Work Package 5 Report

Interaction between Cyclists and Motor Vehicles – the role of infrastructure design and vehicle characteristics

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Executive summary

The aim of the project was to examine interactions between motor vehicle drivers and cyclists at intersections and the impact of infrastructure design and motor vehicle characteristics on interactive behaviour. The project activities included literature reviews on cycling infrastructure at intersections, vehicle driver behaviour and cyclist behaviour; questionnaires among motor vehicle drivers and cyclists across different cities in Sweden; field observations to investigate what cues cyclists use to interpret the intention of motor vehicles they interact with at signalised intersections; on-site interviews with cyclists to explore their strategy in an encounter with a motor vehicle; and a cycling simulator study to examine the behaviour of cyclists when approaching an intersection and the factors that may influence their decisions.

The findings confirm that the way the cycling infrastructure is designed at intersections contributes to how cyclists and motor vehicles interact. Placing cyclists and motor vehicle drivers close (where they are visible to one another) at intersection areas increases the level of presence-awareness for both road users and consequently it increases safety. Though cyclists may feel more uncomfortable (exposed and unsafe) with this solution, they tend to be more careful and attentive. This finding from the literature was confirmed by the field observations showing that mixed traffic, i.e. "no cycle facility" at the intersection is the safest solution and the cycle lane solution is the least safe one. However, the on-site interviews with cyclists revealed that the large majority of the respondents preferred the infrastructure solution with a separated bicycle path. This is a typical case where objective safety and subjective safety stand in opposite relationship.

The findings also revealed that one-directional cycle tracks enhance interaction at intersections, since motor vehicle drivers only expect cyclists from one direction. However, cyclists not following the rule and riding against the prescribed direction create problems and conflictive situations.
Cyclists and the way they use the road infrastructure were found to be highly heterogeneous; the availability of cycling infrastructure at an intersection does not guarantee that cyclists use it as expected by designers and perhaps by motor vehicle drivers, as the infrastructure solution in some cases might not provide the shortest path for the cyclist. The uncertainty in cycling behaviour was found to be more at intersections with no cycling infrastructure. Confidence level among cyclists was found to affect their interaction with motor vehicles which tends to be hard for motor vehicle drivers to predict as different cyclists behave differently depending on their confidence in traffic.

The majority of the interviewed cyclists said that when arriving at an intersection just after a motor vehicle they usually pass it on its right side. This was seen in observations on sites with cycle lane or cycle path but not on sites with mixed traffic. Also, if the motor vehicle was a heavy vehicle (bus or truck), somewhat fewer cyclists passed it on its right side. Also the cycling simulator study revealed that the most significant difference of longitudinal stop position was between the condition

of a narrow lane without cycle lane marking and a truck standing at the stop line and the condition of wide lane with cycle lane marking and a car standing at the stop line, where the average stop position of the cyclist was behind the truck in the first condition and next to the car in the second condition. This finding corresponds to the test cyclists' verbal expressions of the importance of "being visible and avoiding the blind spot". The increased caution associated with the presence of a truck is motivated and in line with previous studies.

At sites with mixed traffic (no cycle facility), compared to with cycle lane or cycle path, the cyclists' scanning behaviour was more complete. At sites with cycle path, the cyclists looked for eye contact with the driver of the motor vehicle to a much larger extent than cyclists at the other two types of sites. Cyclists at sites with mixed traffic (no cycle facility) were more active in their visual search behaviour than cyclists at the other two types of sites. Also, those cyclists who passed the motor vehicle on its right side were more active in their visual search behaviour than those who did not pass the motor vehicle. The share of critical situations indicates that sites with mixed traffic (no cycle facility) is the safest solution and cycle lane solution is the least safe one.

Sammanfattning

Syftet med projektet var att undersöka samspelet mellan cyklister och motorfordonsförare i korsningar och påverkan av infrastrukturdesign och motorfordonsegenskaper på detta beteende. Projektet innehöll litteraturöversikter om cykelinfrastruktur i korsningar, fordonsförarens och cyklistens beteende; frågeformulär bland motorfordonsförare och cyklister i olika städer i Sverige; fältobservationer för att undersöka vilka signaler cyklister använder för att tolka avsikten med motorfordon de interagerar med vid korsningar med signal; intervjuer på plats med cyklister för att utforska dess strategi i ett möte med ett motorfordon; och en cykelsimulatorstudie för att undersöka cyklists beteende när man närmar sig en korsning och de faktorer som kan påverka deras beslut.

Resultaten bekräftar att cykelinfrastrukturens utformning i korsningar bidrar till hur cyklister och motorfordon interagerar. Att placera cyklister och motorfordonsförare nära (där de är synliga för varandra) i korsningsområdena ökar nivån av närvaromedvetenhet för båda trafikanter och därmed ökar säkerheten. Även om cyklister känner sig mer obekväma (utsatta och osäkra) med den här lösningen, tenderar de att vara mer försiktiga och uppmärksamma. Detta fynd från litteraturen bekräftades av fältobservationerna som visade att blandad trafik, dvs "ingen cykelanläggning" i korsningen är den säkraste lösningen och cykelbanelösningen är den minst säkra. Emellertid visade platsintervjuerna med cyklister att den stora majoriteten av de svarande föredrog infrastrukturlösningen med en separat cykelväg. Detta är ett typiskt fall där objektiv säkerhet och subjektiv säkerhet står i motsatt relation.

Resultaten avslöjade också att enkelriktade cykelväg förbättrar samspelet vid korsningar, eftersom förare av motorfordon bara förväntar sig cyklister från en

riktning. Cyklister som inte följer regeln och kör mot den föreskrivna riktningen skapar emellertid problem och konflikter.

Cyklister och hur de använder väginfrastrukturen befanns vara mycket heterogena; tillgången på cykelinfrastruktur i en korsning garanterar inte att cyklister använder den som förväntat av designers och kanske av motorfordonsförare, eftersom infrastrukturlösningen i vissa fall kanske inte ger den kortaste vägen för cyklisten. Osäkerheten i cykelbeteende befanns vara mer i korsningar utan cykelinfrastruktur. Förtroendegraden bland cyklister visade sig påverka deras interaktion med motorfordon, vilket tenderar att vara svårt för motorfordonsförare att förutsäga eftersom olika cyklister uppför sig olika beroende på deras förtroende för trafiken.

Majoriteten av de intervjuade cyklisterna sa att när de anländer till en korsning precis efter ett motorfordon, passerar de vanligtvis det på dess högra sida. Detta sågs i observationer på platser med cykelfält eller cykelväg men inte på platser med blandad trafik. Om motorfordonet var ett tungt fordon (buss eller lastbil) passerade något färre cyklister det på dess högra sida. Cykelsimulatorstudien visade också att den mest signifikanta skillnaden i längsgående stoppläge var mellan å ena sidan ett smalt körfält utan cykelfältmarkering med en lastbil som stod vid stopplinjen och å andra sidan ett brett körfält med cykelbanemarkering med en bil som står vid stopplinjen. I den första av betingelserna var det genomsnittliga stoppläget för cyklisten bakom lastbilen och vid den andra betingelsen bredvid bilen. Detta resultat är kopplat till deltagarnas verbala uttryck för vikten av att ”vara synlig och undvika döda vinkeln”. Den ökade försiktigheten i samband med närvaron av en lastbil är motiverad och i linje med tidigare studier.

På platser med blandad trafik (ingen cykelanläggning), jämfört med cykelfält eller cykelväg, var cyklernas skanningsbeteende mer fullständigt. På platser med cykelväg letade cyklisterna efter ögonkontakt med föraren av motorfordonet i mycket större utsträckning än cyklister på de andra två typerna av platser. Cyklister på platser med blandad trafik (ingen cykelanläggning) var mer aktiva i sitt visuella sökbeteende än cyklister på de andra två typerna av webbplatser. De cyklister som passerade motorfordonet på dess högra sida var också mer aktiva i sitt visuella sökbeteende än de som inte passerade motorfordonet. Andelen kritiska situationer indikerar att platser med blandad trafik (ingen cykelanläggning) är den säkraste lösningen och cykelbanelösning är den minst säkra.

