive action, magnitude of spatial proximity or mass/speed differences between involved road users. Conflicts are more frequent in traffic than accidents. Thus, they are regularly used in safety analysis as surrogates for accidents (Laureshyn et al., 2017). The conflicts can be studied either indirectly, using surveys or directly by naturalistic studies and by observation the traffic with a camera or with a human observer. Each method has its limitations, e.g. regarding the ability of surveys' respondents to correctly remember, interpret and self-report the conflicts or technological challenges in detecting and tracking cyclists in video recordings, particularly within complex urban environments (Sayed et al., 2013). In addition, methodological concerns regarding the validity and reliability of the indicators used in conflict studies still remain. It is not always clear if and how the certain conflict or behaviour is linked to the accident risk (validity of conflict indicators) and whether the observations and analysis of conflicts are not influenced by observers' subjectivity (reliability of method).

The examples of the most recent bicycle conflict studies using video observations present a study from Canada investigating the safety effects of cycle tracks at signalized intersections, applying the post-encroachment time as a surrogate indicator of the severity of the interactions between cyclists and turning vehicles travelling in the same direction (Zangenehpour et al., 2016), a Danish study comparing the safety of cyclists at five bicycle facility layouts in signalized intersections at various traffic volumes using both reaction- and time-based indicators (Madsen and Lahrmann, 2017) or a Norwegian study comparing three surrogate safety methods of evaluating cyclist safety at three intersection in Oslo (Laureshyn et al., 2017). Examples of the surveys and naturalistic studies present UK study using the travel diaries to investigate the occurrence of "non-injury incidents" (Aldred and Crosweller, 2015), German study using video cameras on the regular participants' bikes (Schleinitz et al., 2015) or Swedish study using specific test bikes with recording instruments to search for "safety critical events" (Dozza and Werneke, 2014)

The observation and analysis of interactions and smooth, undisturbed events may both provide further data about risk factors and reveal patterns potentially leading to the occurrence of conflicts and accidents. Interactions and smooth events may be captured by surveys and observational or naturalistic studies. A recent example of such analysis is found in a study from Ottawa that combines video observation and a survey to identify the factors in mixed urban traffic that may affect the lateral spacing between bicycles and vehicles and their subsequent effect on bicyclists' comfort levels (Apasnore et al., 2017).

5 RESULTS AND DISCUSSION

This chapter highlights the most important results of each applied method and puts them into the context. The results of conflict and behavioural analysis are presented completely here, as the application of video observations in truck-bicycle safety studies presents a rather unique approach, and not all the sites analysed using this method have been included in the papers. Furthermore, this chapter contains an overview of the infrastructure risk factors identified with each method and the evaluation of common Norwegian cycle infrastructure layouts. For complete results, readers are referred to the papers enclosed in the Appendix. Figure 9 illustrates the overview of the methods and relevant papers.

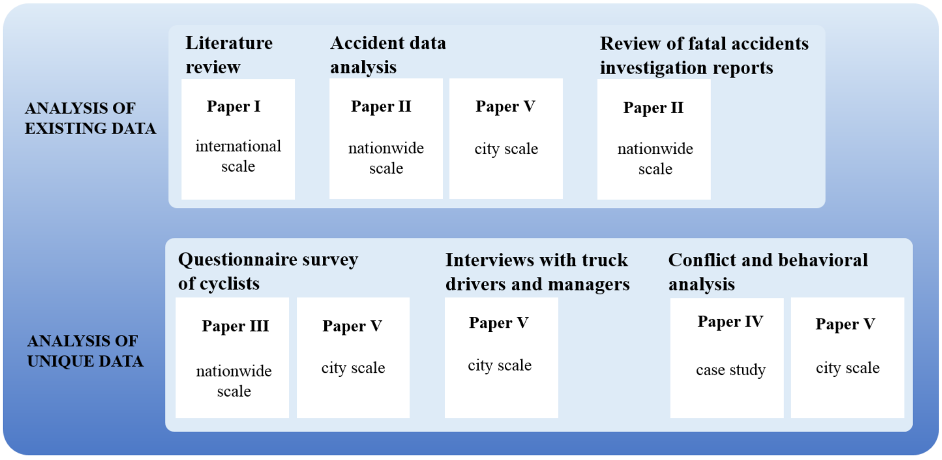


Figure 9 – Overview of the methods and relevant papers

5.1 Literature review

The exploratory literature review summarises the English written documents identified in Web of Science and Scopus databases and published in period 1990 – 2016. In total 56 research papers and reports were identified and studied, with 25 of them devoted specifically to truck-bicycle safety. There has been an evident increase in research activity in recent years, as 70% of those 25 documents have been published from 2011 onwards. Focusing only on research papers (n=15), the majority originates from UK (40%), followed by Germany, US and Netherlands. From those papers, 30% regard accident analysis (using police database or in-depth analysis of fatal accidents) and 30% describe a testing of new technologies for detecting cyclists in proximity of trucks. The rest represent a medical study, an evaluation of safety programmes, a risk perception survey and a conflict observation. The blind spots and right turning trucks are the focus of 50% of the papers and reports.

In the remaining 31 papers and reports, the topic of truck-bicycle safety is presented as a part of the document scope – e.g. truck volumes are included as one of the variables in an accident model, safety concerns regarding cyclists are mentioned in an interview with truck drivers, overrepresentation of trucks is found in cyclists fatal accidents or trucks are identified as one of the significant factors affecting bicycle accident severity Again, most (65%) of those documents were published recently (from 2011 onwards).

The common characteristics of TCA found in the literature are as follows (see Paper I for complete reference information):

- TCA typically occur in urban areas, between 6am and 6pm, during the working days, under good weather conditions, at intersections.
- Truck drivers are characteristically males in 40+ age categories, while cyclists are spread in all age groups. The majority of cyclists involved in TCA are males, however female cyclists are overrepresented compared to other types of bicycle accidents.
- The types of trucks involved in TCA depend on local conditions. There are indications that construction and municipality trucks may be overrepresented in fatal TCA.
- Turning TCA (right turning truck) are considered as the most serious.
- The speed of both, cyclist and truck are typically low - truck speeds are in almost all cases below 30 km/h and bicycle speeds below 20 km/h.
- Involvement of a truck radically increases the degree of injury severity of cyclist accidents. TCA are typically associated with severe torso injuries coupled with severe massive bleeding and with injuries in multiple body regions.
- The huge differences in size, mass, and forces between trucks and cyclists are the most significant injury factors.
- Limited visibility from the truck cab (blind spots) is considered the fundamental risk factor.

Following risk factors related to infrastructure design were identified in the literature (see Paper I for complete reference information):

- Complexity of urban intersections
- Poor configuration of advanced cycle boxes, which “places” cyclists into the truck’s blind spot

- Absence of a cyclists-only signal phase or pre-green phase for cyclists on signalised intersections
- Insufficient distance of the stop lines at traffic lights, which increases the risk of turning TCA
- The poor design of docking/delivery/parking areas that does not respect the needs of both, cyclists and trucks
- Configuration of cycle lanes adjacent to parking lanes, which increases the risk of conflicts and usage of cycle lanes for parking
- Insufficient separation of the road space
- The presence of high curbs in locations with turning trucks, as a cyclist can be "locked" between turning truck and the curb
- Installation of cycle lanes on roads with high truck traffic
- Road narrowing, which increases the risk during overtaking and head-on passing manoeuvres
- Road damage, for example pot holes, which can destabilise cyclists

It is evident that accident databases, based mostly on police reported accidents, present the main data source for truck-bicycle safety analysis. Due to the significant numbers of fatal TCA, in- depth investigation data about fatal accidents are often used in the analysis (e.g. GIDAS in Germany). Interestingly, only a few studies have analysed less severe truck-bicycle encounters. These include an observational study from the US that analysed the conflicts between bicycles and parking trucks on different cycle lanes' layouts (Conway et al., 2013) and several UK studies that evaluated gender differences in cyclist behaviour in proximity of trucks and the effects of roadside mirrors on truck-bicycle interactions (Frings et al., 2012; Transport for London, 2010). The small number of these studies can be explained by the low frequency of conflicts between trucks and cyclists compared to other conflicts. This low occurrence can be seen in the results of recent naturalistic studies (Dozza and Werneke, 2014, Schleinitz et al., 2015).

5.2 Accident data analysis

Analysis of police-based accident records (for period 2000-2014) were first conducted for the whole Norway and then for Trondheim alone. The national dataset contained in total of 252 TCA. The results of descriptive statistics confirmed that consequences of TCA in Norway are significantly higher than for other types of cycle accidents, as is the case in many other countries (Manson et al., 2012; Kaplan et al., 2014 and Kröyer, 2015). There is a distinct downward trend in annual numbers of TCA in last 15 years. However, 35% share of cyclist killed in TCA from all fatal accidents involving cyclists presents one of the highest in Europe.

The majority of TCA (77%) occurred in urban areas and the same applies to fatal TCA (70%). Focusing on urban TCA, these were reported mostly during working days (93%), in the morning and afternoon (both 35%) and under good (weather-related) visibility conditions (85%). Half of urban TCA were recorded in residential areas, while only 12% in commercial and 9% in industrial areas. The high frequency of TCA in residential areas is surprising given that one would expect there to be fewer trucks in residential areas, when compared with mixed use, commercial, or industrial environments. While there are fewer trucks in residential areas, there still will be trucks making deliveries to local stores and using collector roads for through-trips, as well as temporary truck traffic generated by construction sites. At the same time, residential areas are likely to have significant volumes of cyclists as they are an origin or destination of many cycle trips. One explanation for the high TCA rates is perhaps a lack of separated infrastructure in these areas. Intersections were their most frequent location (56%). TCA connected to crossing (within intersection) and other maneuvers within the intersections were the most frequent accident categories in urban areas (28%, respective 24%). Blind spot TCA accounted for 12% of TCA and their average severity was higher than for other accident types. Blind spot TCA occurred mostly at signalized intersections (54%) and roundabouts (21%). These results indicate the importance of safe layout of intersections and crossings, which should encourage good visibility.

One out of ten TCA had fatal consequences compared to only 1.2% of other cycle accidents (though the underreporting-phenomena probably has inflated these numbers). In 50% of fatal TCA, the road surface was wet. The results of binary regression model confirmed that from the included variables, wet road surface is a significant factor for TCA consequences in urban areas. This finding is consistent with Kaplan et al., (2014) and Kim et al., (2007). It might not be the road surface that is of concern, but the decreased visibility during a rainy time. Another interesting finding is that almost 50% of cyclists killed in TCA were females, while for other fatal bike accidents that percentage was 20%. The similar difference was found for non-fatal accidents (40% vs. 20%). Such finding is consistent with Frings et al. (2012) and Niewoehner and Berg (2005). Frings et al suggest that gender differences in risk perception could play a role.

Older cyclists (over 60 years) were involved in 10% of all urban TCA in 2000-2014, while their share in fatal TCA was 26%. This difference suggests the well-known effect of older age on consequences of accidents, mainly because of increasing vulnerability of human body.

Furthermore, the age can affect cyclist's behaviour, which could contribute to higher share of older cyclists in fatal TCA.

Looking at the TCA specifically in Trondheim, left-turning trucks were the most common in TCA. This is surprising given that right-turning accidents are reported to be the most frequent in other studies (Volvo Truck, 2017; Niewoehner and Berg, 2005) and in Norway in general. Nevertheless, because of the small sample size (21 reported TCA during a total of 15 years in Trondheim), it is not possible to make a valid conclusion from this finding. On the other hand, the data quality was relatively high and consistent in Trondheim during the whole period of study. This factor, along with local knowledge, enabled the estimation of the accidents' circumstances more precisely than was possible within the nationwide analysis. For example, in Trondheim it was possible to conclude that the truck's speed was lower than 20 km/h in at least 60% of TCA, and that reduced visibility due to blind spots or sight obstructions could have contributed to at least 40% of TCA.

5.3 Review of fatal accident investigation reports

Since 2005, fatal road accidents in Norway have been investigated by the special teams of the National Public Road Authority (NPRA). These teams produce in-depth investigation reports about each fatal accident. In order to identify the risk factors, investigators typically break down each accident into the sequence of events/actions related to each of the road users and vehicles involved in the accident. Reports on all fatal urban TCA investigated from 2005 (n=13) were obtained from the NPRA and reviewed. Those TCA represent all urban fatal TCA recorded by police in this period in Norway. The trucks involved in TCA were relatively modern, mostly 3-axled "compact" trucks without a trailer (see Figure 10), and equipped with a variety of safety devices. All were driven by fairly experienced drivers.

Figure 10 – Examples of trucks involved in fatal TCA in Norway (source: NRA reports)

The speed of trucks before the accident was lower than 30 km/h in 85% of the fatal TCA; in several cases, the speed was even lower than 10 km/h. The reports further demonstrated that a combination of several risk factors can be identified for each accident occurrence. Reduced visibility was mentioned in the majority reports as the most important risk factor; however, it was never named as the sole factor. In addition to blind spots, the other factors related to truck drivers and cyclists' behaviour (e.g. inattention), risky infrastructure layout (e.g. cycle path inducing cyclists' high speed near the crossing), lack of winter maintenance, or unsafe procedures in close proximity to a construction site (see Figure 11).

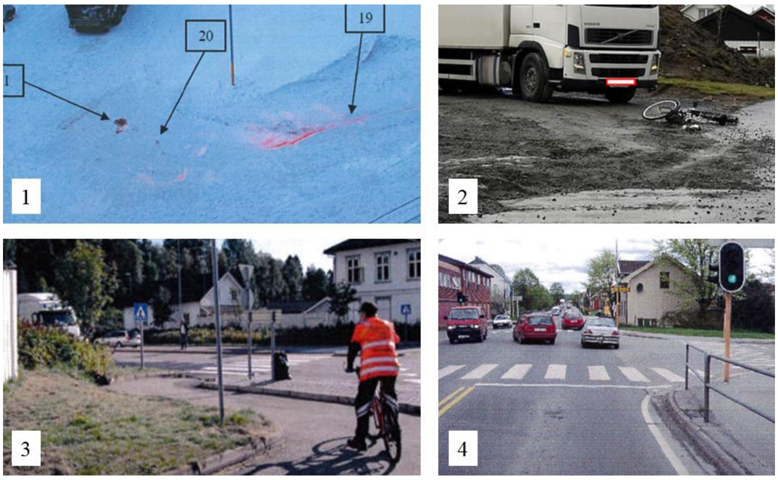


Figure 11 – Examples of the risk factors in fatal TCA in Norway - lack of winter maintenance (1), insufficient safety management in proximity to a construction site (2), visibility limited by greenery (3) and lack of dedicated cycle infrastructure (4) (source: NPRA reports)

5.4 Retrospective survey of cyclists about their conflicts with trucks

The online questionnaire survey has been disseminated in all over Norway in order to collect data about cyclists' involvement in conflicts with trucks. The results were first analysed nationwide and then for Trondheim alone. Upon examining the answers obtained, it was evident that many cyclists are experiencing conflicts with trucks in Norwegian cities, as sixty percent of 673 valid respondents reported at least one conflict with a truck during the one-year study period. Responding to four conflict categories (right-turning truck; left-turning truck; straight-intersection and straight-section), the most frequently reported conflicts on a nationwide scale were *straight-section* conflicts, followed closely by *right-turning truck* conflicts. Regarding particular conflict types, *overtaking* and *right-turning truck vs. a cyclist riding parallel with the truck within the traffic lane* were most frequently reported on a nationwide scale (see Figure 12), while in Trondheim, the most frequent conflict types were *truck entering a roundabout while cyclist riding in the roundabout* and *a truck turning right while cyclist riding on parallel cycle path* (see Figure 13).

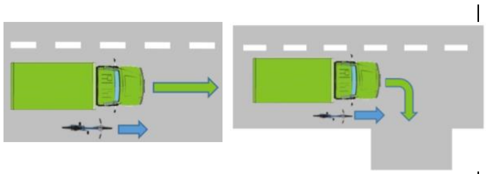


Figure 12 – Two most common conflict types nationwide

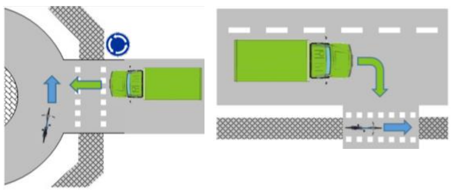


Figure 13 – Two most common conflict types in Trondheim

This difference in conflict types could be explained by the larger network of segregated cycle infrastructure in Trondheim than in many other Norwegian cities. The "city difference factor" is supported by the results of multinomial logistic regression that tested the effects of age, gender, education and city on the conflict category for the sample of respondents from cities Bergen, Oslo, Trondheim and Tromsø. Among the selected variables, only *city* was found to be significant.

To find out, if the distribution of conflict categories corresponds with accident categories, the results from the cyclists' survey were compared with the accident categories identified in nationwide analysis of police accident database (see Table 3).

Table 3 – Frequency of accident and conflict categories, identified in accident database and by the cyclists' survey

	Right-turning truck	**Left-turning truck**	**Straight-intersection**	**Straight - section**	**Other**
Accidents	26%	13%	17%	13%	31%
Conflicts	29%	6%	27%	31%	7%

The chi-square statistic was calculated and statistically significant difference at $p < 0.05$ was found (p-value = 0.000015), indicating that the distribution of the accident categories does not correspond with the conflict categories. However, note that data on accident categories are based on 15-year records. During this period, infrastructure, technological, behavioural, or political changes could influence the frequency and occurrence of particular accident categories. Therefore this comparison can only be considered to be indicative. The low number of accidents does not allow such statistical comparison separately for Trondheim alone.

5.5 Interviews with truck drivers and managers

The face-to-face interviews were conducted using a sample of drivers and managers from several companies operating in Trondheim. These companies represented the construction industry, dairy production and delivery, maintenance, and waste disposal. The interviews revealed several procedural diversities depending on the companies' particular business and size. However, there were a few common findings. For instance, all truck drivers recognised the encounters with cyclists to be "delicate" and were aware of an ever increasing number of cyclists. Nevertheless, they did not consider cycle routes within truck route planning. Managers from construction companies mentioned the difficulties of maintaining high safety standards within the supply chain of subcontractors.

5.6 Behavioural and conflict analysis

This section expands on the findings discussed in papers IV and V. Eight sites (marked from A to H) have been selected in Trondheim for behavioural and conflict analysis (see Figure 14 for their locations).

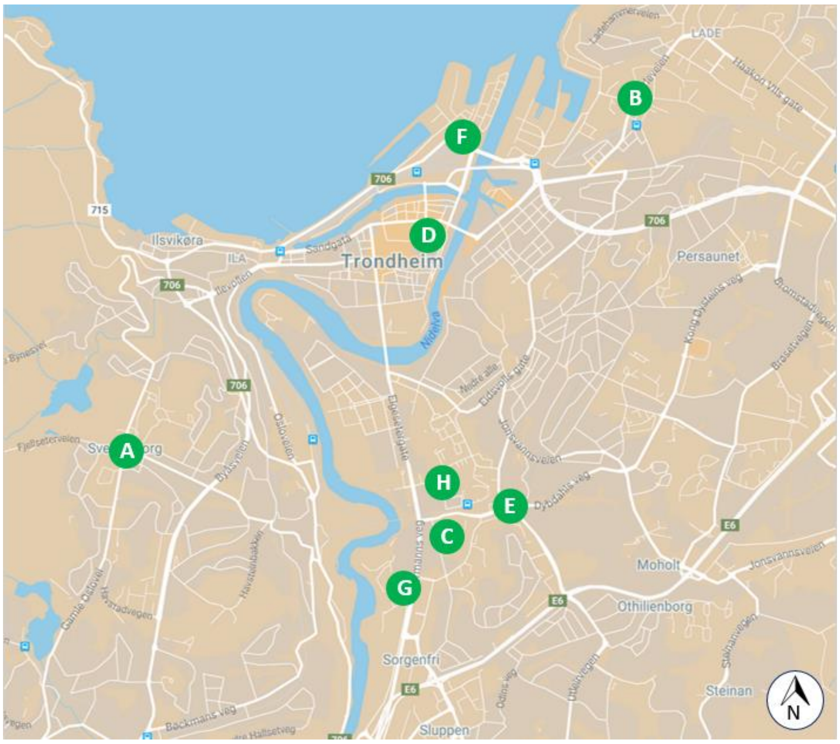


Figure 14 – Location of observed sites

The sites were selected based on following criterions: sufficient cycle and truck volumes in desired directions (particularly crossing of cyclists and right turning trucks vs. parallel riding cyclists), diversity in infrastructure layout, perceived as risky by road users (indicated by cyclists and truck drivers within the survey and interviews), and possibility to install the recording unit. As result, the sites can be merged into three focus categories:

1) right-turning trucks on signalised intersections (sites A-D)
2) cycle and zebra crossings at non-signalised intersection's leg (sites E-G)
3) delivery area along the cycle lane (site H)

The results of analysis are described separately for each category. For each site, traffic volume counts were made for one 8-hour day (assumed to be an average observation day), while encounters were identified over the entire observation period.

5.6.1 Right-turning trucks on signalised intersections

Four signalised intersections have been observed. All intersections have simultaneous green phase for right turn and straight direction. Their characteristics, together with numbers of observation hours, detected encounters and identified conflicts are summarised in Table 4. Encounters between right-turning trucks and straight riding cyclists were primarily of interest. Additionally, encounters between right-turning cyclists and trucks were evaluated where it was possible.

Table 4 - Overview of characteristics of signalised intersection sites

	Site A	**Site B**	**Site C**	**Side D**
GPS	63.417556, 10.353639	63.441528, 10.432444	63.412500, 10.401278	63.433083, 10.403722
Cycle infrastructure	None	None	Cycle lane	Cycle lane, advanced box
Speed limit	40 km/h	50 km/h	30 km/h	30 km/h
Road category/ Land use	Collector/ Residential	Collector/ Residential-industrial	Local/ Mixed	Collector/City centre
Cycle volume (8 hours)*	114 straight, 58 right turning	46 straight and 12 right turning on the road, 45 straight on the sidewalk	530 straight	456 straight, 242 right turning
Truck volume (8 hours)*	12 right turning	58 right turning	8 right turning	43 right turning
Total observation time (hours)	104	45	80	112
Number of encounters	5	4	19	210
Number of conflicts	0	1	0	6

**The volume shows the traffic count obtained from the video in a typical working day during the observation hours. All bikes and trucks performing observed manoeuvres were counted.*

There are essentially two basic types of encounters between right-turning trucks and cyclists – static and moving type. In the static encounter, both trucks and cyclists wait for the green light. When the signal turns green, they both start to move, with the right-turning trucks yielding to cyclists riding straight. In the moving encounter, both trucks and cyclists are approaching and manoeuvring through the intersection during the green phase. The process of the moving encounter depends on the mutual position and behaviour of both the cyclist and truck. Three scenarios were observed, depending if the cyclist rides behind the truck (1), tries to undertake the truck along its right side (2) or rides in front of the truck (3). To summarise, the following types of right-turning encounters are distinguished on signalised intersections: *Static*; *Moving #1* (cyclist rides behind truck); *Moving #2* (cyclist undertakes truck) and *Moving #3* (cyclist rides in front of truck).

Site A is a four-arm intersection in a residential area in Byåsen. The observed one-lane approach was affected by the adjacent construction site, as the existing cycle lane was temporarily closed (see Figure 15).

Figure 15 – Position of the camera (blue triangle), the camera coverage (blue) and the observed approach (red)

Only five encounters were observed when a truck was turning right (either from a stationary or moving position) and a cyclist was in the truck's proximity. In all these encounters, cyclists stayed behind the truck and did not attempt to ride along the truck's inner side. The space aside from the truck was rather narrow due to the limited lane width, which could discourage cyclists from making this manoeuvre (if there was a personal car, cyclists were not afraid to move alongside). Additionally, the adjacent construction site generated several risky truck manoeuvres, as large trucks used the intersection as their turning area (see Figure 16). However, no conflict was observed at the site.

Figure 16 – Turn-around manoeuvre within signalised intersection

Site B is a four-arm intersection in a residential/industrial area in Lade. The observed approach has two traffic lanes, one being designated for right turn only. There is no specific cycle infrastructure in the intersection, and cyclists ride on the road or use the adjacent sidewalk (see Figure 17).