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1. Introduction

1.1 Overview

This report is the final work package report of the "Interaction between cyclists and motor vehicles - the role of infrastructure design and vehicle characteristics" research project conducted with support from the Strategic Vehicle Research and Innovation Programme (FFI) and Ramboll.

The aim of this final work package is to validate and discuss survey results, the empirical study results and the simulation study results in work packages 2, 3 and 4. Furthermore, recommendations will be developed as well as project conclusions.

1.2 Scope

The scope of this work package is distributed over three tasks as follows;

1. Validation and discussion of the studies conducted in work packages 2, 3 and 4. This will also include evaluation of how each of the research questions has been addressed and answered.
2. Draw up conclusions and recommendations for implementation, as well as for further research.
3. This work package will also serve as the summary of the results and discussions of previous work packages in this project.

2. Literature review, Accident data analyses and Surveys

2.1 Overview

This work package was divided into three tasks. The first task focused on cycling infrastructure at intersections, the second focused on vehicle driver behaviour and the third focused on cyclist behaviour.

The aim of the first task was mainly to gain insight into what has been learned in Sweden and other EU countries over the years through comprehensive literature review and how cycling infrastructure has contributed to the outcome of Motor vehicle – Cyclist (MV - Cyc) interactions in traffic through analysis of two accident databases. This was used as a basis for selecting the intersection types for further studies in work package 3 and 4.

The second task aimed at investigating MV - Cyc interactions at intersections through literature review of different vehicle types. Insights from the literature review were used to develop behavioural survey questions for motor vehicle drivers across different cities in Sweden to understand how their demography affects their interaction with cyclists in traffic.

The third task was focused on understanding cyclist behaviour in traffic, with respect to their interaction with motor vehicles at intersections through literature review. The insights were also used to compile a cyclist behavioural survey across cities in Sweden to understand their perception at different intersection infrastructure types.

2.2 Cycling infrastructure review

In this review, several cycling infrastructure types and their respective safety measures in Sweden, Denmark and The Netherlands were listed and discussed. The system of cycling infrastructure at intersections was observed to be largely inconsistent (which sometimes without notice, changes from separated tracks to cycle lane or disappears completely) compared to motor vehicle infrastructure, which creates confusion during interaction in traffic. Some of the main issues found are highlighted below.

It was established that cycling tracks that are physically separated from motor vehicle traffic either with curb stones or other materials, were found to result in less MV – Cyc accidents on road sections, but more MV - Cyc accidents at intersections. This cycling infrastructure was however found to perform better (i.e. result in fewer accidents) at intersections when set-back several meters away from the sideroad. This infrastructure type is thus encouraged at intersections with traffic signals, as the "set-back" distance was observed to create the risk of unclear yield priority in the absence of traffic signals.

Bi-directional cycling infrastructure compared to one-directional was found to be less safe and caused more MV – Cyc collisions than one-directional infrastructure, as motor vehicle drivers didn't have to worry about cyclists showing up from the wrong and unexpected direction. Converting cycling tracks (separated) into cycling lane (marked or coloured) 20 – 30 meters before the intersection was found to be a much safer measure, as this increase presence awareness and alertness for both cyclists and motor vehicle drivers. It also makes it possible for motor vehicles with nearby object detection sensors to function optimally. This measure also reduces the possibility for cyclists entering the intersection from the wrong direction.

Advanced stop lines for cyclists at signalised intersections was found to be less effective because a large percentage of drivers block the stop line to prevent cyclists from stopping/waiting in front of the motor vehicle, especially when either cyclists and/or motor vehicle drivers cycle/drive through on yellow light.

2.3 Accident data analyses

Two accident databases were used in this analysis namely; Swedish Traffic Accident Data Acquisition (STRADA) and IF P&C Insurance database. The latter database was used to complement the former, which lacked information on scenarios leading to the reported accidents, though the latter only contains information on Car – Cyclist Car – Cyc) accidents.

About 10 000 MV – Cyc accidents were found in STRADA to have occurred at intersections across Sweden between 2008 – 2017, while over 1 100 Car – Cyc accidents were found in the IF database between 2011 – 2017. About 60% of these accidents (IF database) were found registered in STRADA while the remaining 40% were not. Three-quarter (75%) of the accidents found in STRADA led to slight injuries, 17% resulted in moderate injuries, 4% led to severe injuries, 2,5% led to no injury and 1% resulted in fatality among cyclists. In the IF database, 90% of the accidents led to slight injuries, 6% led to moderate injuries, 2% resulted in severe injuries and remaining 2% led to no injury among cyclists. Overrepresentation of slight injuries may be due to the fact that most of the accidents occurred between 30 – 50km/h.

Male cyclists (53%) were found to be slightly more represented in these accidents against Female cyclists (47%), especially when compared to the population statistics (Male 49%, Female 51% (SCB, 2017)). Cyclists below the age of 20 were found to be most represented in the STRADA accidents (23%). These are mostly pupils with little or no traffic knowledge, which may have led to them having problems to interact with motor vehicles in traffic.

54% of the accidents found in STRADA were recorded in 14 municipalities (Malmö, Stockholm, Göteborg, Uppsala, Lund, Linköping, Helsingborg, Örebro, Norrköping, Halmstad, Västerås, Kristianstad and Växjö), where at least 100 accidents had occurred. Thirty-five percent of these municipalities are in the region of Skåne, the southwestern part of Sweden. This region was reported to have a relatively high and consistent accident reporting record than other regions between 2008 – 2016 where several accidents were found missing in STRADA. An average of about 1 000 accidents per year was observed, with a dip in year 2008, credited to reporting error. Weighting the share of cycling in the listed cities on their accident record was found to produce a normalizing effect, where Malmö still had the most accidents (18 per thousand cyclists) while Linköping had the least (6 per thousand cyclists).

Both databases confirmed cyclist accident variation over seasons, weekdays and time of the day with most cyclist accidents in September and the least in February, and most cyclist accidents on Wednesdays and during morning and afternoon peak hours. About 60% of these accidents occurred in daylight and good weather.

93% of the accidents found in STRADA occurred with Passenger car, while 3% occurred with Bus and 4% occurred with Trucks. Given that the total vehicle kilometres travelled in Swedish roads in 2017 was approximately 81% Passenger cars, 17% Trucks and 1% Buses (Trafikanalys, 2018), Passengers cars and Buses can be said to be well overrepresented in accidents with cyclists at intersections. One out of every twenty cyclist accidents with Trucks at intersections was found to lead to cyclist fatality while buses were found to cause more severe injuries to cyclists than other vehicle types.

Intersection design with separated cycling infrastructure, where both cyclists and motor vehicles were entering the intersection, was found as the scenario with most accidents in the IF database.

2.4 **Literature review**

Interaction in traffic was discussed in the literature review as a consequence of simultaneous desire of road users for mobility with minimum disruption at desired speed. This they do anonymously and with restricted or short communication, which makes misunderstanding each other inevitable. Some factors that may cause motor vehicle drivers to interact poorly in traffic are identified and discussed.

When motor vehicle drivers are irritated, it was found that they behave poorly and become disposed to anger, which interferes with the driver's attention and their ability to objectively process information, leading to bad judgement. Using the Swedish version of the Driver Aggression Scale (DAS) which focuses on irritation rather than anger, Björklund (2008) found many drivers reported to be irritated and thus reacted aggressively when their progress in traffic was disturbed, especially at peak hours. "Look-but-failed-to see" (LBFTS) errors (Herslund & Jørgensen, 2003) was found as a common error among motor vehicle drivers, where the drivers actually scan for other approaching road users but fail to recognise cyclists in the search because they are mostly looking out for other motor vehicles.

Speed, which affects both reaction time (of motor vehicle drivers and cyclists) and collision severity was found to be a key factor in MV – Cyclist interaction at intersections. The speed of the approaching vehicle and the nearness of the cyclist to the point of conflict was reported to be the most influencing factor for motor vehicle driver's decision to yield for an approaching cyclist. When and where more people cycle (i.e. more cycling exposure), Jacobsen (2003) found that cyclists to be safer, which is called the "safety-in-number effect". This was however argued to be effective only when motor vehicle volume is kept at a constant (Elvik, 2013). Increased volumes of vans, large automobiles and trucks were associated with higher risk of collision with cyclists by Prati, et al., (2017), mainly due to blind spots around these vehicles. Blind spot mirrors and cameras (onboard) were found to potentially improve interaction. More men than women were found to be aggressive towards other vehicles when impeded in traffic, even though more women were found to be irritated when impeded than men. Inexperienced drivers were also found to display more irritation and aggression than experienced drivers (Björklund, 2008). Elderly drivers were also found to compensate for their perpetual and cognitive difficulties by driving slower at intersections, misleading cyclists (and other road users) to interpreting the speed reduction as an intention to yield.

Other contributing factors to MV – Cyclists interaction are available cycling infrastructure at the intersections and cycling experience by motor vehicle drivers.

2.5 Surveys

Two surveys were conducted in this work package. The first was focused on the behaviour of motor vehicle drivers towards cyclists at intersections, while the other was focused on cyclist behaviour at different intersection infrastructure designs. The two surveys were conducted by the same company "Norstat" via the internet. Focus cities were selected based on population size, recorded accidents among cyclists and motor vehicles (54% of the total accidents analysed on WP2 section 3.4 occurred in 14 cities, from which the focused cities were drawn) and the total number of subjects was 5000 (2500 per survey). Table 1 below shows the selected cities, the number of inhabitants and the number of responses per survey. The small cities were selected based on NUTS2 (Nomenclature of Territorial Units for Statistics, discussed further in 2.6.2) which includes the following; SE11 (Stockholm), SE23 (Västsverige/West Sweden), SE22 (Sydsverige/South Sweden), SE12 (Östra Mellansverige/East-Mid Sweden), SE31 (Nora-Mellansverige/North-Mid Sweden) and SE21 (Småland).

Table 1: Survey responses by location

Group	City	Inhabitants (Approx.)	Vehicle driver survey responses	Cyclist survey responses
Focus cities	Stockholm	960 000	922	811
	Malmö	312 000	417	454
	Gothenburg	573 000	402	403
	Lund	91 000	168	230
	Small cities	20 000 – 50 000	608	594

The number of the survey responses were validated using population statistics (SCB, 2017) in the cities where the surveys were conducted. The results are shown in Table 2 below. The tables show how the percentages in the survey results compared to the population statistics. Table 2 shows similar pattern as the population statistics. The table also shows almost the same pattern as the population data, the "master" education category seems much lower and the "Bachelor" category is higher in the survey responses than in the population statistics.

Table 2: Number of responses by gender

Gender	Percentage count	Population statistics
Male	51%	50,2%
Female	49%	49,8%
Age group	**Percentage count**	**Population statistics**
Under 30	13%	23%
30-39	14%	21%
40-49	15%	16%
50+	58%	40%
Education level	**Percentage count**	**Population statistics**
Basic school/Grundskola	7%	12%
High school/Gymnasium	43%	35%

Bachelor/Kandidat	31%	18%
Master	17%	33%
PhD/Doktor	2%	2%

2.6 Method

In this section of the report, the methods used to arrive at the results in subsection 2.5 are discussed.

2.6.1 Sample size

The size of the survey samples used in both surveys were calculated according to the formula below;

$$\pm z \times \frac{\sigma}{\sqrt{n}}$$

where z represents standard normal distribution (usually set to the value 1,96 for 95% significance level), σ represents the standard deviation for the population and n is the sample size.

Table 3: Sample size, confidence interval and error margin for motor vehicle and bicycle surveys at 95% significance level.

City	Sample size MV Survey	Confidence interval	Error margin	Sample size Cycle survey	Confidence interval	Error margin
Stockholm	922	3,2%	+/- 6,4	811	3,4%	+/-6,8
Malmö	417	4,8%	+/- 9,6	454	4,6%	+/- 9,2
Gothenburg	402	4,9%	+/- 9,8	403	4,9%	+/- 9,8
Lund	168	7,6%	+/- 15,2	230	6,5%	+/- 13

The sample sizes are estimated to have a significance level of 95%.

2.6.2 Stratification

The survey company used stratified (by participant's age, gender and location) random selection for the surveys during the participant recruitment process. This was done by crossing age, gender and the NUTS region of the respondents to form a matrix of stratified random selection that is representative of the population statistics. NUTS is an acronym for Nomenclature of Territorial Units for Statistics, which is a geocode standard for referencing the subdivisions of countries for statistical purposes. It is used for the regional grouping within the EU for statistic audit according to SCB (2008). This is implemented at both the mailing stage and through quota of incoming responses as a screening filter by the survey company. The latter was used as a control measure for the former.

2.6.3 Possible sources of error

Survey error can be thought of as the difference between an estimate that is produced using survey data and the true value of the variables in the population that one hopes to describe (Dillman, Christian, & Smyth, 2014). According to Dillman et al., (2014) there are four types of errors common to surveys. These error sources were anticipated and resolved during the process of the survey as follows;

- **Coverage error:** This error occurs when every member of the population being surveyed is not included in the sample frame or a list of the targeted population. To avoid this error, the survey respondent sample was drawn from an area home to approximately 7,1 million inhabitants which is more than 70% of the total country population as shown in **Error! Reference source not found.** below.

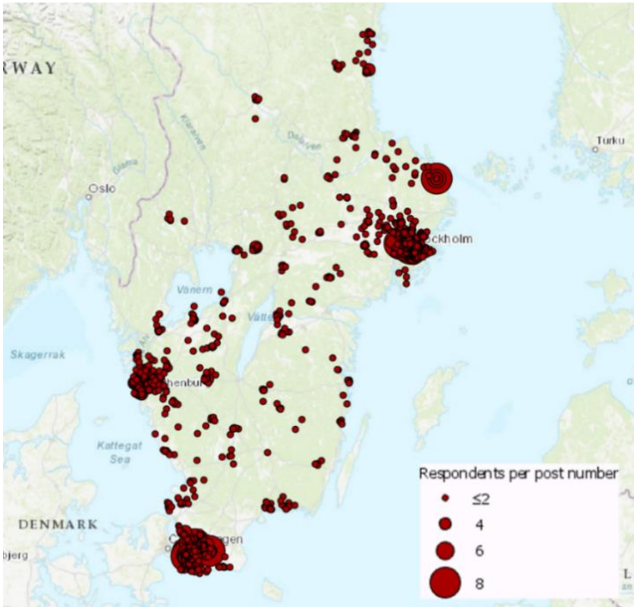

Figure 1: Geographical coverage of the survey responses (circle sizes represent responses per post number).

- **Sampling error:** This error may occur when only a sample of the population are the respondents of the survey, rather than the entire population. This error type is known to be an unavoidable result of obtaining data from only some rather than all members on the sample frame. This error is however reduced to the minimum in this work with respect to the sample size of the population per city.
- **Non-response error:** This error type occurs when the respondents who do not participate in the survey are different from the respondents that participated in a way that influences the estimated result. This error was taken care of by the survey plan selected.
- **Measurement error:** This occurs when inaccurate answers are provided to the asked question by respondents, either due to misunderstanding or unwillingness to give the right answer. Measurement error can result from two types of problems, namely response bias and response variance. Response bias occurs when estimates are systematically shifted one way or another, either due to question order effect or extreme responding. Question order effect occurs when respondents react differently to questions based on the order in which the questions appear in the survey, while extreme responding is a form of bias that drives respondents to only select

most extreme options or answer not available (Meisenberg & Williams, 2008). In order to avoid measurement error and its biases, the survey questions and their corresponding alternatives were carefully worded, formulated and structured to ensure easy comprehension of the questions and their corresponding alternatives, grouping of questions by their objectives for clearer understanding, as well as re-ordering of questions prone to produce any form of these biases.