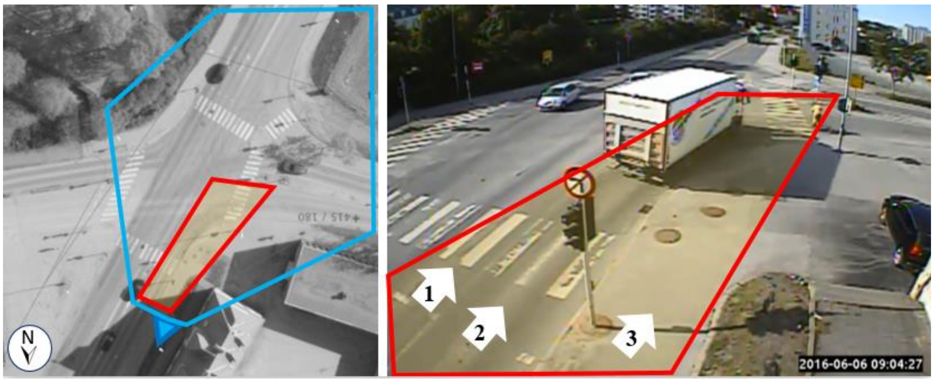


Figure 17 – Position of the camera (blue triangle), the camera coverage (blue), the observed approach (red) and the possible cyclist's alternatives (white arrows)

Almost 80% cyclists were riding straight, 21% were turning right. Cyclists riding straight have three alternatives (see Figure 17): using the straight traffic lane (1), using the right-turn lane, but cycle straight (2) or using the sidewalk and continuing across the zebra crossing (3). Most of the cyclists chose alternatives #2 and #3 (46% for each alternative). Only a minimum number of cyclists (8%) used alternative #1, probably because their position on the road exposed them to motorised traffic.

There were only four truck-bicycle encounters observed in total, and one conflict was recorded within these encounters; a truck had to brake hard to avoid colliding with a cyclist, who was riding on sidewalk and had unexpectedly started to cross the zebra crossing in front of the turning truck.

Site C is a three-arm intersection; however, cyclists can use the intersection as a four-arm. The site is located in the mixed land use environment (university, football stadium) in Lerkendal. The observed approach has one traffic lane and a red painted cycle lane (see Figure 18).

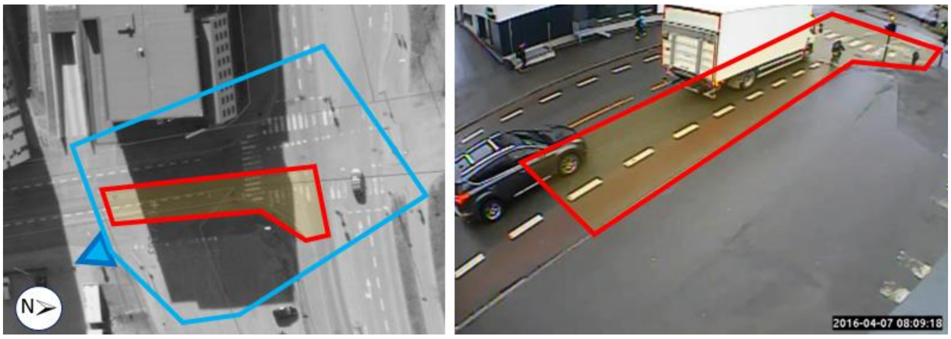


Figure 18 – Position of the camera (blue triangle), the camera coverage (blue) and the observed approach (red)

Although there were only very few right-turning trucks, almost each turning manoeuvre resulted in one or more encounters with cyclists, as their numbers are high at this location. The moving encounter #2 (cyclist undertaking the truck – see Figure 19) was recorded between 4 trucks and 8 cyclists. No conflict was identified in those encounters, as all truck drivers slowed down and let cyclists undertake them. The static encounter was recorded between 5 trucks and 11 cyclists. The cyclists typically rode alongside the standing truck and placed themselves deep into the intersection to wait for the green signal (position #2 and #3 at Figure 20). This type of manoeuvre makes them more visible for drivers and saves time to cross. Only one observed cyclist waited within the cycle lane (position #1 at Figure 20).

Figure 19 – Cyclist undertaking moving truck

Figure 20 – Cyclists' waiting positions

Site D is a four-arm intersection in the city centre area. The observed approach has two traffic lanes (with one designated as right turn only) and a red painted cycle lane with the advanced cycle box (see Figure 21).

Figure 21 – Position of the camera (blue triangle), the camera coverage (blue) and the observed approach (red)

In total, 197 encounters between right-turning trucks and cyclists riding straight were recorded. The majority (75%) of encounters were static ones, with cyclists waiting either in the cycle lane, in the advanced cycle box or in front of the cycle box. When the signal turned green, truck and cyclist(s) both started to move, with the right-turning truck yielding to cyclists riding straight. No conflicts were observed within static encounters, as cyclists were accelerating faster than trucks when the green light turned on, thus “escaping” from trucks’ proximity.

The mutual positioning of trucks and cyclists when waiting for the green light (static encounters) were evaluated. It was hypothesised that cyclists choose their positions differently in the presence of a truck, a personal car and in absence of any vehicle. Four cyclists ‘waiting areas were recognised based on the expected visibility between the cyclist and drivers, area A being considered the safest and area D the most risky (see Figure 22). Only the independent events that were not influenced by other cyclists already waiting in the box were analysed (n=90). According the results of chi-square test, there was a statistically significant difference at $p<0.05$ (with p-value < 0.00001) between the chosen positions of cyclists in the three scenarios. Cyclists were selecting the safest positions when trucks were present (see Figure 22).

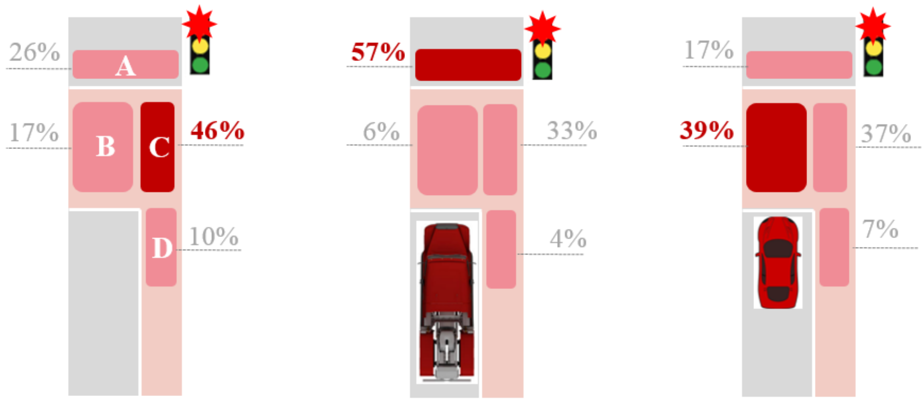


Figure 22 – Positions of cyclists without a vehicle, and with presence of a truck and a personal car

It was further assumed that in case of cyclists' presence, the truck drivers and personal cars' drivers would stop a certain distance in front of the advanced cycle box (considered as safe position) more frequently than in the cases of cyclists' absence. In cyclists' absence, it was assumed that drivers would stop directly next to the stop line more frequently. Once again, 90 events were evaluated. The majority of truck drivers (78%) selected "safer" positions farther back from the stop line (distance > 1 m), gaining a better overview of the area whenever a cyclist was present. Interestingly, the same behaviour was less frequent for personal cars' drivers (44%). When cyclists were not present, the behaviour of both truck drivers and car drives was almost similar – around 30% of them stopped in safer position (see Table 5 for the results).

Table 5 – Comparison of observed positions of vehicles

	Presence of a cyclist	**Absence of a cyclist**
% of trucks in safer positions	78%	34%
% of personal cars in safer positions	44%	27%

Moving encounters were recorded in total of 49 cases. From those, 20 encounters were type #1 (cyclist behind the turning truck). In 10 of those encounters, cyclists were riding in the cycle lane; slowing down to let the truck turns. Seven cyclists preferred to ride in the traffic lane behind the turning truck, thus avoiding the risk of being placed in the truck's blind spot. Additionally, three cyclists were observed overtaking the turning truck. Such manoeuvre generated potentially risky encounters with the vehicles driving behind the truck, as cyclists suddenly moved outside the cycle lane in front of the vehicles. However, no obvious conflict was observed in any of encounter type #1.

Within 21 recorded moving encounters #2 (cyclist undertaking truck), six conflicts were identified. In four of them, the cyclist had to brake after being “blocked” by a cut-in manoeuvre of the truck (see Figure 23, left), in one case, a truck had to stop rapidly and in the last conflict, a cyclist performed sudden turn in front of moving truck (see Figure 23, right). In the rest of moving encounters #2, either truck driver or cyclist slightly slowed down to let the other road user continue. In couple of cases, cyclists were waving their arms to thank the truck drivers to let them go first.

Figure 23 – Cyclist “blocked” by the truck (left); Risky manoeuvre of cyclist in blue (right)

Moving encounter #3 (cyclist in front of truck) was observed eight times. There was no conflict identified in those encounters. Truck drivers typically slightly slowed down in order to keep the safe distance from the cyclists.

There was also a significant volume of right turning cyclists on the observed approach. Most of them were cycling on the sidewalk. Nevertheless, there were 13 encounters observed when a cyclist was turning right, using the cycle lane, and simultaneously a right-turning truck was present. Such scenario can result in situation that cyclist is hit by the side of the turning truck because of the truck’s cut-in-manoeuvre. All observed encounters seemed confusing for the truck drivers, as cyclists were riding relatively fast next to the trucks, typically without any indication of the turning manoeuvre. In two cases, the truck driver stopped the truck due to the uncertainty of cyclist’s movement.

5.6.2 Crossings

In total three crossing sites were observed. Their characteristics, together with numbers of observation hours, detected encounters and identified conflicts are summarised in Table 6.

Table 6 - Overview of characteristics of signalised intersection sites

	Site E	Site F	Site G
GPS	63.413556, 10.412028	63.439583, 10.405139	63.408639, 10.397306
Cycle infrastructure	Cycle path, zebra crossing	Cycle path, zebra crossing	Cycle path, separated cycle crossing
Speed limit	50 km/h	30 km/h	30 km/h
Road category/ Land use	Collector/Mixed -residential/ university	Exit from harbour area/Industrial	Local/Residential
Analysed encounters	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)*	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)*	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)	104	64	60
Number of encounters (smooth/yielding)	109/191	95/370	71/161
Number of conflicts	15	7	3

**The volume shows the traffic count obtained from the video in a typical working day during the observation hours. All bikes and trucks performing observed manoeuvres were counted.*

There are different yield rules at sites E and F (zebra crossing) compared to site G (cycle crossing). At zebra crossings cyclists on the bike must yield to vehicular road traffic (while the vehicles must yield to pedestrians). Typically, a cyclist has three options: yielding to drivers; cycling over the zebra crossing while hoping drivers will yield; or forcing drivers to yield by dismounting and walking over the zebra crossing. In case a cyclist stays on his/her bicycle, the approaching driver has two choices: driving on as the law suggests or yielding to the cyclist. While at site G, because of a designated cycle crossing, cyclists have the right of way over vehicular traffic.

Depending on the truck and cyclist's directions, several encounter types are distinguished. These encounters are further divided into smooth and yielding encounters. In smooth encounters, neither the cyclist nor the truck change their speed, while in yielding encounters there is a yielding manoeuvre from one of the road users. As the conflicts were identified based on an evasive manoeuvre, conflicts were found only within the yielding encounters.

Site E is a four-arm roundabout in Lerkendal in the mixed land use environment (university, football stadium, residences). The observed zebra crossing overtakes two traffic lanes on the approach and one traffic lane on the exit (see Figure 24). The exit and approach are divided by the traffic island. There is a sidewalk on the southern end of the crossing and a bidirectional cycle path on the northern end.

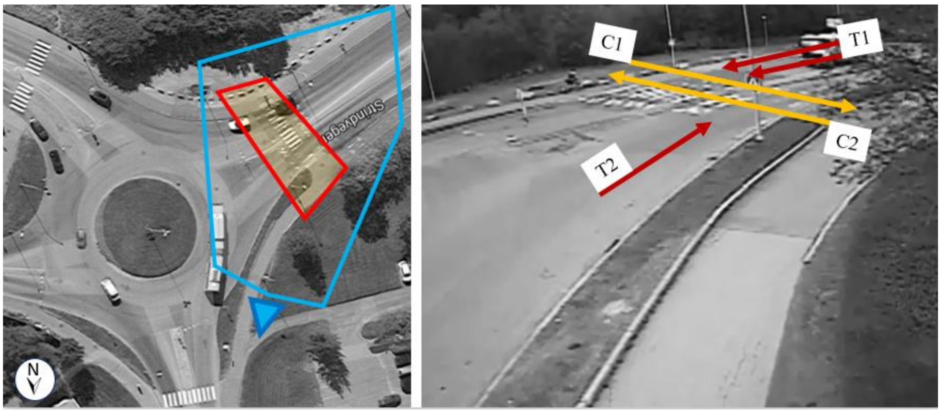


Figure 24 – Position of the camera (blue triangle), the camera coverage (blue), observed approach (red) and observed directions (C=cyclist, T=truck)

Sixty-seven exiting (T1) and 97 entering (T2) trucks and 500 cyclists crossing from the south (C1) and 417 from the north (C2) were counted on an average observation day. During the entire observation period, 15 conflicts were observed in total, a truck making the yielding action in 80% of the cases. C1T2 and C2T1 encounters had the highest share of conflicts from the number of encounters (12% each). Those conflicts occurred within the "simple" yielding encounters (one truck vs. one cyclist scenario) and could be easily considered as normal yielding behaviour, as the evasive action was not very strong. In absolute numbers, most of the conflicts (n=6) were recorded in C1T1 encounters¨, nevertheless it represents 7% of the encounters. Three of the conflicts occurred within the “simple” yielding encounters, similar to those described above. The remaining three conflicts related to the approach’s two-lane configuration (one truck and one other vehicle vs. one cyclist scenario) - a vehicle in the lane closest to the cyclist yielded to a cyclist; however, it did so while simultaneously reducing the visibility between the cyclist and vehicles approaching in the adjacent lane.

Site F is a four-arm roundabout near Trondheim port. The observed cycle and zebra crossing on the eastern leg crosses one traffic lane on the approach and one traffic lane on the exit (see Figure 25). The exit and approach are divided by the traffic island. There is a sidewalk and bidirectional cycle path on both ends of the crossing.

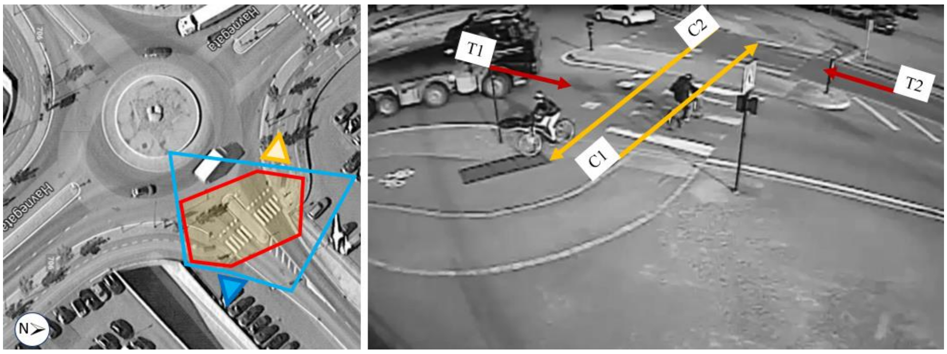


Figure 25 – Camera’s pilot position (yellow triangle) and final position (blue triangle), the coverage area (blue), observed area (red) and observed directions (C=cyclist, T=truck)

Two hundred eighteen exiting (T1) and 250 entering (T2) trucks and 468 cyclists crossing from the south (C1) and 409 from the north (C2) were counted on an average observation day. During the entire observation period, seven conflicts were identified. All these conflicts related to yielding manoeuvres, four being observed in C2T2 encounters and three in C1T2 encounters.

Another type of conflict was captured during the pilot recording at this site, when the camera was placed in position different from the one eventually used during the recording (see yellow triangle in Figure 25). This conflict is not included in the analysis, nevertheless as it demonstrates a risky manoeuvre of a cyclist, it is described here as well for illustrative purposes. The conflict was observed within a C2T2 encounter. The short distance between the crossing and the roundabout’s boundary combined with a high number of long trucks entering the roundabout contributed to situations where trucks blocked the crossing while waiting for a suitable moment to enter the roundabout. This blockage forced cyclists to either wait or make a potentially unsafe manoeuvre around the waiting truck (109 such “blocking” situations were observed). Typically, the cyclists waited or went around the truck from its rear. However, one cyclist decided to go in front of the truck, using the roundabout in contra-flow. Unfortunately, at this same moment the truck started to move. The truck driver noticed the cyclist at the very last moment and braked hard to avoid a collision (see Figure 26).

Figure 26 – Conflict between truck and cyclists (obvious from the truck cab's vertical movement caused by excessive braking manoeuvre), captured by camera's position #1

Site G is a three-arm T-intersection in a residential area in Tempe. The observed red painted raised cycle crossing (combined with zebra crossing) crosses one traffic lane on the approach and one traffic lane on the exit (see Figure 27). The exit and approach are divided by a traffic island. There is a sidewalk and bidirectional cycle path on both ends of the crossing. Eighty-nine trucks (49 from T1, 29 from T2 and 11 from T3 direction) and 246 cyclists from the north (C2) and 354 from the south (C1) were counted on an average observation day.

Figure 27 – Position of the camera (blue triangle), the coverage area (blue), observed approach (red) and observed directions (C=cyclist, T=truck)

During the entire observation period, there were three conflicts observed; in every one a truck performed an evasive (braking) manoeuvre. However, these evasive actions were not intense; on the contrary, they could nearly be called controlled manoeuvres.

5.6.3 Delivery area

This **site H** was analysed separately from other sites as a part of the larger case study. A supermarket's delivery area, situated along a busy cycling street equipped with a red painted cycle lane, was the subject of observation. The site is located in a residential/university area in Elgeseter (GPS 63.415389, 10.399417). The speed limit is 30 km/h. Originally, the video recording aimed at a before-after evaluation of proposed rumble strips. The intent behind rumble strips was to alert cyclists to the position of a truck delivery ramp. Before this measure was implemented, a camera was placed in position so that the entire delivery area was covered (see Figure 28). In total, the area was recorded for five working days, each day between 7:00-17:00.

Figure 28 – Position of the camera (blue triangle), the coverage area (blue) and observed area (red)

The analysis of recording before the implementation of rumble strips did not identify any truck-bicycle encounters related to the proposed measure that could be compared within a before-after study. After the implementation of the rumble strips, a camera was placed above the rumble strips for one day in order to observe the behaviour of cyclists riding across the rumble strips. Furthermore, a number of cyclists and truck drivers were interviewed to find out their understanding of the measure's purpose. It was found that the measure had no desirable effects and its purpose was not recognised by road users. Nevertheless, other safety issues connected with the trucks' manoeuvres to reach their delivery positions and their encounters with cyclists were identified during the recordings. Two conflicts were recorded during these manoeuvres.

5.6.4 Observation summary

During 619 hours of video observations, 993 truck-bicycle encounters were identified. In total 34 of them resulted in a conflict defined by an evasive action, which means that one conflict was observed per 18 recording hours (or per 29 encounters). The frequency of encounters at the observed sites ranged from 0.05 to 4.35 encounters per observation hour, with higher values recorded on crossings (on average seven times more than on signalised intersections – see Table 7). Note that on average, there were twice more cyclists and eight times more trucks counted on crossings compared to signalised intersections. The number of encounters between trucks and cyclists was affected not only by the traffic volumes, but also by the diversity of local conditions, as each site has different infrastructure layouts and surrounding environment.

The speeds of the road users involved in the encounters were not specifically measured; however, from the observations it is obvious that in the majority of encounters, road users' speeds were very low. However, as seen from the analysis of accident records and review of fatal TCA, even at low truck speeds, accident consequences can be very serious for cyclists. Very low cyclist speeds are believed to pose a certain risk, as more effort to stabilise the bicycle is needed, and maintaining lateral control is more difficult (Stelling-Konczak et al., 2017). Nevertheless, no such stability problems have been observed in the recordings.

To estimate the risk related to each site and compare those sites, the event-based approach to measuring the exposure and risk was applied and the risk ratio R_r was calculated. To compensate for different lengths of observation periods at each site, the risk ratio R_r of each site was calculated as:

$$R_r = [(\text{total nr. of conflicts/total nr. of encounters})/\ \text{hours of observation}] \times 10^3$$

Table 7 shows the values of R_r for each site, together with frequencies of conflicts and encounters. For crossing sites, only yielding encounters are calculated.

Table 7 – Comparison of observed sites

	Signalised intersections				**Crossings**			**Delivery**
Site	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Nr. of encounters/hour	0,05	0,09	0,24	1,88	1,84	5,78	2,68	0,66
Nr. of conflicts/hour	0,00	0,02	0,00	0,05	0,14	0,11	0,05	0,04
Conflict/Encounter	0,00	0,25	0,00	0,03	0,08	0,02	0,02	0,06
Risk ratio R_r	0,00	5,56	0,00	0,26	0,76	0,30	0,31	1,21

The risk ratio R_r was highest at site B (signalised intersection without any cycling infrastructure). However it is important to note that the very low total number of encounters affected the resulted risk ratio at this site. Thus, when comparing the sites with a higher number of encounters (more than one encounter per hour), site E (zebra crossing on two-lane approach/one-lane exit to/from roundabout) scored as having relatively highest number of conflicts. In this particular instance, the existence of two-traffic lanes on the approach; higher speeds of trucks, poor road marking of the crossing and high share of students' cyclists could contribute to that result.

Right-turning encounters at signalised intersections

Regarding right-turning trucks vs. straight riding cyclists' encounters at signalised intersections, all conflicts except one were observed within the moving encounters #2 at site D, when the cyclists were trying to undertake the right-indicating trucks when both were approaching the signalised intersection having the green light. At site C, several examples of moving encounter #2 were observed as well, however no conflict was recorded. At site A, the possibility for cyclists to undertake the trucks was eliminated by the temporary closure of the cycle lane. It seems that all the cyclists involved in moving encounters #2 undertook the right-indicating trucks without any hesitation, relying on their belief that truck drivers were aware of them. However, even the cyclists have right a-way in such scenario, truck drivers may have limited visibility and cyclists should be aware of that. The combination of cycle lane and simultaneous green phase for right-turning trucks and straight riding cyclists contributed to that behaviour. The observations did not reveal whether truck drivers did not see cyclists or if they drove in an aggressive manner to force the right turn in those conflicts. The only different conflict was observed at site B, when the cyclist in question was riding on the sidewalk, and the conflict occurred at the zebra crossing.

Furthermore, encounters that involved right-turning cyclists and right-turning trucks (recorded at site D only) seemed confusing for the truck drivers. Cyclists were riding relatively fast next to the trucks, typically without any indication of the turning manoeuvre, thus the truck drivers were not certain about the cyclists' intentions.

Several forms of risk awareness were observed at signalised intersections. The observation of waiting positions at site D revealed that cyclists and truck drivers are aware of the risk and adjusted their behaviour accordingly, positioning themselves as safely as possible in majority of encounters. Such behaviour was not so frequent if the personal cars were present. Similarly, at site C, cyclists waiting for the green signal placed themselves "deep" into the intersection, thus further away from waiting trucks. Another form of risk awareness was observed in encounters when cyclists ride in the traffic lane behind the turning truck, thus avoiding riding in the cycle lane parallel to the truck. This type of maneuvering requires a certain level of cycling experience if cyclists are to anticipate potential conflicts with other motor vehicles and feel comfortable riding within traffic lanes; however, it eliminates the occurrence of encounters with right-turning trucks. However, to confirm those assumptions it would be necessary to conduct an additional survey to obtain the data directly from involved road users.

Crossing encounters

The conflicts at the crossing sites related to the yielding encounters. They were characterised by only slight evasive action and could easily be considered normal behaviour. Both cyclists and truck drivers seemed to be aware of each other and, as a result, both reduced their speed; additionally, cyclists typically crossed in front of trucks. The conflicts with more intense evasive action were related to the "unexpected" scenarios (e.g. cyclists trying to go around trucks blocking the crossing or limited visibility on the two-lane approach). To compare the encounters, the risk of each encounter type was calculated as the share of conflicts in the encounter type (nr. of conflicts/nr. of encounters). Table 8 summarises the risk of encounter types recognised at crossings. Encounters C1T2 and C2T1 at site E were evaluated as the most risky ones. Both encounters occurred on the crossing's outer edge (from the cyclist's point of view).

Table 8 – Comparison of the risk of encounters' types at observed sites

Site	Type of encounter	Total nr. of encounters	Nr. of yielding encounters	Nr. of conflicts	Share of conflicts in yielding encounters
E	C1T1	140	86	6	0,07
	C1T2	64	34	4	0,12
	C2T1	56	41	5	0,12
	C2T2	40	30	0	0,00
F	C1T1	69	52	0	0,00
	C1T2	186	149	3	0,02
	C2T1	63	44	0	0,00
	C2T2	147	125	4	0,03
G	C1T1	121	93	1	0,01
	C1T2	30	18	0	0,00
	C1T3	19	10	0	0,00
	C2T1	47	33	2	0,06
	C2T2	12	6	0	0,00
	C2T3	3	1	0	0,00

Considering the observations at all three crossing sites, it was possible to discuss the yielding behaviour of vehicles, when cyclists were on the bike in close proximity from the crossing. Only independent yielding encounters uninfluenced by other road users were analysed. Table 9 compares drivers' yielding behaviour at all three sites. The bold values present the correct behaviour according to the traffic rules.

Table 9 – Yielding behaviour of truck drivers and car drivers (while cyclists on the bike)

	Truck		**Personal cars**	
	did not yield	**yielded**	**did not yield**	**yielded**
Site E (n=62)	**27%**	73%	**13%**	87%
Site F (n=152)	**30%**	70%	**11%**	89%
Site G (n=59)	5%	**95%**	0%	**100%**

About 70% of truck-bicycle encounters at sites E and F proceeded against the traffic rule (a truck yielding to a cyclist when the truck had the right of way), for personal cars that share was almost 90%. The similar finding, that majority of car drivers yield to cyclists at zebra crossings contrary to traffic rules, was reported in a recent Norwegian study (Bjørnskau, 2017). Bjørnskau observed three locations and on two of them, around 80% of car drivers yielded to cyclists. It demonstrates a willingness among drivers to share the road space, even when the cyclist is in the wrong. When comparing yielding behaviour of truck drivers and personal cars' drivers on those two sites, significantly more truck drivers (at $p < 0.05$) did not yield to cyclists. This could be explained by more demanding stopping and starting to move again for trucks than for personal cars. At site G, 95% of truck-bicycle encounters and 100% of personal car-bicycle encounters were processed according to the traffic rules, which is not surprising given the layout of the site.

Additionally, cyclists' crossing behaviour in encounters with trucks was analysed, particularly the percentage of cyclists crossing while either riding or not riding their bikes. At site G, all cyclists rode their bikes while crossing. This is unsurprising given that they have priority here; thus, there is no "advantage" to dismounting. However, there was a significant difference between sites E and F even though the same traffic rule applies to both sites. At site E, cyclists dismounted from their bikes in 44% of crossing encounters with trucks (behaving as a pedestrian and thus having the right of way), while at site F only 4% did so. This difference could be explained by the different perception of each site, as site F is newly built and looks more like a separate prioritized cycle crossing than a typical zebra crossing, while site E has poor road marking (see Figure 29). Additionally, site E is more difficult to cross, as it is wider, more complex and the speeds are higher. Thus, more cyclists would rather dismount from their bikes and behave as pedestrians on site E than on site F.

Figure 29 – The same traffic rule, the different crossing/yielding behaviour at those sites. Site E on the left, site F on the right (source: google maps)

Furthermore, there was a significant difference at $p < 0.05$ observed between the behaviour of cyclists in their encounters with trucks and with personal cars on site E. Significantly more cyclists dismounted from their bikes in crossing encounters with trucks (44%) than with personal cars (14%). No such difference was observed on other sites. It seems that encounters with trucks are being perceived by cyclists as more challenging on site E and thus they more frequently behave as pedestrians.

Delivery area

Upon examining the results of this case study, it is evident that the implementation of any safety measure should be preceded by a safety analysis. Such analysis identifies the risk factors and provides necessary knowledge to implement the effective countermeasures. The usage of video recordings enabled the evaluation of this complex situation in the proximity of the delivery area over a long period, which in turn provided enough evidence about risky behavioural patterns that would have otherwise remained hidden. Seen from a more systematic perspective, it is alarming that this level of risky layout has been implemented within formally correct decision making processes. This situation highlights the need for closer cooperation between different stakeholders, including those involved in the fields of urban planning and freight logistics.

5.7 Urban infrastructure risk factors

Each method applied within the project revealed several infrastructure risk factors - see Table 10 for their summary.

Table 10 - Overview of the infrastructure risk factors identified in each method

Method	Risk factors
Accident database analysis	Wet road surface Roundabouts, signalised intersections and crossings
Review of in-depth investigation reports on fatal TCA	Alignment of the cycle path encouraging higher speeds of cyclists before a crossing Simultaneous green phase for vehicles and cyclists at signalised intersections Proximity of construction sites to locations with frequent cycle traffic: in particular no fencing around the construction site; no suitable place to turn around provided for trucks, temporary road closure does not respect the needs of cyclists Lack of winter maintenance (snow on the road increases braking distance; snow piles limit visibility) Visibility at intersections/crossings reduced by greenery and traffic signs Driver's vision impaired by the sun
Questionnaire survey of cyclists' conflicts with trucks	Cycle paths in commercial areas, as they frequently cross exits and accesses used regularly by trucks Narrow streets, signalised intersections and roundabouts
Face-to-face interviews	Sites with high concentration of students - cyclists Insufficient layout and location of docking/delivery areas Construction sites in residential areas
Conflict and behavioural analysis	Insufficient layout of delivery areas at locations with high level of cycle traffic Two + one lane approach/exit of a roundabout combined with the cycle/zebra crossing Short distance between the crossing and boundary of a roundabout combined with a large number of long trucks Simultaneous green phase for vehicles and cyclists in combination with cycle lane along busy truck routes Poor marking of the crossing

Behavioural and conflict analysis, along with the review of in-depth investigation reports of fatal TCA, identified more detailed risk factors, while the accident analysis and surveys discovered more general factors. The difference is not only in the amount of detail, but also in the level of objectivity and validity. Risk factors found during the in-depth investigation of fatal TCA objectively contributed to the accident occurrence; however, surveys and interviews provided the list of factors that are "only" perceived as risky by the respondents. The conflict analysis identified risk factors that affect the occurrence of conflicts. At the same time, it is not obvious how those factors are valid for predicting the accident occurrence.

5.8 Evaluation of cycle layouts

The acquired knowledge about truck-bicycle safety has been applied to the safety evaluation of the infrastructure layouts contained in the Norwegian Cycle Handbook V122 (2014) that represent common cycle infrastructure in Norway.

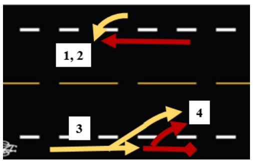
The evaluated layouts present the ideal situations, which are in themselves simplifications of the complex reality. The local conditions and specifications, together with diversity of risk factors require that each site in the real world should be individually assessed by safety evaluators who keep these ideal situations in min and take the local conditions into consideration.

The recommendations provided in this chapter aim at both the road transport system's lower level factors (e.g. particular measures for ensuring sufficient visibility and providing adequate information or specific design requirements), as well as higher level factors (e.g. maintenance planning, strategies for implementation of consistent and forgiving infrastructure and traffic calming measures). The information which follows could assist, for instance, when conducting road safety audits and inspections or establishing new infrastructure guidelines. As within the scope of this project, the evaluation focuses on encounters and risk factors associated specifically with trucks.

For each layout, potentially risky encounter scenarios are illustrated, with the yellow arrows symbolizing cyclists and red arrows symbolizing trucks. Risk factors associated with each scenario are defined, and safety recommendations are suggested.

CYCLE LANE

Cycle lanes provide dedicated space for cycling within a road. They are considered risky particularly along the sections with high volumes of truck traffic. The presence of cycle lanes can affect the driving behaviour of passing trucks (inducing smaller passing distances and higher speeds), as drivers perceive the cyclists to be protected within the cycle lane. The air turbulence from a passing truck can be difficult to manage for cyclists in such scenario. Furthermore, the areas with high demand for truck deliveries (e.g. streets with high density of shops) present a higher risk for cyclists, as trucks can misuse the cycle lane for parking when making deliveries. Such behaviour was observed within this research on one of the analysed sites (site H), along with conflicts between the truck drivers crossing the cycle lane while making deliveries and cyclists. When trucks are parked in the cycle lane, cyclists must overtake the truck, which exposes them to motorised traffic. Particularly risky are situations when the truck is entering or leaving the parking position, as passing cyclists can be hidden in truck's blind spots. There is also a risk that cyclist will hit the parked truck – such accidents were identified within this research. Therefore, providing dedicated delivery areas for trucks presents the important task for city planners. The maintenance (both regular and winter) of cycle lanes is important as well, as any major unevenness in the cycle lane surface or presence of snow can cause unexpected manoeuvres or cyclists' falls, or force them to ride within the road.



Scenario 1: *Cyclist falls under passing truck*

Risk factors: Unevenness of cycle lane surface; Lack of maintenance; High speeds/proximity of trucks causing air turbulence

Scenario 2: *Cyclist suddenly moves into the traffic lane in front of passing truck*

Risk factor: Unevenness of the cycle lane surface; Lack of maintenance; Illegal usage of cycle lane by parked cars

Scenario 3: *Cyclist hits parked truck, "dooring"*

Risk factors: Illegal usage of cycle lane by trucks

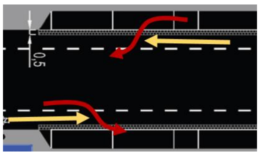
Scenario 4: C*yclist tries to overtake a truck that is starting to merge into the traffic lane from a parking position (or truck is entering cycle lane to park)*

Risk factors: Illegal usage of cycle lane by trucks; Blind spots

Recommendations: Systematic, year-long maintenance; Providing dedicated delivery areas; Ensure low speeds of trucks

CYCLE LANE ALONG PARKING LANE

The risk related to cycle lanes situated along parking lanes is connected particularly to trucks' parking manoeuvres (either manoeuvring to or from parking positions), as cyclists can be placed in the truck blind spots during those manoeuvres. Additional risk presents a potential for "dooring" incidents, however no such accident was identified within this research.



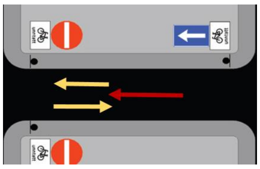
Scenario: *Cyclist in cycle lane collides with a truck manoeuvring to/from parking position*

Risk factors: Limited visibility; Overlap of delivery times and cyclists' peak-hours; Blind spots

Recommendations: No visibility obstacles hiding cyclists; Providing designated areas/times for truck deliveries

ONE-WAY STREET WITH CYCLISTS IN CONTRA FLOW

Allowing cyclists to ride in the contra flow of a one-way street is common measure to make cycling more attractive by providing better accessibility and making the network more coherent. The presence of trucks can cause a discomfort to cyclists, particularly if streets are too narrow. Attention must be particularly given to the layout of the one-way street's start/end and to the surface maintenance.



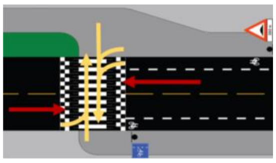
Scenario: *Conflicts between cyclists in both directions and passing truck*

Risk factors: Traffic lane is too narrow; Obstacles on the road; Visibility obstructions at the start and end of one-way street, Trucks drive too fast

Recommendations: Following the recommendations provided by Handbook V122 regarding the number of trucks and minimum width of traffic lane; Providing alternative truck route; Considering traffic calming measures; Systematic maintenance; Inspecting the intersections at the end/start of the one-way street

ZEBRA/CYCLE CROSSING

Crossings were identified within this research as one of the most risky locations. It is the place, where cyclists leave the safe segregated environment and must interact with motorised traffic. Crossing can be designed either as shared zebra crossing (where cyclists should behave as pedestrians in order to have the right of way) or separated cycle crossing (where cyclists have the right of way over motorised traffic). Several crossings (as part of an intersection) were analysed within this research. It was found that on zebra crossing, truck drivers are less willing than car drivers to yield to cyclists, if cyclists stay on their bikes. However, around 70% of truck drivers yielded to cyclists in such situation and most of the observed encounters were relatively smooth, with both users being aware of each other. Therefore, ensuring an eye contact between cyclists and truck drivers is vital and the visibility in the proximity of the crossing should not be reduced by any obstacles. The number of traffic lanes seems to be an important risk factor as well, as several severe conflicts were observed on a site with two traffic lanes in one direction – in such scenario, a vehicle in the lane closest to the cyclist yielded to a cyclist; however, it did so while simultaneously reducing the visibility between the cyclist and vehicles approaching in the adjacent lane. Furthermore, the layout of cycle infrastructure adjacent to the crossing should induce lower crossing speeds, and the road should be designed to slow down road users while approaching the crossing.



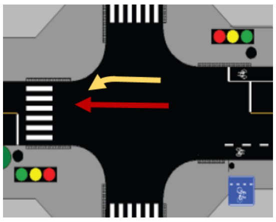
Scenario: *Crossing cyclists colliding with trucks*

Risk factors: Lack of visibility; High speed of crossing cyclists induced by the sidewalk/path's geometry; Two traffic lanes on the approach to the crossing; Blind spots, High speeds

Recommendations: Checking the visibility in adverse conditions (darkness, rain, snow) and recommend lightening if needed; Infrastructure layout inducing lower crossing speeds and establishment of eye contact; No visibility obstructions (signs, greenery), Raised crossing to alert and slow down road users

ROAD NARROWING

Road narrowing or unexpected ending of a cycle lane (e.g. behind the intersection) can present a risky location particularly when the narrowing is not expected by the road users. Furthermore, the merging manoeuvres can be problematic in case of too narrow traffic lane, existence of a high curb (as it limits the eventual escape manoeuvre of a cyclist) and insufficient surface maintenance (as it can force cyclists to move deeper into the traffic lane). Note, that overtaking conflicts were reported by cyclists' survey as the most frequent conflict type in Norway. Therefore, proper signage, maintenance and forgiving road layout are important in such locations.



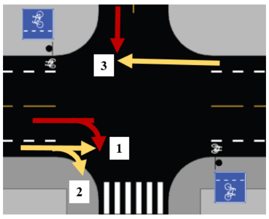
Scenario: *Conflicts during merging*

Risk factors: Traffic lane is too narrow; Lack of information about narrowing in advance; High curb at the narrow point; Lack of maintenance

Recommendations: Providing adequate information to road users in advance (road marking, signs); Ensuring forgiveness of the merging section (e.g. low curbs); Proper maintenance in the merging section

X and T-INTERSECTION

Intersections in general are recognised as the most risky locations for cyclists, because of the many potential collision points and encounters that can occur within manoeuvring through the intersection. The results of this research support that finding. Particularly the intersections in residential areas have been identified as the frequent location of truck-bicycle accidents. At X and T-intersections without traffic signals, the ensuring the sufficient visibility, low speed of motorised traffic, and explicitness of the traffic rules/required movements is vital. Ideally the cycle infrastructure should not suddenly disappear within the intersection, but as seen earlier, this is not always the case. The presence of a cycle lane together with high volumes of right-turning trucks can generate right-turning (blind spots) accidents, which are the most severe types of TCA. There should be an adequate space, forgiving layout (e.g. low curbs) and continuous cycle infrastructure provided for right turning cyclists, as they can be "locked in" by the simultaneously right turning truck.



Scenario 1: *Cyclist going straight vs. truck turning right*

Risk factors: Blind spots; High speed

Scenario 2: *Cyclist and truck both turning right, cyclist is "locked in" during the manoeuvre*

Risk factors: Lack of escape possibilities for cyclists; Missing cycle infrastructure in adjacent section ("behind the corner"); Small curve radius

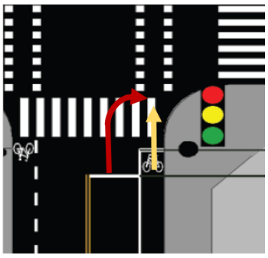
Scenario 3: *Truck from the minor road, cyclist on the main road*

Risk factors: Visibility obstructions

Recommendations: Provide adequate visibility; Low curbs in right turns; Consistency of cycle infrastructure, Traffic calming measures, Clear and understandable signing/marking

SIGNALISED INTERSECTION WITH "SMALL" CYCLE BOX

Signalised intersections have been recognised in this research as the most frequent location of right-turning (blind spot) accidents. The layout of cycle infrastructure, together with the timing of signal phases play an important role in the occurrence of those accidents. Ideally, separated green phases for right turn and straight direction should be provided and the cycle infrastructure should not "invite" cyclists into the potential trucks' blind spot areas. From that point of view, "small" cycle box seems not to be an ideal solution.



Scenario: *Cyclist going straight vs. truck turning right (both from stationary position)*

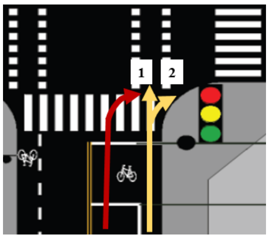
Risk factors: The dimensions and position of cycle box places cyclists into blind spot areas

Recommendations: Providing separated green phases; Providing a warning sign/marking; Providing an external mirror for trucks; Putting the stop line further back; Improving cycle box dimensions

SIGNALISED INTERSECTION WITH "LARGE" CYCLE BOX

"Large" cycle boxes allows cyclists to place themselves further from the trucks, outside the blind spot areas. Such a scenario was analysed within this reseach (site D). A certain degree of risk awareness was observed at this site, as both cyclists and trucks were placing themselves into safer positions, when the other one was present in the area. Regarding conflicts, the moving encounters, when a right turning truck and straight riding cyclist are moving next to each other, both having green signal, were identified as the most risky. Several cyclists seemed unafraid to undertake the right turning truck but then had to break hard, as truck drivers did not notice them. Therefore, segregated green phases are considered as good solution. It is also possible to install a mirror within the intersection to reduce the blind spots (however, such mirror could cause behavioural adaptation, as cyclists can assume that they are more visible). A warning sign to raise awareness about blind spots can be installed as well.

It was further observed, that cyclists turning right typically do not indicate such a manoeuvre, which can confuse the truck drivers, as they expect them to ride straight. There should be adequate space, forgiving layouts (e.g. low curbs) and continuous cycle infrastructure provided for right turning cyclists, as those can be "locked in" by the simultaneously right turning truck.



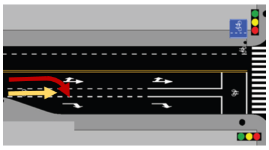
Scenario 1: *Cyclist going straight vs. truck turning right (both moving prior to the turn)*
Risk factors: Simultaneous green phase; Blind spots

Scenario 2: *Cyclist and truck both turning right, cyclist "locked in" during the manoeuvre*
Risk factors: Lack of escape possibilities for cyclists; Missing cycle infrastructure in adjacent section ("behind the corner"); Small curve radius

Recommendations: Providing separated green phases; Low curbs in right-turning curves; Providing a warning sign/marking, Providing an external mirror for trucks

CYCLE LANE BETWEEN TRAFFIC LANES

Such layouts expose cyclists to trucks that are moving into the right turning lane, which is risky especially when the cyclist is located in the truck's blind spot area. A warning sign/marking can be provided to raise awareness of cyclists.



Scenario: *Cyclist hit by a truck moving into right-turning lane*
Risk factors: Blind spots

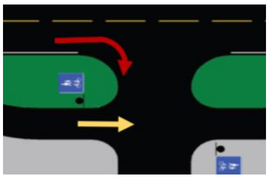
Recommendations: Providing a warning sign/marking

CYCLE PATH/SIDEWALK PARALLEL TO ROAD – CROSSING

Cycle paths/sidewalks are considered by many cyclists as very safe cycle infrastructure, because they provide physical segregation from motorised traffic. Nevertheless, at locations where the cycle path/sidewalk crosses the road, cyclists are exposed to motorised traffic. Crossing related accidents were the most frequent accident type identified within this research. Furthermore, such a scenario was reported by cyclist's survey as the second most frequent conflict type in Trondheim. Therefore, these locations require increased attention.

Lack of mutual visibility between truck driver and cyclist present the important risk factor, therefore the segregation strip between the road and the cycle path/sidewalk should be obstacle free in the proximity of the crossing. If the segregation strip is too narrow, the cyclist can occur in the blind spot area of the parallel driving truck. Furthermore, the layout of cycle infrastructure adjacent to the crossing should induce lower crossing speeds and establishment of eye contact –

the same is true for the road and vehicles. Installation of a sign warning drivers about the crossing and/or marking/sign on the cycle lane to warn cyclists about the crossing present another potential safety measure. Installation of a raised crossing can be considered as well.



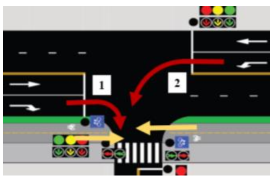
Scenario: *Cyclist on parallel path is hit by a truck turning from the main road*

Risk factors: Limited visibility; Blind spots; High crossing speed; Lack of information about crossing

Recommendations: No visibility obstructions (signs, greenery); Infrastructure inducing lower crossing speeds and establishment of eye contact, Installation of a warning sign/marking; Installation of a raised crossing

CYCLE PATH/SIDEWALK PARALLEL TO ROAD – SIGNALISED CROSSING

This layout was reported by cyclists' survey as risky with this research, particularly in case of several consecutive crossings along the short section of a road with trucks frequently turning from this road (e.g. nearby the large shopping malls located next to a main road outside the city centre). If the crossing of parallel cycle path/side walk is located within a signalised intersection, the timing of signal phases presents the most critical risk factor. To limit the possibility of any encounter between trucks and bicycles, green phases should be segregated in such a way, that crossing cyclists have the green light separately from other traffic movements. However, one must not forget, that many cyclists do not always respect the traffic signals, particularly in specific situations (e.g. in off-peak hours or bad weather). Therefore, there should be no visibility obstructions between the road and the cycle path in the proximity of the crossing.



Scenario 1: *Cyclist on parallel path is hit by a truck turning right from the main road*

Risk factors: Timing of green phases; Limited visibility; Blind spots

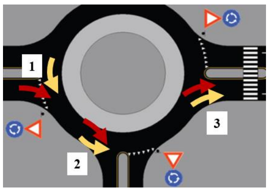
Scenario 2: *Cyclist on parallel path is hit by a truck turning left from the main road*

Risk factors: Timing of green phases; Limited visibility; Blind spots

Recommendations: No visibility obstructions (signs, greenery); Providing separated green phases

ROUNDABOUT WITHOUT CYCLE INFRASTRUCTURE

Regarding cyclists' safety, roundabouts are generally considered as the most risky intersection layout. Roundabouts were reported as potential risky by both the truck drivers and cyclists within the surveys conducted within this research. If cyclists ride within the roundabout together with the motorised traffic, the potential conflict locations present the roundabout's entrance and exit. Scenario #1 (truck entering the roundabout) was identified as the most frequent conflict type in Trondheim. There must be no visibility obstructions reducing the possibility for eye contact between truck drivers and cyclists on the roundabout entrances. The layout of the entrance should not induce high speeds of the trucks. Both entrance and exit should preferable have only one traffic lane. The width of the traffic lane within the roundabout should not allow parallel movement of truck and bicycle and induce excessive speeds of trucks.



Scenario 1: *Cyclist in the roundabout hit by entering truck*
Risk factors: Lack of visibility; Angle of approach; Two lanes on the approach; Lack of visibility; Blind spots

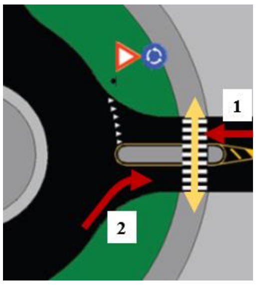
Scenario 2: *Cyclist in the roundabout hit by exiting truck*
Risk factors: Too wide traffic lane on the roundabout; Blind spots
Scenario 3: *Both truck and cyclist are exiting from the roundabout*
Risk factors: Too wide traffic lane on the roundabout; High curb; Blind spots

Recommendations: One-lane approaches and exits; Sufficiently narrow traffic lane within the roundabout

ROUNDABOUT WITH SEPARATED CYCLE PATH

If segregated cycle infrastructure is provided within the roundabout, the crossings present the risky locations, as the conflicts with both the entering and exiting trucks can occur there. Such layout was observed in two locations within this research (sites E, F). The majority of conflicts at those locations was characterised by only slight evasive action and could easily be considered normal behaviour. Both cyclists and truck drivers seemed to be aware of each other and, as a result, both reduced their speed; additionally, cyclists typically crossed in front of trucks. The conflicts with more intense evasive action were related to the "unexpected" scenarios (e.g. cyclists trying to go around trucks blocking the crossing or limited visibility on the two-lane approach). The most risky encounter types were observed on the crossing's outer edge (from the cyclist's point of view).