2.6.4 **Motor vehicle driver behaviour**

The purpose of the motor vehicle driver survey was to test four main hypotheses, which were formulated based on the findings from the literature review. These hypotheses are as follows;

1. The age of a motor vehicle driver has no effect on the driver's behaviour towards and interaction with cyclists in traffic.
2. The gender of a motor vehicle driver has no effect on the driver's behaviour towards cyclists in traffic
3. The level of education of a motor vehicle driver has no effect on his/her behaviour towards cyclists in traffic
4. The city where a driver resides has no effect on the driver's behaviour towards cyclists in traffic.

2.6.5 **Result**

The survey questions were formulated to focus on three key areas namely; the driver's background which covers demographic information, the drivers involvement in accidents and near-misses, and the driver's perception and behaviour during interaction with cyclists.

The results were analysed using chi-squared tests, which looks at the significance of associations between the categories of different variables from which the questions were formulated.

The statistical analyses shows that the first hypothesis is false, that the age of drivers was found to affect their perception of cyclists and hence their behaviour towards them. Young drivers were particularly found to be more irritated and hence aggressive towards cyclists, while older drivers were found to be more respectful towards cyclists.

The second hypothesis was also found to be false, as the gender of drivers was found to influence their perception of cyclists, and thus their behaviour towards them. Male drivers were found to perceive cyclists more as equal road users than female driver. Yet, male drivers were also found to be more aggressive towards cyclists than female drivers. The opposite of this would have been expected, that seeing cyclists as equal road users or disturbance on the road would translate to less aggressive or more aggressive behaviour towards them respectively. The result however shows that the cyclist perception by female drivers does not necessarily translate into aggressive behaviour towards them, and vice versa for male drivers. More male drivers than female drivers also reported that they have been involved in both accidents and near-miss incidents with cyclists in the last 12-months before the survey, which clearly validates the result.

The third hypothesis however could not be rejected, as the education level of drivers was not found to affect their perception and interaction with cyclists. No statistical correlation was established.

The fourth hypothesis was found to be false as the city where drivers reside was found to affect how they perceive cyclists and thus how they behave towards them. Drivers in smaller cities proved to respect cyclists more and were more well behaved towards them than drivers in large cities. This makes sense, as there are chances of vehicle drivers being more aware of the roads and where to expect cyclists or perhaps have the cyclist as an acquaintance in smaller cities than in large cities.

2.6.6 **Cyclist behaviour**

A survey on attitudes, intentions, and behaviour of cyclists was designed across the cities in Sweden as well as how they use cycling infrastructures at intersections, and whether they feel safe in traffic, as well as where and why. The purpose was both to perform age and gender analyses and to use the results in the empirical and simulation study scenario development.

The survey questions were divided in four sections as follows; background including demographic information, cyclist type used in previous studies at VTI (Kircher et al., 2018; Kircher et al., 2017), interaction (experienced position of power and question of giving way for motorists), and behaviour in specific intersections.

In the present data set, women were significantly less confident cycling in mixed traffic than men, with approximately 60 % of the men, but only 35 % of the women being rather or very confident. The level of power of cyclists in traffic was generally experienced to be rather weak (28,5 % "very weak", 55,1 % "rather weak", 15,0 % "rather strong" and 1,4 % "very strong"). There was a very strong relationship between experienced power and confidence in mixed traffic. The higher the experienced level of power as cyclist in comparison to motorised traffic, the more likely it was to ride with the intention to claim one's right to go first or to keep on cycling without any special precautions.

Behavior differed between municipalities. It was less likely to report using the road in smaller towns and in Gothenburg. Instead, the pedestrian facilities were used to a greater extent. With a dedicated cycle path present, it was least likely to use this in small towns as well as in Stockholm. In the former case, pedestrian facilities were used instead, and in the latter case, the road was more likely to be used than in other towns. For those intersection types where both a signalized and a non-signalized option was asked about, it was more common to cycle on the road when a traffic signal was present.

Respondents who chose to stay on the road in mixed traffic and on the cycle lane when there was one, assessed their route as more efficient than respondents who chose pedestrian facilities or other paths. Respondents who chose pedestrian facilities evaluated the safety and security of their route as higher than those who had selected routes on the road. When off-road cycling facilities were available in level crossings, these were experienced as about equally efficient as the road, however a dedicated cycle path without pedestrians received the highest efficiency score. A cyclist and pedestrian tunnel seen as the most efficient solution, and at the same time judged to be both safer and more secure than any other solution. In addition, it was also selected as the route of choice by most respondents. Signalized intersections were experienced as slightly more efficient, safe and secure than non-signalized intersections of the same type.

There is a trend that people who describe themselves as fast cyclists are more likely to use the road, whereas people who characterize themselves as slow and typically not in a hurry prefer the pedestrian facilities. A clear trend was found to the effect that people who want to be efficient are more likely to use the road than people who are not interested in cycling efficiently. In general, the most common type of bicycle used for transportation was the so-called comfort bike – usually relatively cheap, with few gears and a rather upright seating position. While this bike type dominated in almost all categories of propensity to use the road, racing bikes and hybrids are mainly used by people who are more prone to choose routes on the road. More people who are confident in mixed traffic ride racing bikes and hybrids, whereas e-bikes are slightly more frequently ridden by people not confident in mixed traffic.

3. Field observations of cyclist behaviour and interviews with cyclists

3.1 Overview

The aim of the study was to investigate what cues cyclists use to interpret the intention of motor vehicles (MVs) they interact with at signalised intersections with different bicycle infrastructure facilities (no dedicated space, cycle lane or cycle path) and different types of MVs (car/van/bus/lorry). This was performed through on-site observations of vehicle – cyclist interactions at intersections with three different types of infrastructure design.

3.2 Method

3.2.1 On-site observations

Situations, when cyclists aiming to cycle straight through the intersection and MVs aiming to turn right approached the intersection simultaneously were observed. In these situations, cyclists' visual search behaviour was categorised. The main observational variables were:

- Type of MV involved: car/van/bus/Lorry;
- Arrival of cyclist: just ahead of a MV / head to head with a MV / just after a MV;
- If arriving just after a MV: a) the cyclist stays behind the MV or b) passes the MV;
- Cyclist’s visual search of intention of the MV: a) looks at the entire MV, b) looks at turning indicator of MV, c) looks for eye contact with driver, d) other, e) does not look at MV at all.

The observations were carried out by human observers during September 2018 to August 2019, during morning and afternoon peak hours of working days. Three types of sites were selected for the study (see Figure 2): (A) No cycle facility at all (cyclists use the same lane as MVs), (B) Cycle lane; (C) Cycle path. The sites are located in the cities of Kristianstad, Lund and Malmö in Sweden.

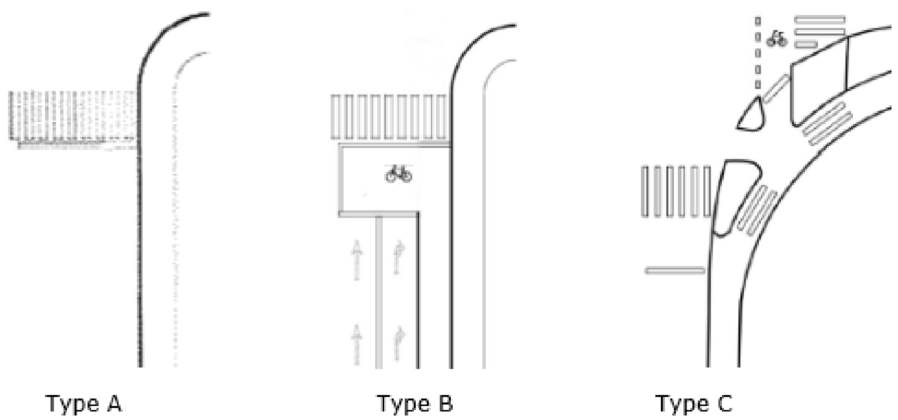

Figure 2: Types of sites for the field observations.

3.2.2 **On-site interviews of cyclists**

Cyclists were interviewed on-site at the three different types of sites (see Figure 2) to explore their general strategy in searching for cues to interpret the intention of the driver of the MV and their behaviour generally in an encounter. At each of the three different types of sites, around 100 cyclists were stopped (after they passed the intersection in straight direction) and interviewed. The interviews were made on working days during 7:00 and 17:30.

3.3 Observational results

The number of observed situations at the different types of sites is presented in Table 4.

Table 4: Number of observed situations at the different types of sites.

Type of site			**All**
Type A	**Type B**	**Type C**	
174	453	789	1416

3.3.1 **Cyclists arriving just after a MV**

At type A sites, 67 cyclists arrived just after a MV, and of those, 35,8 % passed the MV on its right side, see Figure 3. At type B sites, 219 cyclists arrived just after a MV, and of those, 73,5 % passed it on its right side. At type C sites, 212 cyclists arrived just after a MV and of those, 74,5 % passed it on its right side.

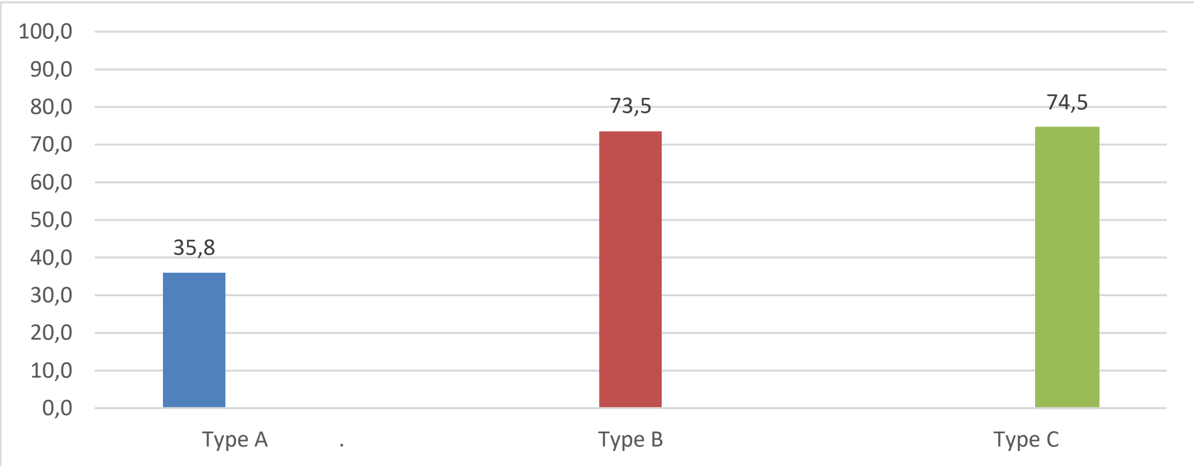

Figure 3: The share of cyclists, who arriving just after a MV passed the MV on its right side.

Regarding motor vehicle type, only at site types B and C could any analyses be made, due to the low number of MV types other than passenger car at type A sites. At B and C type of sites, the share of buses/lorries was 11-13 % of all MVs. At both these site types, there are some indications that cyclists arriving just after a MV pass it to a larger extent if the MV is a passenger car than if it is a heavy vehicle, see Table 5. However, the number of situations involving buses/lorries is too low to make definite conclusions.

Table 5: *Share of cyclists who, when arriving after a MV, passes it on its right side - depending on MV type: car versus bus/lorry at site types B and C.*

Type B sites		Type C sites	
Car (N=197)	**Bus/lorry (N=22)**	**Car (N=196)**	**Bus/lorry (N=16)**
74,1 %	68,2 %	75,0 %	68,8 %

3.3.2 Cyclist's visual search behaviour to foresee the intention of MV

At type A sites, among all cyclists (N=174), 63,2 % did not look at the MV at all, while 28,7 % scanned the MV to foresee its intention, see Figure 4. None of the cyclists looked for eye contact with the driver of the MV.

At type B sites, among all cyclists (N=453), 59,2 % did not look at the MV at all, while 26,0 % scanned the MV to foresee its intention and 12,1 % looked at the turning indicator of the MV. Very few looked for eye contact with the driver of the MV.

At type C sites, among all cyclists (N=789), 53,8 % did not look at the MV at all, while 27,7 % scanned the MV to foresee its intention and 9,1 % looked at the turning indicator of the MV. Only 8,4 % looked for eye contact with the driver of the MV.

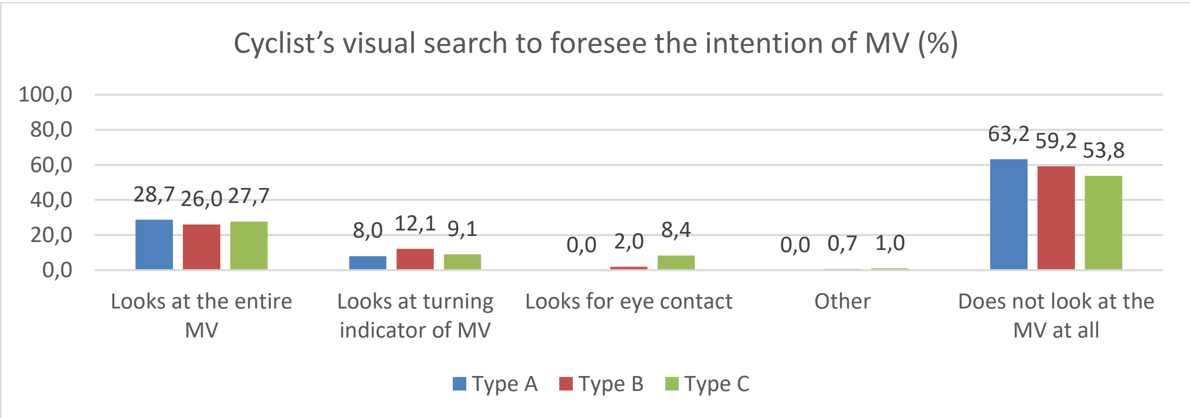

Figure 4: Visual search by cyclists to foresee the intention of MV at the three different types of sites.

Regarding vehicle type, only at site types B and C could any analyses be made, due to the low number of MV types other than passenger car at type A sites. At these types of sites, the share of buses/lorries was 11-13% of all MVs. At site type B, if the MV was a bus/lorry, cyclists looked more at the entire MV, looked less at the turning indictor of the MV, and to a larger extent did not look at the MV at all, if the MV was a car, see Table 6. At site type C, cyclists did not look at the MV at all to a larger extent if the MV was a bus/lorry.

Table 6: Visual search by cyclists to foresee the intention of car versus bus at site types B and C.

Cyclist's visual search	Type B sites		Type C sites	
	Car/van (N=394)	**Bus/lorry (N=59)**	**Car/van (N=705)**	**Bus/lorry (N=84)**
Looks at the entire MV	24,1 %	39,0 %	22,7 %	21,4 %

Looks at turning indicator of MV	12,9 %	6,8 %	16,2 %	8,3 %
Looks for eye contact	2,0 %	1,7 %	5,5 %	2,4 %
Other	0,8 %	0,0 %	0,6 %	0,0 %
Does not look at the MV at all	60,2 %	52,5 %	55,0 %	67,9 %

Among those cyclists who arrived just after a MV and passed it on its right side at type A sites (N=24), 33,3 % did not look at the MV at all, while 54,2 % scanned the MV to foresee its intention and 12,5 % looked at the turning indicator of the MV. None of them looked for eye contact with the driver, see **Error! Reference source not found.**.