The risk factors related to both the entrance and the exit are the limited visibility, presence of two traffic lanes and infrastructure layout inducing high speeds both of trucks and cyclists. Therefore, the layout of cycle infrastructure adjacent to the crossing should induce lower crossing speeds of cyclists and establishment of eye contact, radius and layout of exit and entrance should reduce the speed of trucks and there should be no visibility obstructions located in the proximity of crossing. In case of very high volumes of long trucks entering the roundabout, the distance between the crossing and the roundabout presents a sensitive issue – too short distance can support blocking the crossing by trucks, while too long distance creates insufficient detour for cyclists.



Scenario 1: *Crossing cyclist hit by entering truck*
Risk factors: Lack of visibility; Excessive speed of cyclist/truck, Two traffic lanes on the approach; Trucks entering the roundabout are blocking the crossing

Scenario 2: *Crossing cyclist hit by exiting truck*
Risk factors: Lack of visibility; Excessive speed of cyclists/truck; Blind spots

Recommendations: One-lane approaches and exits; Sufficiently narrow traffic lanes; No visibility obstructions; The infrastructure layout inducing lower speeds, Consider raised crossing to alert road users.

6 EVALUATION OF THE METHODOLOGY

The evaluation of each single method applied within this research project is fully described in the relevant papers; thus, this chapter focuses on the evaluation of their combined usage.

The crucial question at the start of the project centred around choosing one particular method to study one specific issue of truck-bicycle safety in detail or attempting to combine multiple methods. While the latter approach does not allow an in-depth exploration, it does provides broader knowledge about the studied topic as a whole. The multi-method approach, known as methodological triangulation, should enhance the analysis and interpretation of findings and is typically presented as an unproblematic method of doing rigorous research (Denzin, 1978; Perlesz and Lindsay, 2003). As data are drawn from multiple sources, it broadens the researcher's insight into the different issues underlying the phenomenon (Ochieng et al., 2015). While such methodological triangulation is often called for, it is rarely conducted (Fyhri et al., 2016b).

Because the truck-bicycle safety topic has not been extensively explored within a Norwegian context so far, the second approach has been selected and multiple methods were conducted. Furthermore, no specific hypothesis has been suggested prior to the start of the research, and no strict plan has been set in advance. Such an approach enables the researcher to explore the studied topic freely, follow "the side streams", learn from mistakes and be creative. This type of research is called the inductive research – it does not test a hypothesis, rather its goal is "to develop and build a theoretical, empirical and substantive understanding of the research question" (Jachyra et al., 2015).

As Ottino (2003, cited in Salmon et al., 2012) noted, "complex systems cannot be understood by studying parts in isolation. The very essence of the system lies in the interaction between parts and the overall behaviour that emerges from the interactions. The system must be analysed as a whole''. As it was nearly impossible to analyse the system as a whole within this research, the combination of methods enabled to reveal several interactions between different elements and levels of the system that would otherwise stayed hidden. For instance it was demonstrated within the analysis of the delivery area (site H) that the increased risk for cyclists in the proximity of the trucks' delivery area has its origins in the uncoordinated decision making and planning processes (higher level of the system). This was discovered by the combination of interviews with policy makers, survey of cyclists, video recordings, and subsequent safety analysis of the traffic situation.

The applied methods were particularly suitable for identifying risk factors from the lower levels of the road transport system (i.e. infrastructure layout), as was the aim of this project. Nevertheless, several risk factors from higher levels were encountered as well, mainly during the face-to-face interviews with managers of truck companies and their drivers (e.g. the safety procedures in construction companies or the route planning practices) and the previously mentioned interviews with policy makers.

Important advantage of the multi-method approach is that each method delivered the knowledge that could be used to improve the design and application of the subsequent method. For instance, the knowledge of common accident types gained from accident data analysis provided input for the questionnaire's design; the demographics of cyclists involved in TCA from the accident data determined the survey's target group; and the data obtained within the surveys provided essential information for the selection of sites for video recordings. See graphical illustration of those connections in Figure 30.

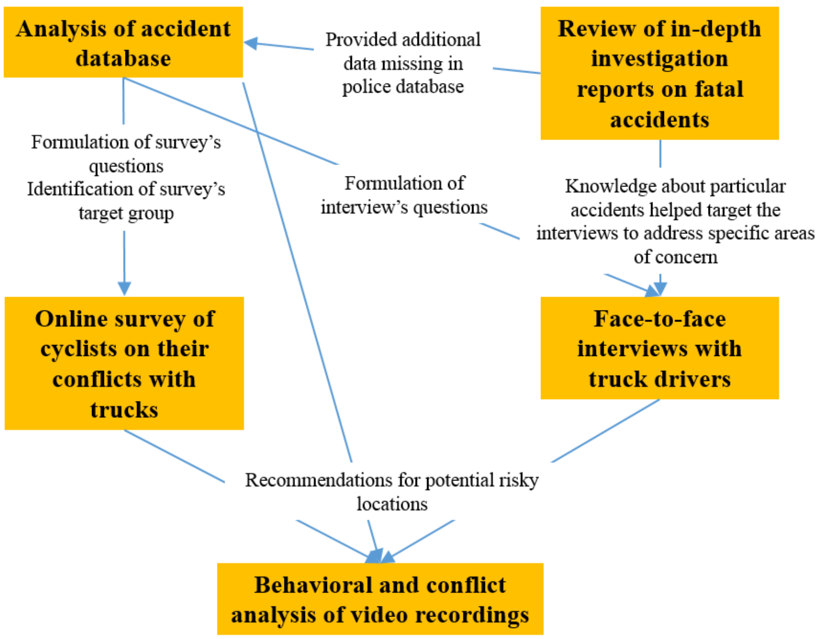


Figure 30 – Connections between the methods

Furthermore, the combination of methods eliminated some limitations characteristic for each method. Analysis of accident reports as well as in-depth investigations are prone to several forms of well-known bias (e.g. low quality/lack of data, underreporting, low number of accidents, and lack of exposure data). Specifically in this research, low number of accidents made the interpretation of descriptive statistics and statistical models challenging. The review of investigation reports on fatal accidents added valuable missing information to the analysis of accident records from police databases, particularly regarding truck types and their equipment, characteristics of drivers and cyclists and local conditions, however very low numbers of fatal accidents means that those findings can be considered as indicative only.

Potentially high level of underreporting of accidents was corroborated by the finding from the survey of cyclists, as 13 respondents reported an accident with truck and none of those accidents was investigated by police. Thus, studying conflicts (using surveys and video recordings) provides an alternative to limit this shortcoming. Nevertheless, the retrospective survey suffers from its own limitations as well (e.g. bias regarding self-reporting of unpleasant/risky behaviour, personal bias involved in conflict interpretation, bias arising from errors in the respondents' understanding of a conflict and from errors in recalling the conflicts). These limitations can be overcome by the usage of video recordings to collect data on conflicts independently from the road users. On the other hand, the recordings lack data about respondents' perceptions and characteristics. This knowledge would make the analysis more accurate, as was demonstrated within the analysis of the delivery area (site H). In this case, the analysis of video was supplemented by the intercept survey, which provided valuable additional data about cyclists' understanding of the evaluated safety measure, a factor which had not been made clear merely from behavioural observation. Furthermore, the evaluation of video recordings is certainly affected by the subjectivity of the researcher, as no objective method to analyse the encounters was applied.

Regarding the exposure, the video recordings enabled the measurement of exposure based on the frequency of particular encounters, which is more representative for risk assessment than usage of other exposure measures (e.g. frequency of cycling reported by the respondents of the survey).

To conclude, the applied research approach is suitable for more general exploration of the research topic, as has been done within this PhD project, rather than for a very detailed study of one particular phenomenon. The diversity of identified risk factors supports the usefulness of the multi-method approach, as each method identified different risk factors.

7 CONCLUSIONS

The main research goal – to explore truck-bicycle safety in Norwegian urban areas – was achieved through five papers produced as components of the overall PhD project. One particular strength of this research lies in its combination of several methods, both of the data collection and their evaluation, to study the common phenomenon. This multi-method approach has enabled the exploration of the studied topic from several angles and provided more comprehensive insight into the risk factors involved with truck-bicycle encounters. As a result, it was possible to identify common urban infrastructure risk factors as well as evaluate typical Norwegian cycle infrastructure layouts.

Even though the accidents between trucks and cyclists are rare events, they have typically very severe consequences. The author hopes that findings of this research will contribute to implementing safer infrastructure solutions, both for cyclists and truck drivers.

7.1 Identified knowledge gaps

Within the presented research, several knowledge gaps have been discovered that call for further exploration, including the following:

- *Complexity of risk factors*: While this research has focused on infrastructure, it would be ideal to take into account the transport system as a whole in order to identify factors from all levels of the system. The focus should not only be limited to basic systemic elements (infrastructure, road users and vehicles), but also consider city logistics, infrastructure planning, legislation, companies' policies regarding safety and staff training etc.
- *The magnitude of risk factors*: The list of identified risk factors is "merely" informative. Further research into analysing the magnitude of these risk factors would be highly beneficial.
- *Urban freight characteristics*: When trying to find out the exposure data (traffic volumes) and routes of truck traffic, it was evident that these are not covered by the existing traffic surveys. For example in Norway, truck volumes are "hidden" in long vehicles' volumes, which also include buses. As having knowledge about traffic volumes and truck routes is crucial for traffic analysis (and developing strategies/policies), traffic surveys should be conducted in such a way to reveal the relevant data about truck traffic.
- *Truck – bicycle safety and construction logistic in urban areas*: The number of large construction sites in Norwegian cities is currently high and will probably increase in the near future. Construction sites generate enormous volumes of temporary truck

traffic. Truck drivers are often stressed and not familiar with the area in which they are driving. Cyclists are not usually taken into consideration during trucks' route planning, and truck drivers are not aware of the specifics of urban cycling. The design and equipment of trucks used in the construction industry are often more dangerous than other types of trucks. The construction supply chain contains many stakeholders/contractors with different safety environments and standards. Thus, the safety issues between cyclists and urban construction freight requires an attention.

- *Gender differences in TCA involvement*: Female cyclists appear to be overrepresented in TCA, particularly in severe and fatal TCA. Gender-associated differences in behaviour, physiology, and experience probably play a role in explaining that phenomenon; however, very little is still known about this issue.
- *E-bikes vs. regular bikes*: As e-bikes are becoming increasingly popular, it is important to analyse the behavioural differences between the users of e-bikes and regular bikes and their potential effects in relation to truck-bicycle safety.
- *Behavioral observations*: Cycle safety research has been based on quantitative studies. Therefore, more behavioral studies are needed in order to reveal the risks connected to certain infrastructure layouts and traffic situations. It would be beneficial to connect video observations with surveys of the background characteristics and opinions of cyclists and truck drivers.
- *Safety in numbers*: Is that phenomenon valid in truck-bicycle encounters? A certain level of encounters is likely to favour safety, as it keeps road users aware and enables them to learn from these encounters. However, no such study has been conducted so far in the field of truck-bicycle safety.
- *Autonomous trucks*: The expected rise of autonomous trucks requires to study their effects on encounters with vulnerable road users.

7.2 Lessons learned

Being exposed to such a complex research topic enhanced my understanding of urban transport. Particularly my personal discovery of “a new universe” of urban logistics was fascinating. The experience of applying different methods has presented an amazing opportunity to learn and acquire knowledge from different fields of road safety research and extensively explore the research topic. Nevertheless, conducting several methods within the short timeframe of the PhD project has obviously limited the depth attained by each method. Looking back at the start of the PhD project and having in mind the experience gained from conducting this research, ideas regarding the potential modifications of applied methods and use of other methods have been forming in my brain. Several of these ideas are described below.

The survey of cyclists' could be improved by using some kind of travel diaries, though such study would be very time consuming, and its scope would be limited. Conducting a stated/revealed preference study could be beneficial for identifying infrastructure preferences and perceived risks, both of cyclists and truck drivers. It would also be very interesting to carry the face-to-face interviews in a more structured manner using a larger sample of truck drivers, not only in Trondheim but also in several other Norwegian cities.

Regarding the conflict analysis, better camera positioning and using a camera with higher resolution level would enable the application of software for quantifying the conflicts' indicators, which would then increase the objectivity of the conflicts' identification, e.g. by measuring the change in speed or time to collision. However, specific characteristics of truck-bicycle encounters (very low speeds, close proximity of road users) could make such measurements challenging and the higher resolution level might compromise privacy. Such approach would further require the precise calibration of the camera in order to recover the real-world positions of trucks and cyclists (Ismail et al., 2013).

Low number of observed conflicts (approximately one conflict per 18 hours of recording) raises the question about feasibility of the conflict technique for studying truck-bicycle safety. Additionally, the occurrence of relevant accident types is so rare, that any validation of conflicts is almost impossible. Nevertheless, the recordings provided valuable inside into the bike-truck co-existence by observing the behaviour of both cyclists and trucks. Thus, instead of focusing on capturing conflicts, which requires many hours of recording, shorter period could be analysed instead, aiming at detecting potentially risky behavioural patterns. Such analysis could be strengthen by a survey of involved road users.

An issue that could have been handled differently is the typology of truck-bicycle encounters, which has not been uniform within the project (see Table 11). In the analysis of accident data, the typology was based not only on the manoeuvres of road users, but also on risk factors (i.e. blind spot), while later, the typology was based on truck movements, which is more consistent with other safety studies. This change was triggered by understanding the topic better later on in the project. However, it has been still possible to reverse the original TCA types into the new categories.

Table 11 - The different typology used within the project

Accident types – National data	Accident types – Trondheim data	Conflict types – National survey
Cyclist crossing (intersection/exit)	Truck turning right	Truck turning right
Cyclist crossing (section)	Truck turning left	Truck turning left
Intersection movements	Rear end	Truck going straight – intersection
Blind spot	Truck overtaking	Truck going straight – section
Overtaking	Cyclist lost control	Other
Head on	Other	
Cyclist hit parked truck		
Cyclist lost control		

7.3 Final Remarks

Truck traffic is frequently neglected in urban and traffic planning, which contributes to the implementation of risky infrastructure layouts. Indeed, quite often streets and intersections in urban environments are not designed to accommodate large vehicles, which makes their encounters with other road users potentially hazardous (see Figures 31 and 32).

Figure 31 – A truck in Trondheim's city centre

Figure 32 – A truck using a shared cycle path as an unloading area, Trondheim

Additionally, cyclists' needs are often ignored in urban environment as well. Along with specific characteristics of both cyclists and truck traffic, providing safe environments for their coexistence is a challenging task. The term "safe environment" does not only mean minimising an accident risk. Rather, it is also necessary to eliminate the potential for conflicts' occurrence as well, as these present frightening events for cyclists.

There are strategies and safety measures to limit the likelihood of trucks encountering with cyclists and to decrease the probability of accidents taking place. These strategies include truck traffic restrictions, implementation of designated truck and cycle routes and segregated cycle infrastructures, legislative measures (e.g. on retrofitting trucks), or innovative urban freight logistic concepts. More specific safety measures include designing safer layouts for delivery areas, intersections' improvements (e.g. segregated green phases or specific layouts for advanced cycle boxes at signalised intersections) or measures focusing on improving the visibility by eliminating the blind spots aided by mirrors, cameras or external sensors. Modern technological applications (e.g. for cyclists' detection) show promising safety potential, however, their development and implementation still present a challenging task, particularly in complex urban environments. Nonetheless, it is important to remember that even new technologies cannot eliminate every single risk factor.

Therefore, despite all the strategies and measures, trucks and cyclists will continue to encounter one another, particularly at intersections, crossings and in specific situations, such in the proximity of construction sites or during loading/unloading manoeuvres (see Figures 33 and 34). Creating safe infrastructure layout of these locations is therefore crucial, and must respect the needs and specifics of both trucks and cyclists. The unique characteristics of each location call for a context-sensitive approach which takes local conditions into consideration.

Figure 33 – Construction site in city centre affecting the adjacent cycle lane, Trondheim

Figure 34 – Local store delivery on a busy cycle street, Trondheim

This research has provided unique knowledge within a Norwegian context, a particularly important fact given the expected increase in both truck and bicycle volumes in Norwegian urban areas. Even the numbers of TCA are low and show a long-term decreasing trend; the results of this research revealed that cyclists frequently experience encounters with trucks. Upon examining the results of accident analysis and conflict types reported by cyclists, it is obvious that not only are encounters with right-turning trucks typical, but other types of encounters are also frequent. If these encounters result in accidents, the consequences are typically very severe (note that more than 30% of fatal bicycle accidents in Norway have involved a truck). Even if an encounter does not result in an accident, just the experience of encountering a truck can be very frightening for cyclists and has the potential to deter people from further cycling. Thus, there is an evident need to focus the road safety agenda with respect to truck-bicycle safety issues, particularly within the Vision Zero road safety strategy and current political efforts to encourage people to cycle more. Successful safety approaches should focus on containing a combined implementation of several measures and identifying the risk factors from higher levels of the road transport system. The need for coordination and cooperation between freight urban logistics and the cycle and urban planning field is inevitable, requiring wider involvement of relevant stakeholders. Quite clearly, objective knowledge and data should form the basis for rational decision-making.

To summarise, the following key contributions of the PhD thesis to work currently being completed in this field are recognised:

- The literature review presents the comprehensive up-to-date summary of the topic.
- Several methods were applied and evaluated. Their application and results are not limited specifically to Norway; on the contrary, the experience gained may be transferred abroad.
- The scope of observation of truck-bicycle encounters in real traffic presents one of the first studies of its kind, even within the international context. The method proved to be successful for identifying both the behaviour patterns and risk factors. As conflicts are very rare, conducting behavioral analysis seems to be more suitable approach to study truck-bicycle encounters than conflict analysis.
- The research revealed a number of infrastructure risk factors, which if eliminated would improve the safety between trucks and cyclists. The knowledge of infrastructure risk factors could be applied when conducting road safety audits and inspections.
- Knowledge gaps were identified.

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APPENDIX – THE PAPERS

Paper I

Truck-bicycle safety - An exploratory literature review

Pokorny, P., Pitera, K., 2017

Is not included due to copyright

Paper II

Accidents between freight vehicles and bicycles, with a focus on urban areas

Pokorny, P., Drescher, J., Jonsson, T., Pitera, K., 2017

Available online at www.sciencedirect.com

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Transportation Research Procedia 25 (2017) 999–1007

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

Accidents between freight vehicles and bicycles, with a focus on urban areas

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Abstract

Given the growth in urban areas, many cities are developing freight initiatives that include defining policies related to land use and infrastructure, while at the same time implementing transport policies that promote cycling and building cycle specific infrastructure. Growing numbers of trucks and cyclists result in increased safety concerns. Knowledge of risk factors related to accidents between trucks and bicycles can contribute to decisions regarding planning and infrastructure design that reduces the occurrence and consequences of these accidents. The objective of this paper is to explore characteristics of accidents between trucks and bicycles in urban areas in Norway and identify relevant risk factors.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Road safety; Urban areas; Cyclists; Freight traffic; Accident analysis

1. Introduction

As urban populations grow and cycling oriented policies are implemented in many cities, cyclists' safety concerns are also increasing. Safety between bicycles and freight vehicles (referred to as "trucks" further in the text) are of specific concern given the size and mass differential of these two road users and the severity of their potential accidents.

This paper investigates accidents between trucks and bicycles in Norway, with a specific focus on urban areas, in order to identify the infrastructure related risk factors. The current Norwegian National Cycling Strategy identifies a goal that at least 8% of all travel should be done by bicycle by 2023 (compared to 4% in 2009) and that 80% of children and students should walk or cycle to schools. Together with local transport policies, the conditions for cycling in many cities are improving and it is thus possible to expect an increase of cycling in urban areas, as described by Dozza & Werneke (2014). Meanwhile, the number of trucks and distances driven by them are also growing. According to Statistics Norway (2015), the number of vehicle kilometres driven by trucks increased annually in average by 4.6% in the period from 2009 to 2014. This rise, both in bicycle and truck volumes, carries several challenges, with road safety being one of the most significant.

While overall road safety has improved over the past 15 years in both Norway and EU, safety of cyclists (and other vulnerable road users) is still a large concern (ETSC, 2015). Degraeuwe et al. (2015) summarised that the probability and consequences of an accident are higher for cyclists than for car users. Particularly for Norway, Elvik (2009) found that injury rates per million

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Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.
10.1016/j.trpro.2017.05.474

kilometers of travel for various transport modes indicate a considerably higher risk of injury accidents for cyclists than travel by car or bus (data for period 1998–2005). The current Norwegian National Road Safety Plan (2012) estimates that the risk of being killed or severely injured per kilometre travelled is three times higher for cyclists than for car occupants.

Presence of trucks is one of the factors that contributes to higher risk for cyclists (Allen-Munley & Daniel, 2006). Trucks contribute more significantly to severe injury accidents compared to other types of vehicles (Ming et al., 2014). Heavier vehicles have greater momentum at a particular speed than passenger cars (Kim et al, 2007) and vehicles with higher hoods cause greater injuries (Maki et al, 2003). As result, cyclists involved in accidents with trucks are usually more severely injured than cyclists who collided with a car, as shown by Manson et al. (2012), Kaplan et al. (2014) and most recently by Kröyer (2015). Thus, **t**ruck-bi**c**ycle **a**ccidents (referred to as "TCA" further in the text) are considered as one of the most serious type of event a cyclist can experience, while a truck driver is usually not physically injured. As Johannsen et al. (2015) and Seiniger et al.(2015) described, particularly turning accidents, and especially those associated with blind spots, are regarded as the most serious type of TCA. Niewoehner & Berg (2005), Sagberg & Sørensen (2012) and Volvo Truck (2013) pointed out, that the reduced field of vision of truck drivers (both direct and indirect) contributes to those blind spot accidents. Based on a German in-depth accident study by Niewoehner & Berg (2005), construction and municipal vehicles were exceedingly often involved in turning accidents.

According to these previously mentioned studies, most of TCA take place in urban areas, in daylight, under good road conditions and during low speed manoeuvres. With growing numbers of cyclists and trucks in urban areas, TCA have been recognized as a severe road safety problem in many cities. In London, for example, heavy trucks have been the most frequently involved vehicle in accidents resulting in cyclists' deaths for more than two decades, as it was identified in a study by McCarthy and Gilbert (1996), and more recently by Morgan et al. (2010) and Manson et al. (2012). There is still a lack of understanding about TCA, especially how infrastructure influences their occurrence and potential consequences. Such knowledge is essential to provide infrastructure, which accommodates the growing number of cyclists and ensure their safety (and thus further catalyse cycling), while at the same time providing for the needs of trucks, especially in urban areas. Thus the impact of infrastructure and associated land use and planning efforts, as related to TCA in urban areas, is a focus of this research. Furthermore, it aims at developing insights into where, why and how these accidents occur, in order to provide infrastructure-related safety recommendations.

2. Data

Police data forms the basis for official accident records in Norway. They are further verified by Norwegian Public Roads Administration (NPRA) and The Central Bureau of Statistics (SSB), and then collected within The National Database of Road Data (NVDB). Additionally, several accident analysis groups (UAG) are working within the NPRA to conduct in-depth analysis of all fatal accidents in Norway (since 2005). Both sources were used within this research. Note that Norway uses the most common definition of road fatality, i.e. 'dead within 30 days as a consequence of the road accident'.

For period 2000-2014, NVDB contains 271 TCA. Ten percent of those TCA had fatal consequences, while for other types of cycle accidents; this share was only 1.2%. The percentage of fatal TCA from all fatal cycle accidents was almost 20% which is one of the highest in Europe, as can be seen in Evgenikos et al. (2016). In addition, one should note the long-term decreasing trend in annual numbers of TCA (as well as for other types of cycle accidents in Norway); although, there is no such decreasing trend in numbers of fatal TCA (see Fig. 1).

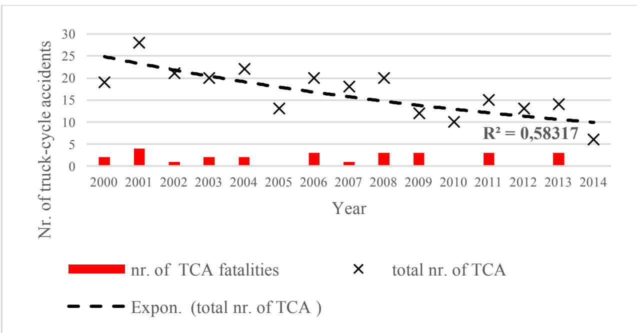

Fig. 1. Annual numbers of all and fatal TCA in Norway (2000-2014)

Because of the nature of police data, several factors may limit the accuracy of road safety analysis relying on this data:

- Underreporting is typically large for cycle accidents, especially for single and slight injury accidents. It would be possible to expect higher reporting level for TCA, as the consequences of those accidents are more severe and there is always a motor vehicle involved. Nevertheless, as Elvik (1998, cit in Erkne & Elvik, 2007) estimated, injury accidents where a large truck is the heaviest party and a cyclist is the counterparty have the mean level of reporting of only 54% in Norway.

According to a more recent analysis by Bjørnskau (2005), the level of reporting is higher than assumed by Elvik (1998), but there are certainly some accidents still missing in the database. It is also reasonable to assume different levels of reporting for different injury severities (higher underreporting level for slight injuries than for fatalities) as reported by Jonsson (2013). However, it was not possible to use hospital data within this research to limit the impact of underreporting, as hospital records in Norway do not distinguish between vehicle categories involved in accidents with bicycles.

- The classification of injury severity applied by the police is slightly less detailed than the Abbreviated Injury Score (AIS) applied by hospitals. Norwegian police use five degrees for severity of accident (1 = fatality, 2 = critical injury, 3 = severe injury, 4 = slight injury, 5 = no injury). The borders between injury levels may not be clear (Veisten et al., 2007). There are considerable inaccuracies when comparing police severity reports with the severity assessment made by medical staff at the time of admission to the hospital, as Mannering & Bhat (2014) showed. Aggregating the severity levels into two categories, "fatal" and "non-fatal", as done in this study, limits this impact
- Information about actual speeds of truck and bicycle at the time of accident were unknown. Only the speed limit at most accident locations was recognised. Although the speed limit can be considered as a surrogate measure of the actual vehicle speed (Eluruet et al., 2008), it could bring some uncertainty into the results, as it may differ from the actual speed at the time of the accident.
- The quality of description of accidents varied across police districts. Some police reports provided full description of accident. However, other provided just basic information (e.g. "bicycle was hit by truck") and it was not possible to fully understand the accident event. Sometimes the information about the speed limit, age of cyclist and other characteristics were lacking. Furthermore, fatal accidents were usually described in more details than other types of accidents.

There are two additional considerations associated with the dataset. First, there is a lack of reliable exposure data (e.g. number of encounters between cyclists and trucks on certain types of infrastructure layouts), thus the results cannot be controlled for exposure. Additionally, the small number of accidents (which is positive for society) can influence the reliability of the findings.

For the analysis, all records where a cyclist was involved in an accident with a vehicle classified by police as truck, semitrailer, tanker, 1-axe trailer or 2-axe trailer were taken into account (n = 271). TCA with unknown GPS locations (n = 8) were excluded, because without known locations it was not possible to identify characteristics such as land use, road type and location. TCA with three or more participants (n = 11) were also excluded because there can be diverse mechanisms involved in them compared to TCA with two participants only. As a result, the final dataset contained 252 accidents. In order to make the data as reliable as possible, these accidents were further reviewed to complete and/or to correct data that were missing or not recorded in the way suitable for the analysis. GPS coordinates of accidents were mapped using Google Maps to gather additional information about accident location. Thus, it was possible to recognize the processes behind accident events, to categorise accidents into the main types (see Fig. 2) and to specify some of the important variables (see Tab. 1). Variables describing road surface conditions, visibility, time of the accident, age and gender were taken from police database without any further specifications. The presence of dedicated bicycle infrastructure was not considered, as it was not possible to determine if and what cycle infrastructure was present at the time of an accident.

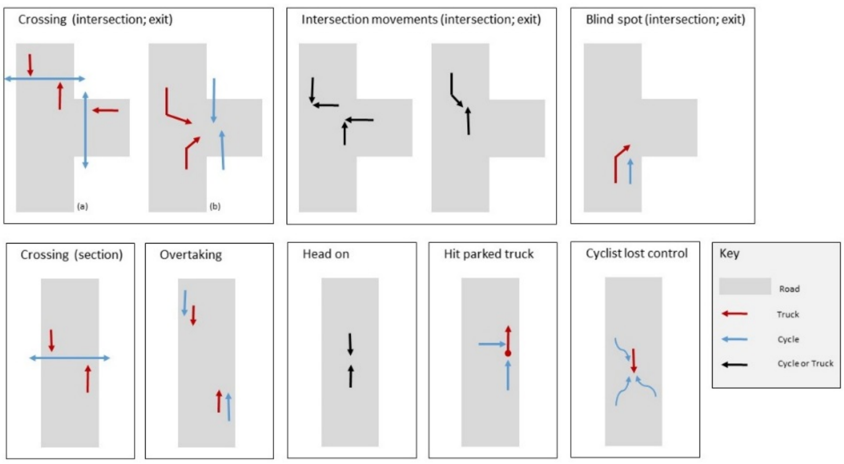

Fig. 2. TCA typology

Table 1. Overview of reviewed variables

Variable	Category	Definition
Road type	Urban/Rural	Urban/Rural
	Arterial/Primary	Main roads with flow/connection function.
	Collector/ Secondary	Roads, which connect residential/local roads with arterials/primary roads.
	Residential/ Local	Roads/streets used mainly for local purposes or to reach collector roads. Utilized for access and residential functions.
Road environment	Urban	Areas with dense housing or commercial/industrial activities. Speed limit is typically 50 km/h or less. Subcategories: residential, commercial, industrial and mixed usage
	Semi-urban	Areas with some housing, farms or other buildings, often interspersed with fields/forest/water. Speed limit is usual higher than 50 km/h.
	Rural	Areas with minimal housing or other buildings, road is typically surrounded from both sides by forest, field or water. Speed limit is usually higher than 50 km/h. Subcategories: forest, fields
Location of accident	Intersection	Intersections with different forms of traffic control - Roundabout, Traffic Lights, Road Signs, Right hand rule
	Section	Section of road between intersections
	Exit	Provide access to the area adjacent to road
Accident type (see also Fig. 2)	Crossing (intersection; exit)	Cyclist is using cyclist or pedestrian infrastructure to cross a road in the intersection/exit area and is hit by a truck that is travelling on/turning to that road/exit. In urban areas, cyclist are typically travelling using pedestrian crossings – in that case, the cyclist should give way to the car (in case of riding a bike). If he/she gets off the bike, the cyclist is treated like a pedestrian and has right of way when crossing.
	Crossing (section)	Cyclist is crossing the road in the section (not at an intersection or exit) and is hit by a truck that is travelling on that road.
	Blind spots	Accident at intersections or exits, when cyclist and truck are both going in the same directions on the road (within the same or adjacent traffic lane) and truck is turning right and crosses into the cyclist's path.
	Intersection/exit movements	All other types of movements (except crossing and blind spots) in the intersection area.
	Overtaking	Cyclist is overtaken by truck, when both travel in the same direction on a road's section.
	Head on	Cyclist and truck collide when driving in opposite directions on a road section. This does not include intersection accidents.
	Hit parked truck	Cyclist hits a parked truck.
	Cyclist lost control	Cyclist loses control (due to some hazard on the road or is influenced by alcohol) and collides with a truck. A truck does not influence the collision's occurrence.
	Other	Other and seldom types of accidents (e.g. rear end collision, cyclist hit by the loose wheel or piece of cargo)
Speed limit	Low; Normal; High	Low: 30-40 km/h; Normal: 50 km/h; High: over 50 km/h

3. Analytical methods

Descriptive statistics and binary logistic modeling were performed, in order to explore the data and relationships between variables.

For the descriptive statistics, the data set containing all reviewed TCA, including the variables highlighted in Tab. 1, was used to find the count and percentage of each relevant characteristic for each accident. The chi-square tests for independence were conducted to determine whether there are any significant associations between TCA variables and the environment (urban, semi-urban and rural) and between urban TCA variables and their consequences (fatal and non-fatal).

Discrete response models in traffic safety are typically used to explore the relationship between accident severity and its contributing factors. As accident severity models can be heavily influenced by size of the sample from which they are estimated (Ye & Lord, 2014), small samples may necessitate more simplistic models (Savolainen et al., 2011). Thus, given the small sample size in this study, a binary logistic regression model was used to estimate the probability that one of two events (fatal or non-fatal urban TCA) occurs, with relation to several independent variables. Two groups of variables were selected: 1) those that are considered to have an effect on severity of an accident between motor vehicles and vulnerable road users (speed limit, age, gender, accident type) and 2) those, which were significant for severity outcome of urban TCA, as identified in descriptive part of the analysis. The variables related to land use and road category were not used in the model, as they are correlated with accident type, and therefore can be expected to confound the results.

Furthermore, UAG reports describing in-depth analysis of fatal TCA were reviewed, in order to get deeper insight into the risk factors. Since 2005, thirteen fatal urban TCA have been investigated by UAG. In order to identify risk factors, the UAG investigators decomposed each accident into the sequence of events/actions related to each of the road users (truck driver and cyclist) and vehicles (truck and bike) involved in the accident. Together with studying the police report, the investigators are conducting the reconstruction of each accident, interviews with witnesses, technical check of vehicles and inspection of the site. The final report includes detailed description of the accident, characteristics of road users and vehicles, the circumstances (visibility, weather conditions), the pictures from the site, list of identified risk factors, and in some cases also recommendations for safety improvements.

4. Results

4.1. Descriptive statistics

The reviewed dataset contains 252 TCA. The majority of TCA (77%) occurred in urban areas and the same applies to fatal TCA (70%). Their average TCA severity (based on police classification) is slightly lower than for rural TCA. There is a distinct downward trend in annual numbers of urban TCA in last 15 years, similar to what was seen in Fig. 1 previously, while less of such a trend for the non-urban TCA.

The chi-square test for independence for significance level 0.05 was used to determine whether there is a significant association between the TCA variables and the environment of TCA. Significant associations were found with TCA location (p-value < 0.00001), accident's types (p-value < 0.00001), time of TCA (p-value 0.001451) and gender distribution (p-value 0.00863).

Table 2. Percentage distribution of TCA variables according the environment (urban, semi-urban, rural)

Variable	**Categories**	**Urban (n=193)**	**Semi-urban (n=30)**	**Rural (n=29)**
		% distribution	***% distribution***	***% distribution***
Severity	Non-fatal/Fatal	90/10	87/13	86/14
Location	Intersection/Section/Exit	56/33/11	37/50/13	7/93/0
Accident type	Crossing (intersection/section)	28 (74/26)	20 (50/50)	0
(most frequent ones)	Intersection Movement	24	0	3
	Overtaking	13	30	59
	Blind spot	12	7	0
	Head on	2	0	14
	Other or Unknown	21	43	24
Day in week	Working/Weekend	93/7	100/0	83/17
Time of day	Morning/Mid/After/Night *(06-10/10-15/15-21/21-06 o'clock)*	35/28/35/2	20/43/33/4	10/14/66/10
Road surface	Dry/Wet/Unknown	68/17/15	78/22/0	84/16/0
Visibility (weather related)	Good/Bad/Unknown	85/2/13	90/3/7	83/0/17
Cyclist age	Young/Adult/Senior/Unknown *(0-15/15-65/over 65 years)*	18/74/8/0	23/67/3/7	14/76/10
Cyclist gender	Male/Female/Unknown	56/44/0	70/27/3	86/14/0

Given the specific interest in urban TCA, those accidents were examined further. Urban TCA occurred mostly during working days (93%), in the morning and afternoon (both 35%) and under good (weather-related) visibility conditions (85%). Intersections were their most frequent location (56%). Blind spot TCA accounted only for 12% of TCA; however, their average severity was higher than for other accident types. Blind spot TCA occurred mostly at signalized intersections (54%) and roundabouts (21%). Half of urban TCA were recorded in residential areas, while only 12% in commercial and 9% in industrial areas. Again, intersections were their most frequent location, particularly those with priority based on right hand rule and traffic signs.

As the number of fatal urban TCA was relatively small, it was difficult to identify any significant patterns or differences from non-fatal accidents. Although, in half of fatal TCA, the road surface was wet, and in 70% of them, a female cyclist was involved. Blind spot TCA were slightly dominant for fatal urban TCA than other accident types. The chi-square test for independence for significance level 0.05 was performed to determine whether there is a significant association between the variables of urban TCA and their consequences (fatal and non-fatal). Significant association was found with road surface conditions (p-value 0.007574) only.

4.2. Binary logistic model for urban accidents

The underlying research hypothesis is that accident severity levels are correlated with various risk factors. The binary logistic regression model was performed for urban TCA with all valid variables (n = 149), using SPSS. Variables used in model are summarized in Tab.3.

Table 3. Variables used in model

Variable	Category	Details
Dependent variable		
Severity	Nominal, binary	Fatal/Non-fatal
Independent variables		
Speed limit	Ordinal	Low (under 50 km/h), Normal (50 km/h), High (over 50 km/h)
Accident type	Nominal	Merged into 5 categories (blind spot, crossing, intersection movement, overtaking and others)
Road surface conditions	Nominal	Dry/Wet
Cyclist's age	Ordinal	Youth (0-15 years)/Adult (16-65)/Senior (over 65)
Cyclist's gender	Nominal	Male/Female

Crossing type accidents, cyclist age of 15-65 years, and a 50 km/h speed limit were selected as reference variables because they are the largest categories within their variables. The results of the model (see Tab.4) show the significance of the road surface variable for the outcome of TCA (p-value 0.014). Additionally, when trying different orders of variables in the model, the variable road surface behaved very stable, indicating its significance. Other variables were not significant when considering consequences of TCA. As there is no fatal urban TCA as result of overtaking, the statistical values for that accident type are off the chart.

Table 4. Results of binary model (for variables with more than two categories the significance value for the variable as a whole is noted in its first row)

Variables	B	S.E.	Wald	df	Significance	Exp (B)
Age_cyclist			2.378	2	0.305	
- Young (0-15 years)	0.843	0.800	1.110	1	0.292	2.323
- Over 65 years	1.268	0.961	1.740	1	0.187	3.552
Accident_type			3.671	4	0.452	
- Blindspot	1.315	0.781	2.836	1	0.092	3.726
- Intersection movements	0.019	0.837	0.001	1	0.982	1.019
- Overtaking	-19.151	8514.720	0.000	1	0.998	0.000
- Other	0.236	0.864	0.075	1	0.784	1.267
Road_surface_conditions	1.564	0.634	6.090	1	0.014	7.777
Gender_cyclists	-0.274	0.608	0.204	1	0.652	0.760
Speed_limit			1.857	2	0.395	
- Low (under 50 km/h)	-1.043	0.930	1.258	1	0.262	0.352
- High (above 50 km7h)	-1.132	1.176	0.926	1	0.336	0.322
Constant	-2.626	0.643	16.676	1	0.000	0.072

4.3. In-depth analysis of fatal TCA

Thirteen fatal accident reports from the period 2006-2013 were reviewed. The trucks involved in those accidents were mostly three-axes "compact" trucks without a trailer. The average age of those vehicles was 5.8 years (with standard deviation 4.5). Most of the trucks were equipped with a side under-run protection and with a variety of mirrors. All truck drivers in the examined accidents were males, holding the truck driving licence for eleven years on average (with standard deviation 9.8). The age of cyclists varied from eight to 84 years (average age 47 years with standard deviation 26).

Some of cyclists were reported as very experienced commuters. Almost half of cyclists (46%) were females. One cyclist was likely under influence of alcohol. The speed of truck before the accident was lower than 30km/h in eleven accidents (85%); in four cases, the speed was even lower than 10 km/h. Rain (or wet road surface) was recorded in seven cases (54%). According to the manoeuvres of both road users/vehicles, the accidents could be categorised into three types:

Type 1 – Truck turning right. As truck is turning right, cyclist is either riding next to the truck within the road or on parallel sidewalk/cycle path and consequently crossing the road the truck is turning to. With six cases, it is the most frequent accident type in the sample (46%). These accidents occurred mostly at signalised intersections. Following risk factors were found:

- Blind zones around truck limiting the ability of truck driver to detect the cyclist

- Lack of winter maintenance (snow on the road increases braking distance; snow piles limits the visibility)
- Unsafe infrastructure layout (road shifted due to construction; alignment of pedestrian-cycle path encouraging higher speeds; simultaneous green phase for vehicles turning right and cyclist/pedestrian crossing)
- Risky behaviour of road users (cyclist using phone; cyclists overtaking the truck from the right; lack of visual contact/communication between driver and cyclist; unexpected turning manoeuvre of truck without direction's indication)

Type 2 – Intersection movements/Crossing. There are four accidents of that type (31%), when both road users are manoeuvring within the area of intersection. Following risk factors were found:

- Risky behaviour of cyclists (insufficient technical conditions of brakes; intoxication; inattention)
- Visibility limited due to heavy rain and obstacles outside the vehicle (signs; sun; vegetation)
- Unsafe infrastructure layout that limits the visibility and encourages higher speeds

Type 3 – Low speed manoeuvres of truck. There are three accidents of that type in the sample (23%). In two cases, the truck was reversing (with cyclist's movements unknown). Following risk factors were found:

- Risky behaviour of truck driver (reversing on pedestrian-cycle path without any assistance).
- Unsafe construction sites' procedures (no fencing around construction site; no suitable place to turnaround provided)
- Visibility limited by several factors (rain drops on the mirror; obstacles outside the vehicle; blind spots)

5. Discussion

In order to gain maximum value from police data and to improve reliability of safety analysis, a comprehensive review of the accident database was carried out. It was possible to conduct such review because the studied sample was not large. Such a method (including studying accident reports, locating in Google Maps, and drawing collision diagrams) would be very time consuming and cumbersome for larger samples, although, as discussed below, it provides valuable information. The review of in-depth analysis reports provided additional information about fatal accidents.

The results of descriptive analysis confirmed that consequences of TCA in Norway are significantly higher than for other types of cycle accidents, as is the case in many other countries as reported by Manson et al. (2012), Kaplan et al. (2014) and Kröyer (2015). One out of ten TCA was fatal compared to only 1.2% of other cycle accidents (though the underreporting-phenomena probably has inflated these numbers). The majority of TCA was recorded in urban areas, mostly during working days (between 7 – 16 h), when more trucks and commuting cyclists are expected on the roads. There are differences between rural and urban TCA regarding distribution of accident types (more diversity in accident types in urban areas), locations of TCA (predominantly intersections in urban areas, while only sections in rural areas), in time of TCA (morning and afternoon in urban areas, while mostly late afternoon in rural areas) and in gender distribution (share of male cyclists is higher in rural areas). This can be explained by the different characteristics of rural and urban areas. E.g., it is evident that there are more intersections and diversity within urban areas compared to rural areas. On the other hand, males are cycling more frequently than females in rural areas and as indicated by the time of rural accidents, they are likely connected to cycling as a sport activity.

Focusing specifically in urban environments, intersections are expectably the most common TCA location in urban areas. Blind spot related TCA had in average more serious consequences than the other accident types, which is in accordance with studies from Niewoehner & Berg (2005), Sagberg & Sørensen (2012) and Volvo Truck (2013). Blind spot TCA were found to be most common at signalized intersections and roundabouts in mix-use environments. TCA connected to crossing (within intersection) and other maneuvers within the intersections were the most frequent accident types in urban areas These results indicate the importance of safe layout of intersections and crossings, which should encourage good visibility.

The high frequency of TCA in residential areas is surprising given that one would expect there to be fewer trucks in residential areas, when compared with mixed use, commercial, or industrial environments. While there are fewer trucks in residential areas, there still will be trucks making deliveries to local stores and using collector roads for through-trips, as well as temporary truck traffic generated by construction sites. At the same time, residential areas are likely to have significant volumes of cyclists as they are an origin or destination of many cycle trips. One explanation for the high TCA rates is perhaps a lack of separated infrastructure in these areas. In residential areas, there is likely to be more shared infrastructure where motorized and non-motorized users occupy the same spaces on the roadway, compared to in mixed use or commercial environments where cyclists may be separated from trucks, and trucks provided with their own infrastructure such as designated loading zones. These infrastructure characteristics have the potential to influence the risk by allowing for more interactions, which could lead to accidents between trucks and bicycles.

Other findings include that there were more females involved in TCA than in other cycle accidents. While this is not focus of our research, it is consistent with Frings et al. (2012), who suggested that gender differences in risk perception could play a role.

The binary regression model was developed to explore the significance of several variables on the consequences of urban TCA. As numbers of fatal urban TCA are low (10% from the sample), the results of model are rather sensitive. The variables used in model were identified in the police database. Thus, it was not possible to include all variables that could represent risk injury factors for TCA, as the police do not collect information about the safety equipment of the truck (mirrors, sensors); educational background (of either cyclists or drivers), or mass and shape of trucks. There are some other limitations related to variables used. Speed limit may be set as a function of road category or maybe influenced by past crash histories, thus its influence on safety must be considered carefully, as Mannering and Bhat (2014) explained. Furthermore, some variables may influence each other. For example, age is correlated with many underlying factors that are likely to affect accident injury severity, such as physical health or reaction time and people of the same age are likely to have differences in these unobserved factors. Nevertheless, the model developed within the study confirmed that from the included variables, only wet road surface is a significant factor for TCA consequences in urban areas. This finding is consistent with Kaplan et al., (2014) and Kim et al., (2007). It might not be the road surface that is of concern, but the decreased visibility during a rainy time.

The review of in-depth analysis reports revealed that trucks involved in fatal TCA were relatively modern, equipped with variety of mirrors and cameras, and that they were driven by experienced drivers. Despite of this, reduced visibility was mentioned in most of the reports as important risk factor (but never as the sole factor). Visibility problems can describe issues beyond blind spots, such as infrastructure hindrances and reduced cyclist visibility due to dark clothing decreases cyclists' perceptibility. Additionally, rain/snow limits the direct visibility between drivers and cyclists and reduce visibility through mirrors.

The UAG reports further showed, that the combination of several risk factors can be identified for each accident occurrence. In additional to blind spots, those factors can relate to behaviour of truck drivers and cyclists, layout of infrastructure, winter maintenance, or nearby construction sites' procedures. The speed did not seem to be significant risk factor, as there were several fatal TCA described where the speed of the truck was very low (e.g. when reversing, starting to drive or performing turning manoeuvre). The mass and shape of involved trucks seems to be more important risk factor than the speed**.** Review of UAG reports and results of accident analysis enable to draft several infrastructure related safety recommendations:

- layouts of intersection/crossing should improve the visibility/perceptibility of road users, including clear delineation of road and cycle path, proper position of stop line and crossing fields, removal of visibility obstacles, and advanced cycle boxes
- layouts of parallel cycle path reduce the speed of cyclist approaching the crossing
- signal plans should be adjusted to protect vulnerable road users, including a green phase for all crossings simultaneously and pedestrian/cycling signals on-demand
- introduction and enforcement of a cycle risk evaluation considering risk assessment in relation to construction sites

In addition to developing insights into TCA, this study also exposed the challenges of working with police accident data within this context. From this experience, it is recommended to collect the following types of data in order to improve the quality of potential safety analysis:

- number of years of truck driver's experience with truck driving
- existence of cycling infrastructure in proximity of accident site
- existence of construction site in the proximity of accident site
- type of truck, its safety equipment and load

Larger scale recommendations include:

- requirements for more detailed description of the accident event (including sketches of accident event)
- effort to increase the consistency in quality of reporting within the country
- implementation of a system that uses hospital reports nationwide

With such additions to accident records, road safety analyses would be more precise and thus more informative.