At type B sites, among those cyclists who arrived just after a MV and passed it on its right side (N=161), 62,7 % did not look at the MV at all, while 19,3 % scanned the MV to foresee its intention and 15,5 % looked at the turning indicator of the MV. Here also, very few looked for eye contact with the driver of the MV.

At type C sites, among those cyclists who arrived just after a MV and passed it on its right side (N=158), 43,0 % did not look at the MV at all, while 32,3 % scanned the MV to foresee its intention and 13,3 % looked at the turning indicator of the MV. Only 10,1 % looked for eye contact with the driver of the MV.

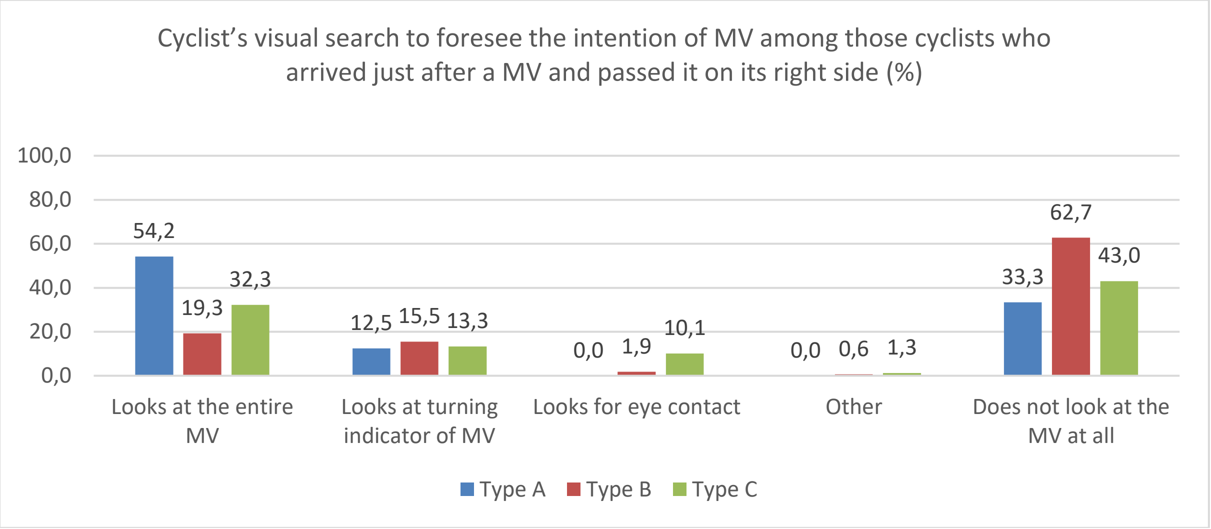

Figure 5: Visual search by those cyclists who arrived just after a MV and passed it on its right side, to foresee the intention of MV.

3.3.3 Who passes the conflict point first?

It was observed whether the MV or the cyclist passed the conflict point first, see Figure 6.

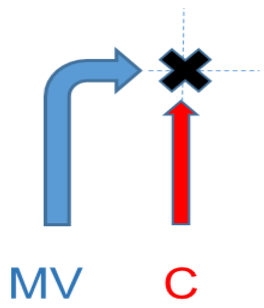

Figure 6: Illustration of the conflict point of passing MV and Cyclist

At type A sites, in 74,7 % of the observed situations (of the total N=174), the cyclist passed the conflict point first, see Figure 7. However, in all 24 cases when the cyclist who arrived just after a MV and passed it on its right side the cyclists passed first the conflict point. One of these cases ended up in a critical situation demanding an evasive action from the MV driver to avoid a collision.

At type B sites, in 87,9 % of the observed situations (of the total N=453), the cyclist passed the conflict point first. However, in all 98 % cases when the cyclist who arrived just after a MV and passed it on its right side the cyclist passed first the conflict point. Fifteen of these cases ended up in a critical situation demanding an evasive action. In fourteen cases, the MV driver made an extreme braking to avoid a collision.

At type C sites, in 86,5 % of the observed situations (of the total N=789), the cyclist passed the conflict point first. However, among those cyclists who arrived just after a MV and passed it on its right side, in 98 % of the cases the cyclists passed first the conflict point. Seven of these cases ended up in a critical situation demanding an evasive action. In six cases, the MV driver made an extreme braking to avoid a collision.

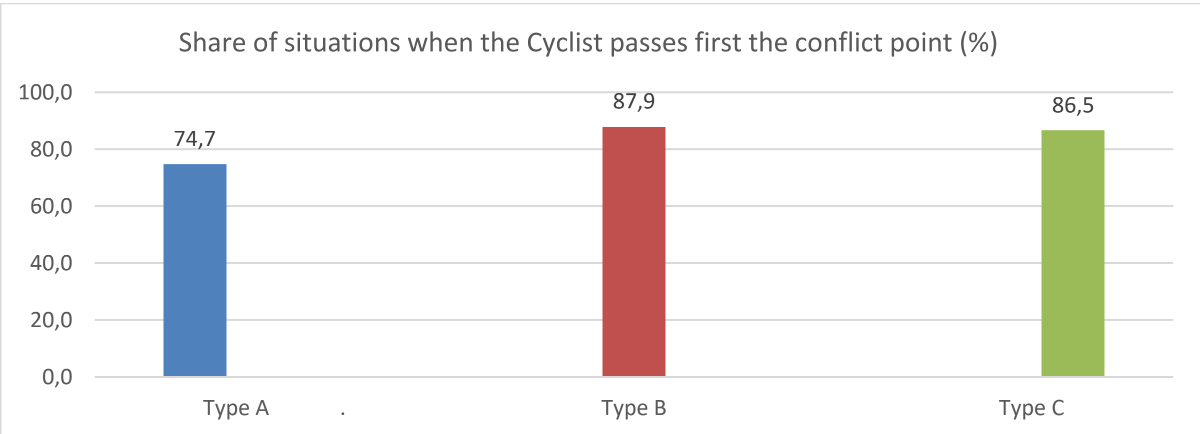

Figure 7: Share of situations when the Cyclist passes the conflict point first.

3.3.4 **Critical situations demanding evasive action**

Totally, of all observed situations, at type A sites 0,011 % ended up in a critical situation demanding evasive action from one or both of the involved road users. At type B sites 0,15 % and at type C sites 0,076 % ended up in a critical situation, see Figure 8.

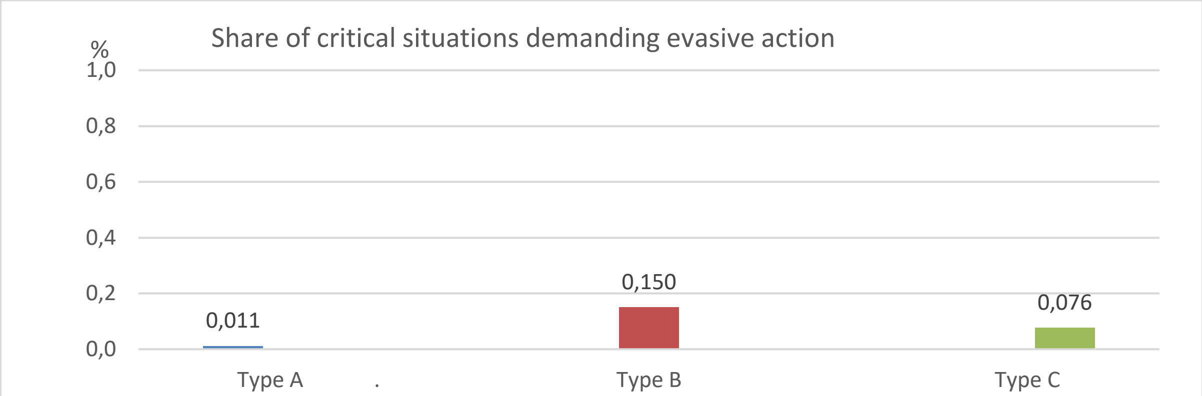

Figure 8: Share of critical situations demanding evasive action from one or both of the involved road users.

The share of critical situations demanding evasive action from the involved road users at type B sites is more than ten times higher than at type A sites and twice as high than at type C sites.

3.3.5 **Summary of observational results**

Totally, at the three different types of sites, 1416 situations were observed. While the great majority, 74 % of cyclists arriving just after a MV passed it on its right side at type B and C sites, at type A sites only 36 % did so. At site types B and C, if the MV was a passenger car then 74-75 % of the cyclists passed it on its right side, while if the MV was a heavy vehicle (bus/lorry) then somewhat less, i.e. 68 % of the cyclists passed it on its right side.

Regarding cyclist’s visual search behaviour to foresee the intention of the MV, the majority (54-63 %) of the cyclists did not look at the MV at all. The next largest group (26–28 %) scanned the MV, and only 8-12 % looked at the turning indicator of the MV. The largest difference between the different sites was that at type C sites, 8 % of the cyclists looked for eye contact with the driver of the MV, while only 0-2 % did it at the other types of sites. Among those cyclists who arrived just after a MV and passed it on its right side, the differences were larger between the various sites. At type A sites, 54 % scanned the MV to foresee its intention and only 33 % did not look at the MV at all, while at type B and C sites the share of cyclists not looking at the MV at all was larger than the share of those looking at the entire MV or its turning indicator.

While at type A sites, the share of situations when the cyclist passed first the conflict point was 75 %, at the other types of sites the cyclist passed the conflict point first in 86-88 % of the situations. The share of critical situations demanding evasive action from the involved road users at type B sites was more than ten times higher than at type A sites and twice as high than at type C sites.

3.4 Interview answers

The number of interviewed cyclists at the different types of sites is presented in Table 7.

Table 7: Number of interviewed cyclists at the different types of sites.

Type of site			All
Type A	Type B	Type C	
63	155	109	327

Regarding the question "What do they usually look at to find out if the motor vehicle on their left side will turn right…" , the largest group of respondents at type A and B sites (43 %, respectively 53 % said they looked at the vehicle's turning indicator, while only a small part did so at type C sites (see Figure 9). Those interviewed at type C sites stated to a much larger extent, that they looked for eye contact with the driver than the respondents at the other two types of sites.

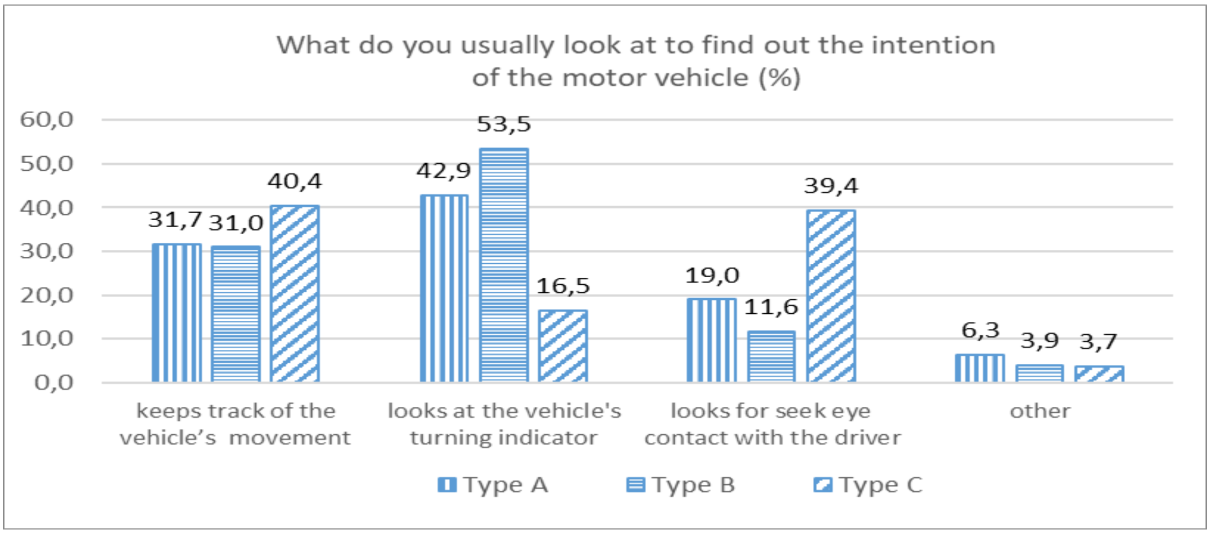

Figure 9: What do the cyclists usually look at to find out if the motor vehicle on their left side will turn right, and if so, it will give the cyclist the right of way at the different types of sites.

Concerning the question "What do you usually do when you perceive that the vehicle on your left will turn right …", the largest group of respondents at type A and C sites (41 %, respectively 43 % said they usually were ready to brake and possibly stop to let the vehicle pass, while only 28 % at type B sites said the same (see Figure 10). Respondents at type C sites said they "did nothing, just continued as usual" to a much smaller extent than the respondents at the other types of sites. Respondents at type A sites said to a much lesser extent that they "only braked if it really became necessary" than the respondents at the other two types of sites.

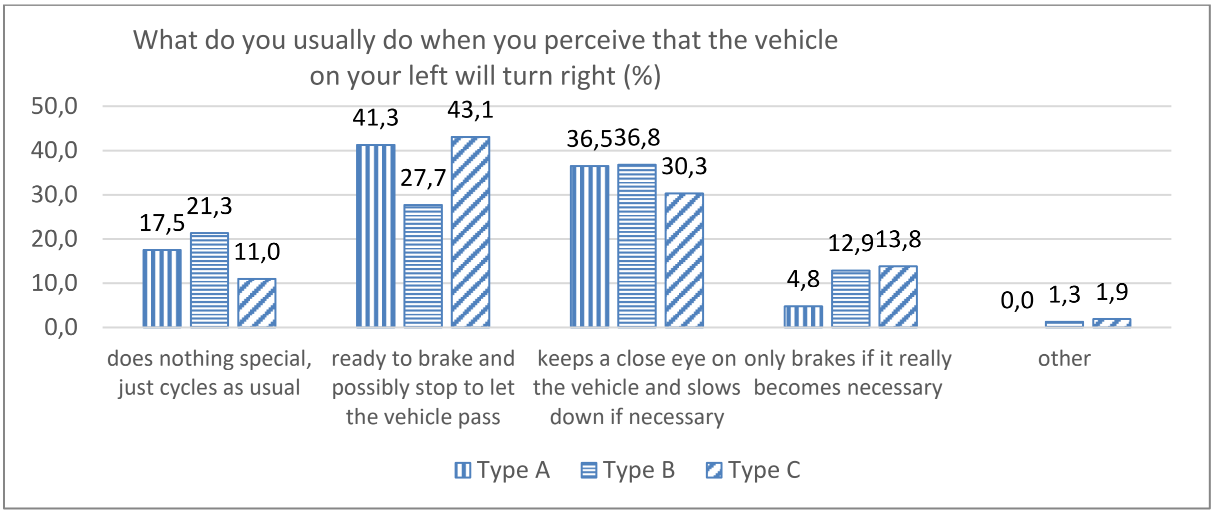

Figure 10: What do cyclists usually do when they perceive that the vehicle on their left will turn right and they judge that they arrive at the point where their trajectories cross each other's at the different types of sites.