6. Conclusions and further work

The numbers of TCA are relatively small in Norway and a decreasing trend in their annual numbers has been observed in last 15 years. Still, the consequences of those accidents are very severe and fatalities resulting from TCA sum up to almost 20% of all cycle fatalities. As numbers of cyclists and trucks are expected to increase, it is necessary to understand risk factors related to their interactions. To create safe and sustainable urban freight and simultaneously safer cycling environments, we need to understand why, where, when and under what circumstances accidents between trucks and bicycles occur.

As the first step to understand TCA in Norway, the analysis of accident database was conducted. Because of small number of TCA, basic descriptive analysis was more valuable than using a regression model. Such an analysis provided knowledge on common accident types and locations. The analysis confirmed that most TAC occur at intersections in urban areas and that the common accident types vary by land use and environment. Additionally, residential areas were identified as locations of concern for further study.

The analysis was complemented by the review of in-depth analysis reports. It is evident from these reports, that there is usually no single risk factor involved in fatal TCA, although reduced visibility issues are frequent. Instead, the combination of several risk factors is seen in TCA occurrence. Such finding supports the effort to increase safety by implementing the array of several safety measures from different components/levels of road transport system, including legislation, education, land use planning, transport planning and vehicle engineering.

The presented accident analysis results within this study will be compared and combined with knowledge gained from road users' surveys in order to identify suitable locations for conflict observations, which will be conducted to gain more understanding into TCA. Conflict observations (where conflicts are defined based on Amundsen and Hydén (1977) as an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged) will increase the sample size of truck-cycle interactions for study, as well as to allow for control of infrastructure, land use variables and exposure. Additionally, it will be possible to compare the distribution of accident types and conflict types in other cities that have diverse infrastructure and planning practices. These further efforts should lead to identification of factors related to infrastructure and land use planning that may influence the occurrence, location, and/or severity of such accidents and inform future infrastructure design.

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Paper III

Conflicts between bikes and trucks in urban areas –

A survey of Norwegian cyclists

Pokorny, P., Pritchard, R., Pitera, K., 2017

ARTICLE IN PRESS

Case Studies on Transport Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Case Studies on Transport Policy

journal homepage: www.elsevier.com/locate/cstp

Conflicts between bikes and trucks in urban areas—A survey of Norwegian cyclists

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ARTICLE INFO

Keywords:
Bike-truck conflicts
Survey
Urban areas

ABSTRACT

Several challenges accompany the current growth of bike and truck volumes in urban areas, with traffic safety being one of the most critical concerns. Bike-truck accidents present a direct measure of the safety; however, these are rare events. Furthermore, accident records are subject to several shortcomings. Thus, safety studies should not rely solely on accident analysis, and conducting the additional methods is advisable (e.g. surveys or conflict analysis). This paper discusses the results of a retrospective survey of Norwegian utilitarian cyclists, which collected data about their involvement in conflicts with trucks in urban areas. An online questionnaire was disseminated within major cities in Norway, and 631 valid responses were analysed. The results revealed large numbers of conflicts experienced by cyclists, with the most frequent types of conflicts being (1) truck overtaking bicyclist and (2) right-turning truck vs. straight-riding bicyclist and. Visibility issues were frequently mentioned as the important risk factors. Almost all cyclists blamed truck drivers as the party responsible for the conflict. The distribution of conflict categories differed between major Norwegian cities, which corresponds with the findings of a previous accident analysis. Insights developed are useful to local policy makers both in Norway and abroad, when considering how to plan for increasing numbers of cyclists and trucks in urban areas.

1. Introduction

Urban cycling has been gaining significant political support in Norway. Policies have been introduced to encourage and motivate people to cycle, as it contributes to improving health, reducing the negative effects of car traffic, and creating liveable and vibrant cities. The current Norwegian National Transport Plan 2014–2023 has introduced a "zero-growth objective" referring to the use of private motorised vehicles (Norwegian Ministry of Transport and Communications, 2013). It states that the expected growth in urban passenger transport is to be made by public transport, cycling and walking. The Government aims to increase the cycling share from 4% (year 2013) to 8% by 2023, and set aside significant annual funding of NOK 0,82 billion (≈EUR 87 millions) towards implementing measures for cyclists and pedestrians. Given such objectives and funding, it is possible to expect a growth of cycling in urban areas, as described e.g. by Pucher et al. (2010).

Meanwhile, the number of kilometres driven by heavy trucks in Norway increased by 5.3% in the period 2011–2016 (Statistics Norway, 2017a), and further growth is expected, particularly on short distances (Norwegian Ministry of Transport and Communications, 2013). Although numerous innovative city logistic concepts (e.g. urban consolidation centres, off-hour deliveries, bicycle deliveries, crowdshipping) that could reduce freight traffic in the cities, the structure of urban areas is such that trucks are highly likely to be the dominant delivery mode for the foreseeable future (Jaller et al., 2013). Moreover, longer and heavier vehicles are expected to be more frequent on the road network (Norwegian Ministry of Transport and Communications, 2013). One of the consequences of this development is that cyclists and trucks are sharing urban roads more than ever, which increases the risk of potentially fatal accidents (Davis and White, 2015).

Based on several road safety indicators, Norway is considered one of the safest countries in Europe (ETSC, 2016). The Norwegian safety policy is grounded on Vision Zero approach, which implies that all the traffic safety work should be based on a vision of no fatal or serious injury accidents. Nevertheless, cyclists are facing considerably higher risk in traffic than passengers of motor vehicles (Elvik, 2009). According to the Norwegian Public Road Administration's accident database, STRAKS, 65 cyclists were killed and 6032 suffered an injury in road accidents in urban areas between 2000 and 2014. The frequency and characteristics of accidents between cyclists and motor vehicles are influenced by variety of risk factors and their combinations. These

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https://doi.org/10.1016/j.cstp.2017.11.010
Received 10 February 2017; Received in revised form 20 June 2017; Accepted 30 November 2017
2213-624X/

Please cite this article as: Pokorny, P., Case Studies on Transport Policy (2017), https://doi.org/10.1016/j.cstp.2017.11.010

factors relate to humans, infrastructure, environment and vehicles. The most common are age, gender, type of infrastructure and intersection, mass and speed difference between a cyclist and other vehicle/s, visibility, weather, inattention, unpredictable behaviour, errors in decisions, reactions or observations (Kim et al., 2007; Bjørnskau, 2005). The frequency of cycling, particularly the number of encounters between cyclists and motor vehicles have an effect on accident rates, too, because of the negative relation between exposure and risk (Elvik, 2015).

Focusing on truck-bicycle accidents (referred as TCA further in the text), a total of 271 occurrences were recorded by the Norwegian police in the period 2000–2014, with 27 cyclists fatally injured. Further, the majority of TCA (80%) and TCA fatalities (85%) were recorded in urban areas. The share of fatal TCA in all fatal cycle accidents in urban areas in Norway (35%) is one of the highest in Europe (Evgenikos et al., 2016). Urban TCA in Norway typically occur at intersections, under low-speed manoeuvres of trucks, during working days and working hours, under good weather-visibility conditions (Pokorny et al., 2016). Existing literature has highlighted that numerous characteristics of TCA are different from other types of bicycle-motor vehicle accidents, particularly regarding the environment of fatal accidents, accident scenarios, severity of consequences, the role of speed, visibility, age and gender of cyclist. While the majority of fatal cycle accidents occurs in rural areas, most of the fatal TCA were recorded in urban areas. TCA are typically very severe – the fatality rate of urban TCA in Norway is more than ten times higher compared to other urban bicycle accidents (Pokorny et al., 2016). This corresponds with findings from the UK, Germany, Denmark or China (Niewoehner and Berg, 2005; Ming et al., 2014; Kaplan et al., 2014). The high severity level of TCA is usually attributed to the mass differences between a vulnerable bicyclist and a truck (Kim et al., 2007), while the speed of a truck is not considered as a significant risk factor (Volvo Truck, 2013). Turning accidents, and particularly those associated with limited visibility around a truck (so-called blind spot accidents), are regarded as the most serious and frequent type of TCA (Johannsen et al., 2015; Seiniger et al., 2015). Female cyclists were found to be overrepresented in TCA (Niewoehner and Berg, 2005; Frings et al., 2012). Specifically in Norway, females were involved in 48% of fatal TCA in urban areas in the period 2000–2014, while regarding other fatal urban cycle accidents, the percentage was 20%. The significant difference was also found for non-fatal accidents (40% vs. 20%). Frings et al. (2012) suggest that gender differences in risk perception could explain this phenomenon. Cyclists involved in TCA are spread over all age groups (Niewoehner and Berg, 2005) and this is true for Norway as well (Pokorny et al., 2016). However, Norwegian data show that older cyclists (over 60) were involved in 10% of urban TCA, while their share in fatal TCA was 26%. This difference suggests the well-known effect of older age on accident severity, mainly because of the human body's increasing vulnerability. Furthermore, age has been shown to affect cyclist behaviour, as older cyclists appreciate pedestrian crossings, signalized intersections and cycle paths significantly more than do younger cyclists (Bernhoft and Carstensen, 2008).

To reduce the risks involved in encounters between trucks and cyclists, it is necessary to have the sufficient knowledge about those encounters, their types and the risk factors involved. Studying TCA is an obvious approach to obtain such knowledge, as accidents are a direct measure of safety and the data are relatively accessible. However, relying solely on accident analysis cannot provide sufficient knowledge (Juhra et al., 2012), as accident data suffer from several constraints. First, TCA are rare events, which makes their statistical analysis challenging (Pokorny et al., 2016). Second, data about accidents involving cyclists suffer from a significant level of underreporting, which depends (amongst others factors) on accident severity (Kaplan et al., 2017). Regarding Norway, it was estimated, that the probability of reporting a bicycle accident is 12% for minor and moderate injuries, 33% for serious injuries, 71% for severe and critical injuries and 100% for fatal injuries (Veisten et al., 2007). As TCA are typically more severe than other bicycle accidents, their level of reporting is probably higher; however, a proportion of TCA is certainly missing in official statistics. Third, the absence of certain data and inconsistency of reporting of TCA were identified within the Norwegian police database (Pokorny et al., 2016).

To compensate for these limitations, the analysis of surrogate measures of safety, including conflicts, has been recognised as an alternative to accident analyses. A conflict is understood here as "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" (Amundsen and Hyden, 1977). The impact of conflicts are associated not with physical harm but can act as a significant psychological deterrent for future cycling (Jachyra et al., 2015; Sanders, 2015), as cyclists are experiencing conflicts in traffic on daily basis and the involvement of trucks in those conflicts is associated with a significant increase of fear (Aldred and Crosweller, 2015).

The current knowledge about traffic conflicts involving cyclists and other vulnerable road users (also referred to as near-accidents or near-misses), was recently summarised by Johnsson et al. (2016). Several methods exist to collect and analyse conflicts, i.e. recording (observing) road users' behaviour and consequently identifying the conflicts based on different criterions, using traffic diaries or conducting face-to-face interviews and surveys. Only a few studies have focused on bike-truck conflicts specifically. For example, an observational study from the US (Conway et al., 2013) analysed conflicts on three different configurations of parking and cycle lanes in commercial areas of New York City. During 92 h of observation, 35 conflict events were recorded.

This paper explores truck-bicycle conflicts from a cyclist perspective within the context of Norwegian urban areas through using a retrospective questionnaire survey. The objectives of this study were to identify the types of conflicts cyclists are experiencing in Norwegian cities; to explore the associations between the conflict types and various background variables, and, more generally, to contribute to filling the knowledge gap regarding truck-bicycle encounters, particularly conflicts.

2. Methodology

A retrospective questionnaire survey was performed focusing on cyclists' involvement in conflicts with trucks, as this type of study design is considered to be appropriate for assessing the interrelation between bicycle safety and infrastructure (Vanparijs et al., 2015). A conflict between a cyclist and a truck was described to respondents as any situation where a cyclist almost collided with a truck, but due to the reactions of the cyclist and/or driver (braking, suddenly changing direction etc.), no accident occured, the cyclist having merely been threatened. This "user-friendly" definition is a modification of the classical Amundsen and Hydén definition mentioned previously. Referring to the survey, a truck was defined as a large road vehicle used for carrying or pulling goods or materials.

2.1. Design of the survey

The survey "*Interactions between bicycles and trucks from a cyclist's perspective*" was designed as an online questionnaire with nationwide coverage. The target group included the adults cycling regularly in Norwegian cities for utilitarian purposes, as those were identified from an accident analysis as being the most common type of cyclists involved in TCA (Pokorny et al., 2016). The questionnaire consisted of four sections. Section 1 contained compulsory questions about background variables. Section 2 collected data about conflict types experienced with a truck during the previous 12 months. Depictions of 18 conflict types were presented here and accompanied by their written description. Respondents could mark numerous conflict types they had experienced within 12 months, describe their most recent conflict type in more details or note that they had not experience any conflict at all. Section 3

Table 1
Questions, answers and variables.

Question	Possible answers	VARIABLE and its categories (if different from possible answers)	Type of variable
1. What is your age?	Number of years	AGE GROUP: 18–30; 31–40; 41–50; 51–60; 60 and more	Quantitative, ordinal
2. What is your gender?	Female; Male	GENDER	Qualitative, dichotomous
3. What is the highest degree of school you have completed?	Basic; Secondary; Bachelor; Master; Doctorate	EDUCATION: Secondary; Bachelor; Master; Doctorate	Qualitative, ordinal
4. Do you have a driving license?	Yes; No	DRIVING LICENSE	Qualitative, dichotomous
5. In what city do you most often ride your bicycle?	Bergen; Kristiansand; Oslo; Stavanger; Trondheim; Other (name)	CITY: Bergen; Oslo, Trondheim; Tromsø; Other	Qualitative, multinomial
6. You use your bicycle mainly for:	Commuting; Transport to other activities; Recreation and sport activities; Other	REASON FOR CYCLING: Utility, Recreation only	Qualitative, multinomial
7. How often do you cycle in the summer? And in the winter?	A few times a day; Almost every day; 2–3 times a week; A few times a month; Never or very seldom	FREQUENCY OF CYCLING: *Infrequently* (a few times a month in the summer and never/seldom in the winter); *Frequent* (2–3 times a week in the summer and a few times a month in the winter); *Very* (at least 2–3 times a week in the winter and at least almost every day in the summer)	Qualitative, ordinal
8. What types of conflict with a truck have you experienced in the last 12 months when riding your bike in the city? (multiple answers possible)	18 different conflict types (from A to R) illustrated with the scheme of each type (see Table 7) and further described by the text	NUMBER OF CONFLICT TYPES EXPERIENCED: 0, 1, 2, 3…	Quantitative, ordinal
9. What was the most recent conflict you experienced?	A-R, other; no conflict	TYPE OF THE MOST RECENT CONFLICT	Qualitative, multinomial
		EXPERIENCING A CONFLICT: yes/no	Qualitative, binomial
10. How would you estimate the degree of severity of that most recent conflict?	Slight – only minimal effort needed to prevent a crash; Serious – almost an accident, intensive effort (braking, swerving) needed to prevent a crash.	PERCEIVED SERIOUSNESS	Qualitative, ordinal
11. What factors played the most important role in your most recent conflict with a truck?	I was breaking the traffic rules; I did an unexpected manoeuvre; The truck driver did not see me; The truck driver was breaking the traffic rules; The truck driver did an unexpected manoeuvre	CONTRIBUTORY FACTORS	Qualitative, multinomial
12. As a cyclist, have you experienced any accident with a truck in the last 12 months?	Yes, once; Yes – multiple times; No	INVOLVEMENT IN ACCIDENT: Yes; No	Qualitative, dichotomous
13. Was that accident investigated by the Police?	Yes; No	RECORDED BY POLICE	Qualitative, dichotomous

was comprised of several questions regarding the respondents' experience with an involvement in an accident with a truck. Section 4 allowed the respondents to leave any additional comments and contact information on a voluntary basis. See Table 1 for the formulation of the questions, the answer options and the description of variables and their categories.

The questionnaire's link was disseminated through cycling-related social media channels, the main Norwegian municipalities' web pages, cyclist organisations, universities, a hospital and a research institute. The link was active for approximately one month during May–June 2015.

2.2. Analytical methods and hypotheses

Given the existing knowledge on truck-bicycle encounters, several analyses were conducted. The descriptive statistics of the sample were conducted separately for both genders, as female cyclists are typically overrepresented in TCA. Chi-square tests of homogeneity ($p < 0.05$) and pairwise comparisons using the z-test of two proportions were applied to compare the differences in distributions among independent background variables. The characteristics of the valid sample were compared with the non-valid sample (the participants who did not complete the questionnaire). Furthermore, the following hypotheses are suggested and tested:

I. The probability of experiencing a conflict with a truck is influenced by the demographics of respondents, particularly by *age* (as older cyclists avoid certain situations/infrastructure), *gender* (possible differences in risk perception), *frequency of cycling* (more cycling increases chance to encountering a truck in the traffic, on the other hand it means more experience in avoiding conflicts), *education* (potential effect of educational degree on risky behaviour) and *city* (differences in transport networks). Binomial logistic regression was performed to ascertain the effects of these variables.
II. The type of most recent conflict is influenced by respondents' independent background variables, particularly by *age*, *gender* and *city* (as described above). Multinomial logistic regression was conducted to test this hypothesis.
III. The number of reported conflict types among the respondents differs for variables *city* and *gender*. Two-sample *t*-tests were applied to test the hypothesis.
IV. The conflict types differ in their contributory factors and severity (perceived by the cyclists). This hypothesis was tested using chi-square test of homogeneity at $p < 0.05$ and pairwise comparisons using the z-test of two proportions.

3. Results

From the survey, a total of 1207 responses were obtained. Respondents who answered that they cycle in more than one city were omitted from the analysis, as it was not clear which city should be assigned the answers. Furthermore, respondents who both stated that they had not experience any conflict in the last 12 months (question #9 in

Table 1) but also marked one or more conflict types in question #8, were omitted from the analysis as they had likely misunderstood the questionnaire. Those who stated that they cycled exclusively for recreational purposes, were also removed from the sample, as their background characteristics (gender, age, education, city, frequency of cycling) were significantly different from the other respondents (tested by chi-square test of homogeneity at $p < 0,05$ with pairwise comparisons using the z-test of two proportions). Finally, those who had not completed the questionnaire were also removed from the analysis. As a result of the above criteria, 631 valid responses remained for the hypothesis testing.

3.1. Characteristics of the respondents – descriptive statistics

The majority (56,4%) of the valid respondents were male. Almost all respondents (97%) had a driver's licence. A total of 92% of valid responses were received from four cities: Trondheim (n = 341), Oslo (n = 140), Bergen (n = 62) and Tromsø (n = 38). Regarding both genders, the age bracket between 31 and 40 years was the most frequent. Approximately 80% of respondents of both genders cycle almost every day in the summer. In the winter, this share drops to 50% for males and 30% for females. The sample is well educated, as nearly 90% of respondents stated that they have completed some form of university education. Tables 2–5 summarise the selected background variables of the valid sample according to gender.

When comparing the proportions in independent variables between genders, significant differences were found in the following variables:

- *city* ($p < 0,00001$), particularly higher share of female respondents in Trondheim than in Oslo and Bergen
- *frequency of cycling* ($p < 0,00001$), with more males cycling *very frequently*
- *education* ($p = 0,03$), with more males with *Master's* degree, while more females with *Bachelor's* degree

Table 2
Gender*Age cross tabulation.

Gender		Age				
		18–30	31–40	41–50	51–60	over 60
Female	Count	55	86	69	51	14
	% of Total	8,8%	13,6%	10,9%	8,1%	2,2%
Male	Count	54	125	106	52	19
	% of Total	8,6%	19,8%	16,8%	8,2%	3,0%

Table 3
Gender*Education cross tabulation.

Gender		Education			
		Secondary	Bachelor	Master	Doctoral
Female	Count	34	116	99	26
	% of Total	5,4%	18,4%	15,7%	4,1%
Male	Count	40	113	164	39
	% of Total	6,3%	17,9%	26,0%	6,2%

Table 4
Gender*City cross tabulation.

Gender		City				
		Bergen	Oslo	Trondheim	Tromsø	Other
Female	Count	18	35	191	17	14
	% of Total	2,9%	5,5%	30,3%	2,7%	2,2%
Male	Count	44	105	150	21	36
	% of Total	7,0%	16,6%	23,8%	3,3%	5,7%

Table 5
Gender*Frequency of cycling cross tabulation.

Gender		Frequency of cycling		
		infrequent	frequent	very
	% of Total	15,9%	11,9%	15,8%
Male	Count	80	79	197
	% of Total	12,7%	12,5%	31,2%

The demographics of the respondents who did not complete the questionnaire (n = 470) were compared with those of valid respondents. The "non-valid" respondents typically stopped answering when they reached Section 2, where they were asked to choose all conflict types experienced in the last 12 months. They were possibly deterred by the requirement to go through 18 conflict types' schemes. Another explanation could be that they simply had not experience any conflict with a truck and decided to stop answering. Alternatively, it could be a combination of both reasons. There were significant differences between those two samples in the following independent variables:

- *gender* ($p = 0,03$), including more females within non-valid respondents
- *city* ($p < 0,001$), including a smaller proportion of non-valid respondents in Oslo than in Trondheim and Tromsø
- *education* ($p < 0,001$), including higher proportions of non-valid respondents in lower educational categories (*Secondary, Bachelor*)
- *frequency of cycling* ($p = 0,002$), including the highest share of non-valid respondents in *infrequently* category

Furthermore, eight females and five males stated that they had been involved in an accident with a truck in the past. Almost all of these (12) had occurred in Trondheim. The police had not investigate any of these accidents. The number of conflict types experienced by these 13 respondents was significantly higher compared to those who had not reported any accident.

3.2. Hypothesis I: likelihood of a conflict

A total of 381 valid respondents had experienced at least one conflict (54,5% of female and 64,9% of male respondents), while 250 had not experienced any conflict A binomial logistic regression was performed to ascertain the effects of *age*, *gender*, *education*, *city* and *frequency of cycling* on the likelihood that respondents had experienced a conflict with a truck. The binomial logistic regression model ($p = 0,206$) explained 3,1% (Nagelkerke R^2) of the variance in conflict experience and correctly classified 61,0% of cases. Of the five predictor variables, only *gender* was statistically significant (as shown in Table 6). The odds of experiencing a conflict are 1,4 times higher for males as opposed to females.

3.3. Hypothesis II: most recent conflict type

Multinomial logistic regression was performed to determine the effects of *age*, *gender*, *frequency of cycling* and *city* on the type of the most recent conflict experienced by respondents. There were 18 conflict types presented to the respondents (see Table 7). Note that Norway is right-hand traffic country and cyclists are allowed to cycle on sidewalks provided they give way to pedestrians. Respondents were asked to mark the particular type of conflict that they had most recently experienced. For further analysis, 18 conflict types were merged into five categories, according the truck's manoeuvre:

1. *Right turn*: the truck is turning right, while the cyclist is going straight ahead on the right side of the truck (either on the road or on a separated infrastructure parallel to the road).

Table 6
Results of binomial logistic regression model.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
gender	0,345	0,170	4,134	1	0,042	0,413
age			2,081	4	0,721	
age(1)	−0,355	0,414	0,734	1	0,392	0,701
age(2)	−0,143	0,394	0,131	1	0,717	0,867
age(3)	−0,061	0,399	0,024	1	0,878	0,941
age(4)	−0,313	0,417	0,563	1	0,453	0,731
frequency			2,738	2	0,254	
frequency(1)	−0,322	0,200	2,573	1	0,109	0,725
frequency(2)	−0,210	0,208	1,018	1	0,313	0,811
city	−0,070	0,087	0,655	1	0,418	0,932
education			2,920	3	0,404	
education(1)	0,538	0,359	2,243	1	0,134	1,713
education(2)	0,345	0,291	1,404	1	0,236	1,412
education(3)	0,445	0,285	2,435	1	0,119	1,560
Constant	0,380	0,534	0,507	1	0,476	1,463

2. *Left turn*: the truck is turning left, while the cyclist is going straight ahead on the opposite side of the road (either on the road or on a separate infrastructure parallel to the road).
3. *Straight – Intersection*: the truck is moving perpendicular to the cyclist, who is either crossing the road within the intersection (e.g. on a zebra crossing) or riding within the intersection.
4. *Straight – Section*: the truck makes a passing/overtaking manoeuvre of a cyclist riding in the roadway
5. *Other*: other types of conflict, specifically described by the respondent (e.g. conflicts related to parked trucks)

The counts of reported most recent conflict categories and the frequencies of particular conflict types are shown in Table 7. The most frequently reported conflict category was *straight-section* conflicts, followed closely by *right turning* conflicts. The most frequent conflict type occurred when a cyclist was overtaken by a truck on the road section (17,1% of all conflicts). The distribution of conflict categories in four cities with most respondents is shown in Table 8.

Multinomial logistic regression was performed to test the effects of *age*, *gender*, *education* and *city* on the *conflict category* for the sample of responses from cities Bergen, Oslo, Trondheim and Tromsø (n = 348). Among the selected variables, only *city* was found to be significant (p = 0,005). See Tables 9 and 10 for more details.

Pairwise comparisons using the z-test of two proportions showed that there were significant differences in the *right-turn category* between Bergen–Oslo and Bergen–Trondheim (less *right-turn* conflicts in Bergen for both comparisons); and in the *straight-section* category between Bergen-Trondheim (more *straight-section* conflicts in Bergen).

Table 7
Conflict categories, conflict types and their frequencies within the whole sample (n = 381).

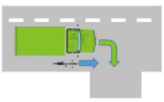
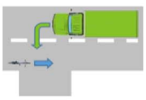
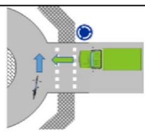
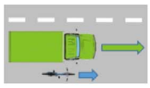
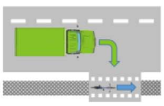
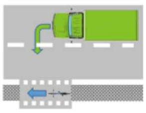
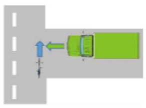
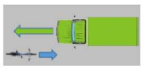
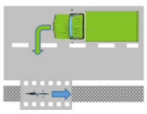
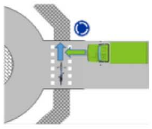
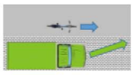
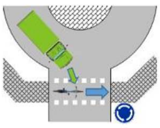
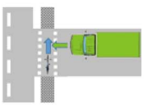
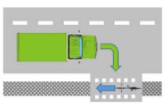
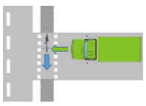
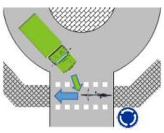
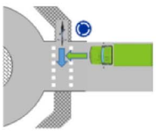
Right turn (n=111; 29,1%)		Left turn (n=22; 5,8%)		Straight – intersection (n=102; 26,8%)		Straight – section (n=118; 31%)		Other (n=28; 7,3%)
	12,9%		2,9%		11,5%		17,1 %	
	9,2%		1,6%		5,2%		8,9%	
	3,4%		1,3%		3,1%		5,0%	
	2,4%				2,9%			
	1,0%				2,5%			
	0,2%				1,8%			

Table 8
Distribution of conflict categories among the cities.

City		Conflict category				
		Right turn	Left turn	Straight intersection	Straight section	Other
Bergen	Count	4	5	7	23	4
	% within City	9,3%	11,6%	16,3%	53,5%	9,3%
	% within Conflict cat.	4,0%	23,8%	7,4%	21,7%	15,4%
Oslo	Count	32	5	24	30	3
	% within City	34,0%	5,3%	25,5%	31,9%	3,2%
	% within Conflict cat.	31,7%	23,8%	25,5%	28,3%	11,5%
Trondheim	Count	61	10	56	43	16
	% within City	32,8%	5,4%	30,1%	23,1%	8,6%
	% within Conflict cat.	60,4%	47,6%	59,6%	40,6%	61,5%
Tromsø	Count	4	1	7	10	3
	% within City	16,0%	4,0%	28,0%	40,0%	12,0%
	% within Conflict cat.	4,0%	4,8%	7,4%	9,4%	11,5%

Table 9
Multinomial logistic regression model-fit information.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	−2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	520,113			
Final	470,1700	49,943	40	0,135

Table 10
Likelihood Ratio Tests.

Variable	Model Fitting Criteria	Likelihood Ratio Tests		
	−2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	470,170	0,000	0	.
City	498,543	28,373	12	0,005
Gender	473,076	2905	4	0,574
Age	483,051	12,880	16	0,681
Frequency of cycling	472,845	2674	8	0,953

3.4. Hypothesis III: total number of conflict types

As each respondent could also check off all conflict types experienced in the last 12 months, the numbers of conflict types experienced by each respondent in each city could be compared. Note that this number does not suggest anything about the frequency or entire number of conflicts experienced by a respondent, as any one type of conflict can be experienced several times, a factor, which is not covered by the survey. There was a significant difference in the mean number of conflict types according to *gender*, as males reported 2.77 and females 1.94 conflict types. Regarding the variable *city*, a significantly lower number of conflict types was reported in Trondheim than in Oslo and Bergen. However, note that there were more female respondents in Trondheim.

3.5. Hypothesis IV: contributory factors and severity

A total of 273 respondents provided their opinion on a contributory factor for the occurrence of their most recent conflict. The differences between contributory factors, conflict categories and background characteristics of respondents were tested. The visibility factor (*truck driver did not see a cyclist*) was reported significantly more frequently in *right-turn* conflicts than in *straight-section* conflicts. Furthermore, the factor *truck driver broke a traffic rule* was reported more often in the *straight-section* than in the *right-turn* category. Female respondents reported significantly more frequently the contributory factor *truck driver did not see a cyclist*.

A total of 342 respondents tried to estimate the conflict's severity. 272 respondents estimated their conflict as slight ("it did not require so much effort to avoid collision") and 70 as severe ("nearly collision, a lot of effort required to avoid collision). There was no significant difference found in the proportion of slight/severe conflicts within the conflict categories.

3.6. Limitations to the interpretation of the results

Several limitations that are typical for a retrospective type of study must be taken into consideration when interpreting the cycle survey's results:

- The survey's response rate cannot be estimated, as the number of people exposed to the survey is unknown.
- The sample is not random. It is possible that cyclists who were involved in a conflict with a truck or who were interested in road safety in general were more attracted to the survey. The number of recorded conflicts is thus perhaps overrepresented due to such a self-selection bias.
- Several areas of bias regarding the self-reporting of conflict can be recognised. For example, there are personal biases involved in the interpretation of conflicts as every respondent has different perceptions and margins of safety. Additionally, there is likely a bias arising from errors in the respondents' understanding of a conflict, even if the definition of conflict was repeated within the survey several times. Furthermore, bias from self-reporting of unpleasant/risky behaviour could have occurred (Nævestad et al., 2014).
- Subjective reports are vulnerable to the influence of recall biases (Schleinitz et al., 2015). The ability to remember a conflict decreases with time from the event (Bernard et al., 1984). The ability to remember likely differs among respondents and is influenced by the severity of the event (Brener et al., 2003).
- Lack of exact exposure data limits the ability to control the data for exposure, which is partly taken into account within the 'frequency of cycling' variable.

4. Discussion

4.1. The sample

The characteristics of valid respondents clearly show that the desired target group, adult cyclists who cycle regularly in urban environments for utilitarian purposes, responded to the survey. The survey sample also appears to be generally representative of the Norwegian cycling population. The proportion between genders in the whole sample corresponds with the National Travel Survey 2013/2014 (Hjorthol et al., 2014), as Norwegian males cycle slightly more than

Table 11
Comparison of main cities.

Indicator	Trondheim	Oslo	Tromsø	Bergen
Bicycle modal share of all trips (Hjorthol et al., 2014)	8,6%	5,0%	4,3%	3,1%
Municipal population 2017 (Statistics Norway, 2017b)	191 000	669 000	75 000	279 000
Typical cycling infrastructure	More separated infrastructure and wide streets. Relatively well connected network outside city centre.	Bicycle lanes along some major arterials, but mostly mixed traffic. Good offering of footpaths and shared paths outside the inner city.	No bicycle-specific infrastructure and only very limited shared path facilities. Common for significant snow conditions to last for up to 4 months, covering road markings.	Almost entirely mixed traffic in inner city with some infrastructure along arterials.
Kilometres of municipal shared cycle/pedestrian paths per 1000 inhabitants, data year 2012 (Haagensen, 2013)	0,9	1,7	0,2	0,4
Satisfaction with bicycle infrastructure available – survey response: satisfied or very satisfied (NCF, 2016)[a]	40,9% (n = 249)	23,5% (n = 801)	18,4% (n = 49)	16,6% (n = 169)
Satisfaction with bicycle network connectivity – survey response: satisfied or very satisfied (NCF, 2016)[a]	14,9% (n = 248)	4,9% (n = 792)	8,0% (n = 50)	4,8% (n = 168)
Combined NCF ranking for city cycling conditions among a total of 30 cities (NCF, 2016)[a]	7	16	22	25
Yearly investment in walking/cycling infrastructure (in millions of kroner)	110 (Strand et al., 2015)	280 (Oslo Municipality, 2015)	20 (Melsås, 2017)	44 (Strand et al., 2015)

Note: Majority of respondents are members of the cyclist organisation and responses are thus not very representative of the entire cycling population (63% in Trondheim and 80–84% across the other cities). Females underrepresented (24% female respondents in Bergen and 30–33% in the other cities). The NCF sample had relatively few respondents under 30 years of age (6%) compared to the retrospective questionnaire for this study.

[a] Norwegian Cyclists' Federation (NCF) '[Being a] cyclist in your city' survey 2016 [unpublished detailed results].

females (they account for 55% of daily bicycle trips). However, the sample shows significant gender differences in particular cities. The majority of respondents were from Trondheim (54%), amongst whom 56% were female. Meanwhile in Oslo and Bergen, the sample contained less females – 25% in Oslo and 29% in Bergen. Such a discrepancy is likely caused by the different places of recruitment to the study between the cities. The majority of valid respondents belong to the 31–40 age bracket and have completed higher education. The sample was slightly younger than the national statistics. According the National Travel Survey, cyclists within the 25–54 age bracket (regardless of gender) make 51% of daily bicycle trips and 58% of bicycle kilometres travelled, and adults who cycle have typically completed a university education. Interestingly, there were significant differences between the individuals who did not complete the questionnaire and those who did.

4.2. Reported conflicts

The results of the survey revealed that 60% of 631 respondents experienced at least one conflict with a truck in the past 12 months. 20% of the conflicts were estimated by the respondents as serious. Such numbers may not appear significant compared to "everyday" occurrence of conflicts with other road users, however, the severity of potential accidents and truck-bicycle conflicts requires recognising them within road safety consideration.

Male cyclists reported conflicts more frequently than females, and, according to the results of the binary regression model, *gender* is the only significant variable explaining if a respondent experienced a conflict or not. Still, more than half of female respondents reported a conflict with a truck. Nevertheless, it is not possible to conclude if female cyclists are as overrepresented in conflicts with trucks as they are in accidents, because there is no relevant data about females involvement in conflicts with which to compare these findings.

Concerning the survey, 13 respondents reported an accident with a truck. Majority of these (8) were females, which supports the overrepresentation of female cyclists in TCA found from the accident analysis (Pokorny et al., 2016). Furthermore, none of those accidents were investigated by the police. This finding confirms previous research, that underreporting is a major issue for bike-truck accidents.

4.3. Conflict types

The most frequently reported conflict type was *being overtaken by a truck* on a road section. *Right-turning truck vs. straight-riding bike* in the same direction was reported as the second most frequent type. This result is surprising, as right-turning accidents (or left in the UK) are considered to be the most frequent accidents in other studies, both in abroad (Volvo Truck, 2013; Niewoehner and Berg, 2005) and in Norway (Pokorny et al., 2016). When considering *city*, overtaking conflicts were most frequent in Bergen, while right-turning conflicts were frequent in Oslo and Trondheim. This difference regarding *city* is supported by the results of multinomial logistic regression that showed significant effect of this variable on conflict category. There are several factors that could explain these differences, e.g. variances in local transport policies, safety culture, traffic characteristics (e.g. frequency of cycling and truck volumes), or different layouts of cycle networks between the cities. The frequency of overtaking conflicts could be associated with both narrow streets and lack of dedicated cycling infrastructure (lack of separation). For example, in Trondheim, the streets are relatively wide (Nordström and Manum, 2015), which when combined with a larger network of separated cycle infrastructure, could contribute to less overtaking/passing conflicts experienced by cyclists in Trondheim. A higher amount of segregated infrastructure could relate to higher percentage of right-turning conflicts in Trondheim, as cyclists' visibility and higher speeds could be an issue. See Table 11 that demonstrates the indicators within the cities, which may influence the frequency of conflict types (Table 11).

4.4. Contributory factors

Visibility issues were the most frequent contributory factor for *right turning* conflicts, which corresponds with the findings of several studies stating that reduced vision (likely connected to blind spots and external visibility obstructions) is one of the important risk factors in right-turning accidents (e.g. Johannsen et al., 2015; Seiniger et al., 2015). While there are many factors associated with poor visibility, improper infrastructure layout is one significant contributor. Breaking a rule was reported most often in the *straight-section* category, which could relate to vehicles failing to maintain a safe passing distance from cyclists. Almost all cyclists blamed truck drivers for the occurrence of the conflict.

5. Conclusion

Analysis of less severe events in traffic, such as conflicts, has the potential to provide additional knowledge to the understanding of truck-bicycle encounters. Despite its limitations, the retrospective survey of conflicts delivered valuable insight into cyclists' coexistence with trucks from the cyclists' perspective. The results of this research show that cyclists are relatively often experiencing conflicts with trucks, particularly those relating to trucks' overtaking and turning manoeuvres. If these conflicts develop into an accident, the consequences can be very severe. Accidents, and likely conflicts, can also impact cyclists' perceptions of traffic risk, which can affect whether and how frequently people cycle. Within Norway, such an effect can be detrimental to goals associated with large increases in the bicycle mode share.

The expected growth in both of bicycle and truck traffic in urban areas carries important safety concerns. Currently, a range of safety measures and policies exist, aimed at reducing the risks associated with truck-bicycle encounters. These measures address all aspects of the transport system, including vehicles, infrastructure, operations, and regulations. A better understanding of truck-bicycle encounters and recognition of risk factors involved in these encounters can provide evidence-based knowledge to policy makers and planners as they develop such measures to account for expected increase in urban freight and bicycle traffic within growing urban areas. The significant variability in types of truck-bicycle conflicts between major Norwegian cities highlights the need for carefully considering local conditions, when proposing safety measures and policies.

Acknowledgments

The authors would like to thank Marianne Dahl (NTNU) for translating several versions of the questionnaire into Norwegian; Terje Andreas Eikemo (NTNU) for great advice on the questionnaire's structure; Thomas Jonsson (NTNU) for advice on statistics; all our colleagues from the Department of Civil and Transport Engineering (NTNU) who tested the questionnaire; and to all others who both disseminated the survey's link and participated in the survey.

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Paper IV

The complexity of planning a shared urban space: A case study involving cyclists and goods delivery

Pitera, K., Pokorny, P., Kristensen, T., Bjørgen. A., 2017

Eur. Transp. Res. Rev. (2017) 9:46
DOI 10.1007/s12544-017-0262-8

CrossMark

ORIGINAL PAPER

The complexity of planning for goods delivery in a shared urban space: a case study involving cyclists and trucks

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Received: 3 January 2017 / Accepted: 11 August 2017

Abstract
Introduction Growth in urban areas has resulted in conflicts between road users as they share the roadway. Such conflicts are only exacerbated by failings in the planning process. The purpose of this study is to examine, through a case study in Trondheim, Norway, issues related to freight delivery on a street section with a high volume of cyclists in order to identify how and where urban freight should be addressed within the urban planning process.
Methods The study consists of two parts: (1) a safety evaluation of the location through video recordings which identifies the risk areas associated with freight delivery and encounters with cyclists, and (2) a mapping of the planning process through semi-structured interviews in order to understand the development decisions involving a facility requiring deliveries and the surrounding streetscape.
Results The safety analysis identified several risk areas mainly associated with the turning manoeuvres of trucks undertaken either before or after deliveries. The mapping of the planning process indicated that there were few to no discussions of freight deliveries during the planning, design and construction of the building; neither were there any for the streetscape projects taking place within the same time frame.
Conclusions The absence of a dedicated freight policy and/or personnel at the governing authority, as well as lack of coordination amongst different plans (construction, street, thematic), are likely to lead to continued problematic and potentially dangerous environments such as that in the case study. Improvements to the Norwegian planning process, namely earlier integration of freight considerations, are required to ensure sustainable freight systems in the urban environment.

Keywords Freight delivery · Urban freight · Safety · Bicycles

1 Introduction

As a result of growing urban areas, both competition for space and conflicts between road users are increasing. One area of notable concern are the encounters between freight vehicles and cyclists, both whose numbers are rising in many cities. Given the size and mass differential of these two road users, their interactions can result in severe consequences for cyclists [1–3]. Within the European Union, 12 % of cyclist fatalities in 2013 were the result of an accident involving a truck [4], while within Norway this number is nearly 20% country-wide, and 35% when specifically considering urban areas [5]. Given such consequences, the co-existence of trucks and bicycles in complex urban areas has started to attract research attention focusing mainly on accident analysis and detection of cyclists in blind spots [5–7]. More complex analysis, like that related to urban planning and design, still needs to be investigated further.

Having goals such as creating attractive and liveable cities, urban development is focused on acknowledging and facilitating different users and activities on shared urban streets. The freight community has identified the potential for conflicts between trucks and non-motorized users as a concern in urban areas [8–11], but this concern has been addressed in

This article is part of Topical Collection on Accommodating urban freight in city planning

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Published online: 19 August 2017

limited ways within practice. Within many freight plans and guidelines of urban freight best practices, including those specific to the location studied in this research, there is little mention of accommodations for sharing the street with non-motorized users such as bicycles, or more specifically, how to design infrastructure to do this. For example, the BESTUFS Good Practice Guide on Urban Freight Transport [12] discusses guidance on goods, vehicle access and loading, but does not mention safety or the need to share infrastructure with different users. Guidance from the Norwegian national level regarding goods deliveries in cities identifies issues associated with freight deliveries, even discussing concerns related to cyclists, among others, sharing street space with trucks. It is stated that for new establishments, it is important to look at the road network and consider the type of conflicts that may occur, specifically mentioning bicycle lanes as an area of concern; however, there is no additional guidance on how to mitigate for such potential conflict [13]. This is similar at the local level. For example, the street use plan for Trondheim [14] recommends that the city provide good and safe delivery conditions in new buildings, but there is no follow-up with specific suggestions as to what this may entail.

Because freight transport is one of the primary users of the urban space, several European cities are now working on developing Sustainable Urban Logistics Plans (SULP) [15]. In order to improve conditions for local freight delivery, the primary objective of an SULP is to enhance the cooperation and predictability between the different actors within urban logistics. Previous projects (e.g. the Enclose Project, see [16] have made attempts at creating guidelines for developing and implementing SULPs. Key components of the guidelines include: setting objectives and targets; identifying the logistics context, including identifying key actors and assessing their requirements for improving city logistics; identifying policy measures and service designs which can be analyzed and assessed; assignment and distribution of responsibilities; and development of implementation and monitoring plans. The interest in developing SULPs has also risen in Norway, and several Norwegian industry representatives have recently proclaimed an urgent need for implementing logistics plans in Norwegian cities [17]. SULPs have the potential to help decision makers and planners/designers to better understand and address the trade-offs and conflicts between users of shared urban spaces; however, more work is required to understand the complexity of urban freight delivery and how laws and regulations affect present systems.

To demonstrate the complexity and challenges with planning effective freight logistics in an urban environment, we conducted a case study in Trondheim, Norway. The selected case, which centres on the planning, construction, and operation of a typical grocery store, illustrates a typical case for developers, planners, and users in urban development. While Trondheim is a medium-size city with nearly 200,000 inhabitants, it has a large bicycle modal share of 9%, which is the highest of all cities in Norway [18], and strongly promotes initiatives to construct and improve bicycle infrastructure in the city. Similar to many small to medium-size urban areas, the city of Trondheim does not have a specific plan for urban freight logistics, but has expressed an interest in developing such a plan.

This study considers the planning and design of a building site having a requirement for truck deliveries, which coincided with the planning and design of a cycling facility in the same location. Observations of the site post-construction have identified safety risks associated with truck deliveries intensified by the high bicycle volumes along the street. It is our hypothesis that the complex urban environment, consisting of overlapping yet often uncoordinated domains, as well as lack of a dedicated freight plan and/or planner, contributed to this situation. The study uses multiple methods to illustrate the lack of focus on freight-related issues within the urban planning process. In combining methods through a common case study, both the cause and the effect are considered together, further emphasing the consequences of uninformed decision-making within urban planning and design.

The article begins with a description of the case study. This is followed by a description and discussion of results of the safety analysis, which consisted of both video observations and an intercept interview. The safety analysis identifies risks associated with good delivery at the site, clearly illustrating the adverse impacts of a disconnect between urban logistics planning and urban mobility planning. The second part of the analysis follows, focusing on the planning process of the site. Through document analysis and semi-structured interviews, the planning process is mapped to identify deficiencies concerning inclusion of urban freight which may have contributed to the risky delivery conditions identified. The article concludes with a discussion integrating the results of both analyses and suggests solutions to mitigate these issues in the future.

2 Case study description

This case study focuses on a section of roadway in front of a grocery store located in a moderately dense mixed-use area in Trondheim, Norway. The site is representative of grocery stores in mixed-use areas within Trondheim, both with regard to the delivery demands of the store and to the movements and activity on the streets in the vicinity of the store. The grocery store shares a building with an academic institution and is located along an important part of Trondheim's cycling network. Additionally, visitors to both the grocery store and school often use cycling as their mode of transport. Cyclists access the building park in either a designated bicycle parking area adjacent to the building or on the sidewalk in the vicinity. In order to make deliveries, trucks are required to park in the traffic lane in front of the building. The delivery must then cross the adjacent bicycle lane situated between the truck and unloading area (see Fig. 1).

An elevated asphalt hump levels the street with the sidewalk; its purpose is to assist deliveries. This hump is occasionally used by cyclists to access the bicycle parking, initially raising safety concerns at the site. Additionally, the street configuration and traffic management in the area results in several trucks having to make a 3-point turn in order to turn around either before or after deliveries are made. Figure 2 illustrates the case study location.

The roadway in front of the building is a two-way street used by both motorised traffic and cyclists, with the northern adjacent block of the street transitioning to one-way for motorised traffic and two-way for cyclists. There are one-directional cycle lanes on both sides of the street in addition to sidewalks. Figure 3 shows the streetscape alongside the building. The speed limit is 30 km/h and the area's function is residential. Based on 2013 traffic count data, the AADT is 2500 vehicles/day, with 3% being trucks (vehicles longer than 5.6 m) (www.vegvesen.no/vegkartreference). In the spring of 2016, a weekday cyclist count conducted within this case study found nearly 1400 cyclists using the roadway section between 6:00 and 18:00 with the highest volumes during the morning (7:00–9:00) and afternoon (15:00–17:00) peaks.

As previously mentioned, a safety evaluation of the site was initially proposed by the municipality after the report of a crash of a cyclist into the truck lift, which was located on the elevated hump in the street. It was reported by truck drivers that cyclists were using the elevated hump to access the sidewalk and cycle parking facility located next to the building. If there is a delivery truck parked there for unloading, the manoeuvre can result in a crash with the truck's lift that is placed on the elevated hump (see Fig. 4, green arrow represents cyclist's movement). Additionally, there is also the risk of conflict between cyclists riding in the cycle lane and drivers using a trolley to deliver pallets across the cycle lane (see Fig. 4 top, blue arrow). After an inspection of the premises, the Norwegian Labor Inspection Authority found the conditions for delivery workers hazardous and submitted a safety directive to the building's owner. In response to this ruling, rumble strips were added on cycle lanes in both directions to raise awareness of cyclists about the presence of delivery trucks. Additionally, a small sign and warning light were installed in order to warn cyclists of deliveries.

3 Safety evaluation

The original intention of the safety evaluation was to observe the street in the vicinity of the loading area before and after implementation of the rumble strips and to analyse their effect on the number and severity of conflicts between cyclists and delivery trucks. During a one-week observation period before the implementation of this measure, nearly no relevant encounters between trucks and cyclists were recorded in the loading area that could be compared using a before-after study. At the same time, safety issues related to truck-turning manoeuvres before or after deliveries were identified as a concern and further investigated. Thus, this research does not have a standard "before-after study" design. Instead, a safety evaluation of the entire section was conducted using video observations and intercept interviews. From these, safety risks at the site can be clearly identified.

Fig. 1 Freight delivery configuration as recommended by the receiver (position #1 further in the text)

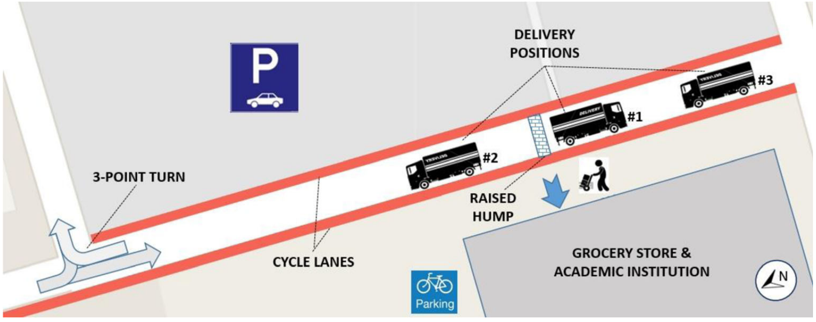


Fig. 2 Map of case study in Trondheim, Norway

3.1 Video recordings

Using three camera locations (see Fig. 5), over 100 h of video was recorded to examine truck manoeuvres and delivery positions, safety levels between bicycles and delivery trucks, and behaviour of cyclists. As previously mentioned, while the original intent of the study was to examine behaviour at the loading zone itself, the videos revealed additional risk issues within the roadway section.

3.1.1 Loading zone

Camera #1 recorded the loading zone for five working days (Mo-Fri; 7:00–17:00) before the implementation of the rumble strips, while camera #3 recorded the behaviour of cyclists after their implementation for one working day (6:00 to 18:00), focusing specifically on cyclists riding across the rumble strips.

Fourteen cyclists were recorded by camera #1 as having used the elevated hump to cross the road whenever there was a truck parked there (before rumble strip installation). No conflicts, indicated by cyclists' evasive action, were recorded during those manoeuvres. After the rumble strip installation, Camera #3 did not capture any observable/significant effect of the rumble strips on cyclists' behaviour. While a few cyclists chose to ride in the traffic lane, thereby avoiding any riding over rumble strips, this occurred very seldom (10 out of 1358 total cyclists) and does not necessarily relate to the presence of the rumble strips.

From the Camera #1 recordings, observation of the co-existence between delivering trucks/trolleys and cyclists was also interesting. Eighteen trucks parked in position #1 (see Fig. 2) when making a delivery to the building during the observation period, spending on average 19 min parked during each delivery. During this time, 165 cyclists rode in the cycle lane closest to the grocery store as they approached the parked truck. Three options were observed by cyclists when passing a truck parked in the loading zone:

1. Continue using the cycle lane
2. Riding around using the sidewalk
3. Riding around using the road

The choice of the passing manoeuvre is logically influenced by the position of the truck in relation to the cycle lane. When the truck was parked next to the cycle lane (as

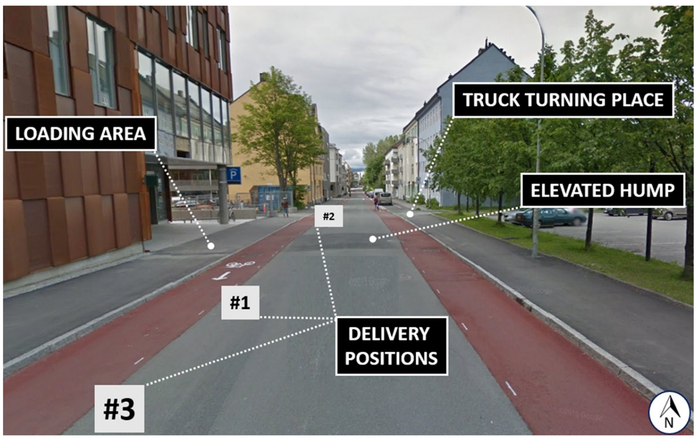


Fig. 3 Streetscape view of case study site (source: adapted from Google maps, 2016)

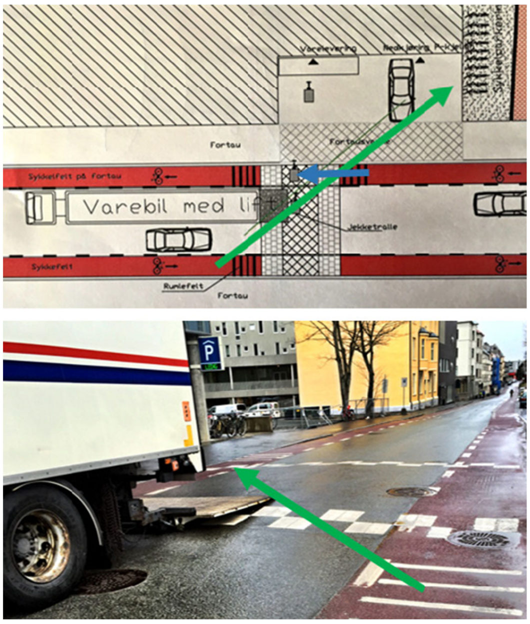


Fig. 4 Scheme of the proposed safety measure and risky manoeuvre (green arrow). Implemented measure on bottom picture

it should be), nearly all cyclists continued to use the cycle lane. When the truck occupied the cycle lane (just 1 occurrence), half the cyclists used the sidewalk and half used the traffic lane in order to go around the truck. There were two recorded conflicts (an avoidance manoeuvre by the cyclist) between cyclist riding in the cycle lane (in the "correct" direction) and delivery trolleys.

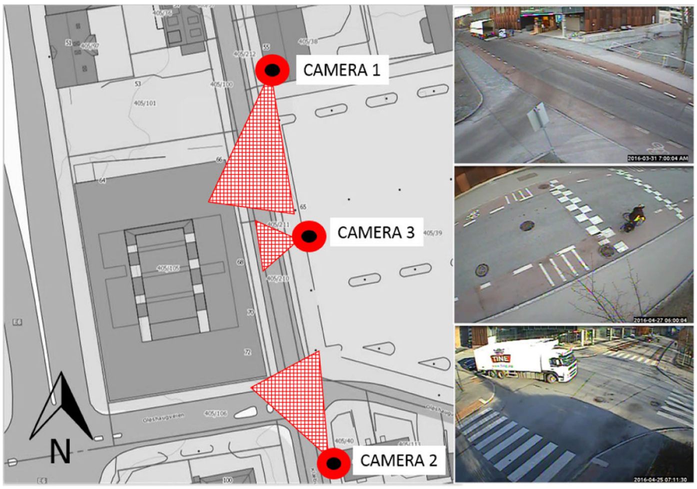
While travel by cyclists in the contra-flow direction was not common (approximately 6%), it was identified as a concern. It is "normal" behaviour for cyclists, who start their trip from the building and continue north towards the city centre. Nevertheless, this behaviour is not easily accepted by truck drivers, as deliveries using trolleys become more obscured when cyclists are riding contra-flow. However, no conflict was observed in these situations.

3.1.2 Truck turning Manoeuvres

The recordings from cameras #1 and #2 also highlighted several types of truck manoeuvres performed in the studied section. All trucks enter the section through the same intersection and then park in one of three different positions (see Fig. 2). Seventy percent of trucks also leave the roadway section through the same intersection; thus they must complete a 3-point turn manoeuvre either before or after making a delivery. This manoeuvre is conducted in the entrance to the parking lot on the other side of the street (see Fig. 2 for location), and the truck must cross over both cycle lanes to make the turn.

During observations over the five working days, 35 trucks made deliveries to the building, with 24 trucks making the previously described 3-point turn manoeuvre. Twenty-eight cyclists rode through the road section during those manoeuvres, with nearly half of them needing to react in some way based on the trucks' movements. These reactions included riding in the opposite traffic lane, going around the reversing truck, and waiting in the cycle lane while the truck was reversing. Two conflicts, both based on an evasive action, were recorded. One concerned a truck leaving the car park whose driver noticed a cyclist riding in the cycle lane from the left too late and had to brake suddenly, and another where a truck driver came to an abrupt stop to accommodate a cyclist who was crossing the road diagonally in front of the truck.

Fig. 5 Locations of camera and areas of interest



3.2 Intercept interviews

As the main purpose of the installation of the rumble strips was to raise cyclists' awareness of the presence of delivery trucks, intercept interviews were conducted after the measure's implementation to determine if cyclists noticed the measure and if they understood its purpose. Several truck drivers were also interviewed in order to provide further insight into the situation. Cyclists who rode across the rumble strips and stopped near the grocery store and truck drivers who delivered goods and parked in the section were interviewed. The interviewer asked the following questions of each group:

CYCLISTS:	TRUCK DRIVERS:
1. How often do you cycle on this section of roadway?	*1. What parking position do you prefer when delivering to the store and why?*
2. Were you aware of the addition of the recent rumble strips in the cycle lanes?	*2. Is there any recommendation from the store regarding what position to choose?*
3. What do you think is the purpose of the rumble strips?	*3. Do you think the recently added rumble strips in the cycle lanes will reduce the conflicts with bicycles while you are unloading?*
4. Have the rumble strips changed your cycling behaviour?	*4. Have you experienced any safety problems with bicyclists at this site?*
5. Have you experienced any safety problems with trucks at this site?	

Thirty-nine cyclists were interviewed. Most respondents were adults who cycle frequently in the area (3–5 times in a week). A truck was presented in 33% of the intercepts. Only 28% of the respondents noticed the presence of rumble strips, and 13% said they changed their behaviour due to the implementation. The majority (80%) thought that the rumble strips' main purpose/function was to slow down cyclists. No respondents connected the rumble strips directly with the delivery trucks, but 23% thought that the rumble strips were implemented as a general warning to increase cyclists' alertness. Interestingly, no cyclists commented on the risk associated with the turning manoeuvres of trucks that was noted in the video recordings. There were significantly fewer comments about delivery trucks when there were no trucks present during the interview.

Five truck drivers were interviewed. Four parked in position #1 (see Fig. 2). All drivers said that this position is recommended by the grocery store because it is closest to the loading dock and does not block the entrance to the garage. The majority of drivers were sceptical about the effect of rumble strips on reducing conflicts with cyclists. Four drivers parked their truck adjacent to the cycle lane. One driver parked in the cycle lane (which is illegal), stating this was done on purpose to avoid conflicts with cyclists during their delivery. Drivers highlighted having difficulties with cyclists during turning manoeuvres and loading operations. Two drivers mentioned the issue of cyclists riding in the cycle lane in a contra flow-direction, which added to the complexity of the situation.

3.3 Identified safety risks

The safety evaluation of the case study site identified several potential risks with unknown magnitudes associated with truck deliveries and cyclist movements. These include:

- Potential crashes of cyclists crossing the road (using the elevated hump) with the truck's lift (the catalyst for the study)
- Conflicts between cyclists and delivery trolleys, especially with cyclists who ride contra-flow
- Conflicts between cyclists and other traffic, if cyclists are unable or afraid to use the cycle lane and go around the truck in the traffic lane
- Trucks or cars driving in the opposite direction and interfering with the cycle lane because another truck is parked there to make a delivery and does not provide enough space for them to pass in the driving lanes
- Conflicts between cyclists and trucks that are performing 3-point turning manoeuvres
- Conflicts between cyclists and cars entering/leaving the underground parking when a truck parked on the road obscures visibility

The addition of the rumble strips and warnings lights attempts to address the safety risk associated with cyclists using the elevated hump, although its efficacy is in doubt, as noted in the interview results and observations. At the same time, the observations did not identify this manoeuvre as being the most critical safety issue when considering numerous additional safety risks identified above. Conflicts related to visibility issues, particularly to blind spots during truck manoeuvres, which have been identified as one of the main risk factors in truck and bicycle accidents [6, 7, 19–21] are thus of great safety concern.

4 Mapping of planning process within the case study

While only one truck-bicycle accident has been recorded at the location thus far, the observations of the truck-bicycle encounters revealed several areas of safety concern. From the safety analysis and subsequent identification of safety risks, it is obvious that encounters between street users (namely cyclists and delivery trucks in this case) were not considered in either the site or street infrastructure design. Given the expected volumes of trucks and bicycles on this street section, it seems obvious in retrospect that the coexistence between these user groups should have been examined in more detail during planning phases. To better understand why this issue was not considered, the planning process associated with the building design and construction was investigated.

As part of a larger project, Sustainable Urban Logistics Plans in Norway (NORSULP) [22], empirical data was collected in order to better understand and map the planning process. For this specific study, we base our findings on: (1) a study of how laws and thematic policy plans for the shared urban space interact with current protocols for freight delivery, and (2) semi-structured interviews with stakeholders in the case, including representatives from the local authorities, e.g., heads and managers of urban planning and case officers, as well as non-governmental representatives, e.g. project owners, architects, and the freight industry. These interviews focused on the different perspectives, priorities, involvement, and interaction the different stakeholders had throughout the specific case leading up to the present situation. Publicly-available case documents and correspondence were used to identify the interviewees, who were selected based upon their roles and experience within urban logistics and the case study project. Six interviews were conducted either in person or over the phone. The questions were open-ended, allowing the interviewees to address and discuss topics they personally thought were relevant for the case. The interviews addressed two overarching themes. First, we enquired about their roles and responsibility in relation to different aspects of urban freight logistics. Second, we asked open-ended questions about their involvement in the specific case and how they perceived the collaboration and communication across departments, plans, and between stakeholders to be. We did not interview any politicians, as this case study aimed to explore the implementation of policies already in place.

4.1 Timeline of the planning process

Based on the case documents and interviews, we mapped the timeline of events associated with the design and construction of the building, changes to the roadway, and freight delivery decisions, in turn relating these events to the planning context and current procedures (Fig. 6).

The bicycle plan developed in 1998 was a thematic plan whose intention was to identify the main bicycle routes that were planned across the city. The street in this case study was identified as being one of the streets where the planned route would go. However, the thematic plan did not specify when the construction of the bicycle infrastructure was to begin or how the infrastructure was going to be designed and laid out along each street. So while the thematic plan was not legal in any sense, it merely served as a guideline.

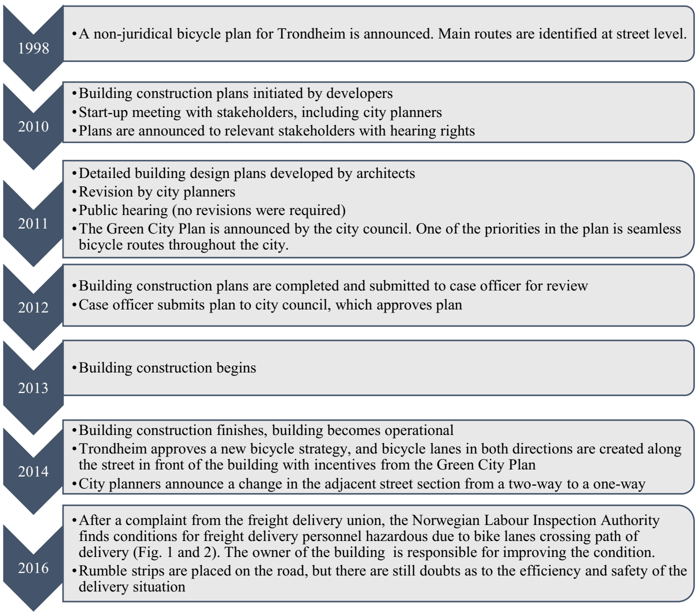
After the initiative for a new grocery store on the site was set in motion by the developer (2010), building construction plans were designed in collaboration with an architect. Next, a designated case officer arranged an obligatory start-up meeting at the city planning office, which presented an arena for the developer to display their plans and discuss with city planning office representatives, among other things, contextual issues about the construction and planned operation of the building. It is not known if issues related to truck deliveries were discussed in this meeting, but at the time there were no city planning department employees who were specifically tasked to consider freight and/or goods movement in the building's planning process.

The central directive for all construction in Norway is the Plan and Building Act. Although the law contains paragraphs relevant to freight delivery, it does not consider delivery situations directly. Directives for freight delivery solutions must therefore be interpreted from general statements found in the law. To support local planners and developers, organisations such as the National Public Road Administration (NPRA) have developed detailed 'best-practice guidelines'. However, these guidelines do not focus on shared urban space for the street users or general delivery isues; instead, they are mainly concerned with technical aspects of the construction plans to ensure a safe environment for workers. Establishment of delivery ramps are evaluated with the current street plans. Because the Plan and Building Act does not require a detailed plan for the building's operation, the project owner, in collaboration with an architect, may initiate the building process of commercial real estate without explicitly knowing what store(s) will reside in the building. This means that from the time the plans are initiated until the construction project is finished, the expected type and frequency of goods delivery may have changed. In the case presented here, the planned use of the building (grocery store) was already determined. However, since the planned use of commercial real estate may change from initiation to operation, start-up meetings typically focus only on the plan's construction.

After the start-up meeting, the building plans were announced officially, and stakeholders such as neighbours and the freight delivery union were notified in writing. Stakeholders were given the opportunity to raise concerns about the building's design and planned operation. In this case, no external stakeholders made any remarks about the plans. When concerns are raised, there may be revisions to the plan and subsequent public hearings. Once the plans were accepted in the review process, the case officer presented the construction plans for the city council. They approved the plan, and construction began (2013). There were no evident discussions regarding freight deliveries at the building location within the review process or approval by the city council.

During the building planning process, the city council announced a thematic 'Green City Plan'. These thematic plans are most often non-juridical and lack the level of detail useful for individual building plans. One of the main priorities of the Green City Plan was to offer continuous bicycle paths throughout the city. In conjunction with the 'Green City Plan', the city council decided to move forward with the

Fig. 6 Timeline of events in the planning process



bicycle plan from 1998, which included the construction of bicycle infrastructure along the street section in the case study. While the bicycle plan contained the planned route, a final decision on the specific street was not implemented until 2014. In addition, the plans did not specify the design of these paths. It is uncertain to what degree, if any, the bicycle plan was updated to reflect changes in the city's development in the 10-plus years since its establishment. Although, with respect to this case study, it is unlikely that there would be any change to the placement of a bicycle route along the road section given that it is a logical link within the bike network with limited route alternatives within the corridor. After the building construction was complete and building became operational, bicycle lanes were installed on either side of the street.

Additionally, after the construction was completed, city planners in collaboration with regional road authorities set in motion a new street plan that altered the road section just north of the building site from a two-way street to a one-way, in effect limiting the mobility of larger trucks. The new street plans were under development at the time the construction project had started. Based on our conversations with the interviewees, it appears that neither the bicycle lane plans or changes in the street configuration were addressed by any of the public stakeholders until after the building was finished and operational and changes to the streetscape were completed.

After complaints were filed by the freight delivery union (LUKS), the Norwegian Labour Inspection Authority determined that conditions for freight delivery personnel were hazardous due to the bike lane crossing the path of delivery. The building owner and the city planning office decided to install the previously discussed rumble strips to alert cyclists to the presence of delivery trucks (and perhaps slow down bicyclists crossing the delivery zone, although this was not the direct intention). Several months after the rumble strips were installed, a small sign and flashing light were also installed to warn cyclists of impending deliveries.

5 Discussion

The technical safety evaluation clearly identifies numerous risk factors associated with truck deliveries and bicycle mobility at the site investigated within this research, while the planning process evaluation highlights the fact that a strategy for freight delivery is lacking for both this specific case study and overall within the city. Together, these evaluations illustrate how the lack of concern for urban freight deliveries within urban planning can result in risky situations for road users. In mapping the planning process, no discussions of freight delivery were identified. The standard planning process is based on laws and regulations which do not include any requirements to do so. Today, urban freight is treated on a case-by-case basis, and if any strategies or objectives concerning urban freight do exist, they are fragmented, which implies that there is not necessarily coordination within or between projects. Thus, even when freight delivery is discussed within a project, there is likely to be a lack of communication and coordination between the different city planning departments involved.

This lack of coordination is evident in the case study, as the city planning office held three separate roles here: (1) responsibility for reviewing and approving building construction plans, (2) responsibility for planning and implementing new bicycle infrastructure, and (3) responsibility for planning and implementing a change in the street function, with minimal to no interaction among these three roles. Additionally, urban freight transport was not considered within any of these roles, despite the inherent need for deliveries given the function of the building. While such coordination can be challenging due to the complexity of city administration, the current set-up provides no opportunity for urban freight transport considerations. The planning timeline indicates lack of coordination between the involved departments, lack of knowledge about how the different aspects of both building and street design impact urban freight, and a lack of focus and strategy related to urban freight transport.

As observed in this case study, the lack of coordinated urban planning resulted in safety concerns in which the delivery situation could potentially result in severe conflicts between trucks and cyclists. In examining the technical solution to address the safety concerns, there are doubts about the measure's effectiveness, further highlighting the lack of understanding of both bicyclists' and truck drivers' needs. The intent of the rumble strips was to raise awareness of deliveries, which is not necessarily evident according to the cyclists and truckers interviewed, especially given their location directly adjacent to the elevated hump. While the rumble strips may slightly reduce cyclists' speeds, which may in turn reduce the potential for or severity of encounters, they also serve as a potential hazard in the lane and may cause additional safety issues (for example, friction issues when the road and markings become wet). Additionally, the risk perceived as high by the municipality differs from those risks identified within safety observations. This discrepancy not only further highlights the lack of understanding regarding mobility at the site, but also clearly demonstrates the importance of the observation method, as it can reveal safety problems that would otherwise remain hidden if only accident data is considered.

Regardless, it is challenging to identify an effective technical solution to improve the delivery situation given the constraints of the completed building and streetscape given the fact that the finished construction project and changes to the delivery configuration are largely restricted to small, cosmetic implementations. This further highlights the importance of discussing freight and delivery issues early in the planning process, when there is still the possibility to make more substantial changes to the designs. This proactive approach is also recommended with regard to road safety in a general sense, where it is suggested that trying to address safety concerns before infrastructure is designed - as opposed to the reactive improvement of deficiencies - will result in an overall better road system [23]. Additionally, while the costs associated with the road construction were small, especially when compared to the costs associated with the building construction, these road constructions are funded through tax-payer contributions. Thus, there is a need for road modifications to address deficiencies soon after initial construction plans are made, as this action may indicate a misuse of these funds.

While there is a mobility plan within Trondheim [24] which attempts to unite planning and transport efforts with the goal of environmental sustainability, it only involves personal mobility by public transport, walking and biking. Any mention of urban freight policy for goods and services is lacking here, and there are no personnel responsible for this task at the city administration level. A freight plan (or a SULP) would be a useful planning tool for the city administration to increase awareness of freight delivery issues as well as identifying and addressing problems similar to that found in this case study. The establishment of this framework would allow for both meaningful interactions between stakeholders and the development of best practices related to urban freight deliveries. The long-term dialogue between stakeholders that can be developed through such a framework can be compared to urban freight partnerships, which have been shown to result in stronger relationships between stakeholders, improved communication and knowledge sharing, and improved decision-making [25]. For the case examined within this study, earlier discussions of deliveries between both private and public stakeholders may have resulted in requiring the building design to include an off-street delivery dock, the use of alternative bicycle infrastructure designs, or consideration of alternative operations such as overnight deliveries. As further development is expected along this street, it is recommended that these discussions take place early in the planning process in order to avoid further exacerbation of mobility and safety issues.

6 Conclusions

In the absence of a dedicated freight policy and/or personnel at the governing authority, it is entirely up to the planner, architect, and developer to ensure good solutions for freight delivery. The lack of planning regulations and specifications regarding freight delivery solutions results in situations where urban freight concerns are commonly discussed far too late in the planning process - or sometimes not at all - often to the detriment of all road users. Numerous safety risks were identified while observing delivery operations in this particular casy study which were the result of limited discussions of freight during the planning process and lack of coordination among various city planning departments. Post-construction mitigation efforts are limited. Early detection of delivery issues through closer cooperation between plans and planners may enable more meaningful corrective action early on in the process. This coordination can also ensure that various plans (construction, street, thematic) are considered holistically and with consideration to other existing plans and development in the area. However, without any dedicated city plans for how freight delivery fits into the shared urban space, current deficiencies in the planning process will likely lead to continued problematic and potentially dangerous environments.

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Paper V

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