Answering the question "… do you usually pass the motor vehicle on its right side", more than half of the respondents answered yes at all three types of sites. However, a larger share (58 %) answered yes at type B sites than at type A sites and an even larger share (63 %) did so at type C sites, see Figure 11.

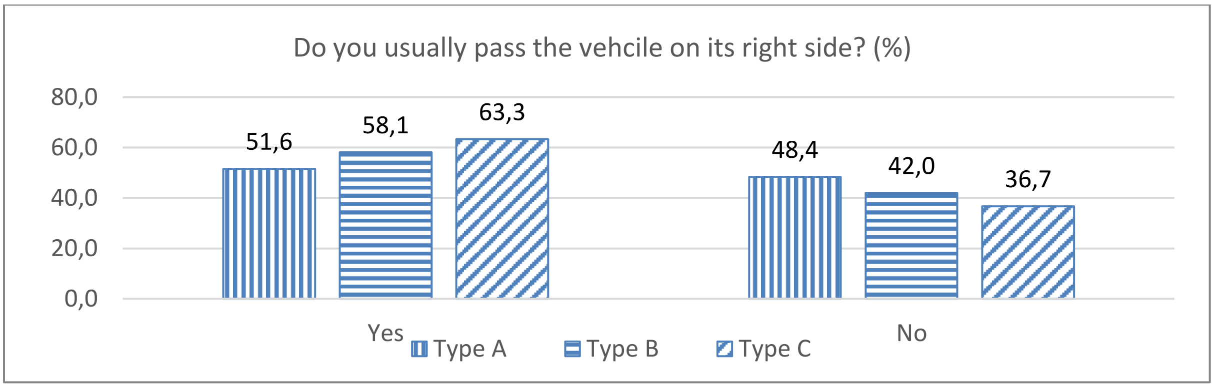

Figure 11: Distribution of answers to the question "Do you usually pass the vehicle on its right side?" at the different types of sites.

Regarding the design of the cycle infrastructure, the majority of the respondents at all three types of sites (59 - 73 %) preferred type C, and only a very small share (1 - 5 %) preferred type A.

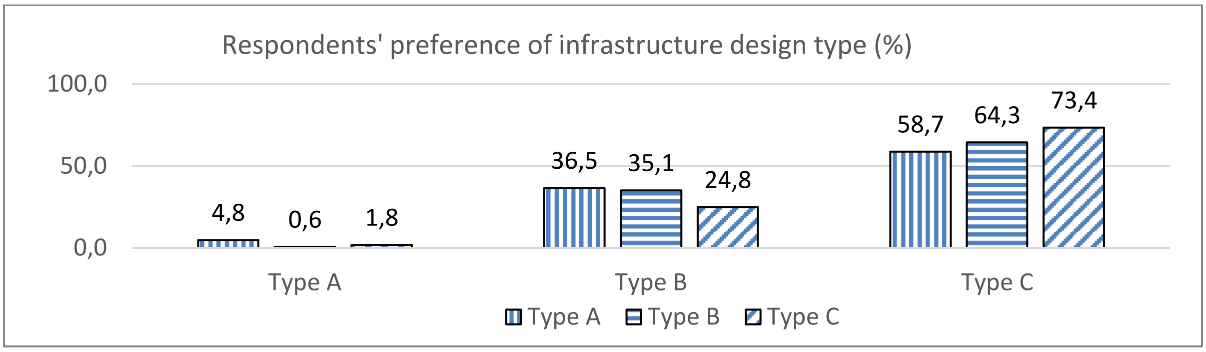

Figure 12: Cyclists' preference of infrastructure design type - answers at the different types of sites.

The main findings from the interview answers can be summarised as follows:

- The largest group of respondents at type A and B sites (43 %, resp. 53 %) said they looked at the vehicle's turning indicator, while only a small part did so at type C sites.
- Respondents at type C sites stated to a much larger extent, that they looked for eye contact with the driver than respondents at the other two types of sites.
- The largest group of respondents at type A and C sites (41 %, respectively 43 %) said they usually were ready to brake and possibly stop to let the vehicle pass, while only 28 % at type B sites said so.
- Respondents at type C sites said they "did nothing, just continued as usual" to a much smaller extent than the respondents at the other types of sites.
- Respondents at type A sites said to a much lesser extent that they "only braked if it really became necessary" than the respondents at the other two types of sites.
- More than half of the respondents answered that they usually passed the motor vehicle on its right side. A larger share (58 %) answered yes at type B sites than at type A sites (52 %) and an even larger share (63 %) did so at type C sites.
- The majority of respondents at all three types of sites (59 - 73 %) preferred type C design, 25 – 36 % preferred type B and only a very small share (1 - 5 %) preferred type A design.

Respondents' comments at type A sites revealed that some cyclists did not like making left turn and they rather chose the pedestrian crossing and walked over there. At type B sites, some respondents said it worked well and it was smooth if everybody acted as expected. Some respondents, on the other hand, were of the opinion that it was unpleasant and unsafe. Some thought that it was messy and that cyclists not following the one-way rule was a problem. At type C sites, some respondents felt that it was insecure due to many cars passing the intersection. Some meant that it was a too small area for all road users to share – "it is difficult when pedestrians and cyclists have to use the same space". Some said that bicycle paths crossing each other was a bad solution: a cyclist waiting for green at the signal can get hit by a cyclist on the crossing cycle path. Some commented that cyclists do not comply with the one-way rule.

4. Bicycle simulator study

4.1 **Overview**

The aim of this work package was to use a controlled environment to examine the typical behaviour among cyclists when approaching an intersection and determine some of the factors that may influence decisions that are made. The following research questions were formulated: At an intersection, with a vehicle waiting for a green light, where do approaching cyclist place themselves depending on 1) Vehicle type (car or truck), 2) Lateral space next to the vehicle, and 3) Presence or absence of cycle lane road markings.

4.2 **Method**

A gender-balanced group of subjects was recruited by advertising on social media. To obtain as homogenous a group as possible, the inclusion criteria was cycling almost daily and age 30-50 years. In total, 33 participants (15 male and 18 female) took part in the study. The participants were assigned to cyclist type categories according to their responses to the question regarding their regular cycling speed compared to others. Three participants responded that they take it easy (category 1), 19 that they cycle as fast as most people (category 2) and 11 that they cycle faster than most people (category 3).

The bicycle simulator at VTI (Bruzelius, 2018) was used, with a scenario with the cyclist approaching an intersection with a red traffic light, where a single motor vehicle, heading in the same direction is waiting at the stop line. Effects of lateral space next to vehicle, presence of cycle lane markings, and of vehicle type (car or truck) waiting at the traffic light on cyclist behaviour were examined by creating combinations of these parameters in 8 different conditions according to Table 8.
In Figure 13, the eight conditions displayed according to the configuration in Table 8 are examples of the conditions with a car and a truck present. A test leader was sitting behind the cyclist throughout the test and asked questions as the participant stopped after each intersection. These were open-ended questions regarding why he or she chose that position to stop, and what it felt like to stop there.

Table 8 Independent variables. Each participant cycled 8 times, covering all combinations.

Condition number		Width	
		Narrow (0,95 m)	Wide (1,35 m)
Cycle lane marking	Car	1	5
	Truck	2	6
No cycle lane marking	Car	3	7
	Truck	4	8

Figure 13 The eight conditions displayed according to the configuration in Table 8

Longitudinally, zero is the stop line at the red light, and start position is approximately 80 meters before the assumed stop line (-80). The following longitudinal positions are defined: a is the rear end of car (-11.4 m), b is the rear end of truck (-16.2 m), c is placed between the end of truck and the start position (-46.3 m). The front of both the car and the truck was at -7.04 m when they were standing still, waiting at the red light. Laterally, zero is the center line (no center line marking is present) and the right roadside is at -4 m. When a 10 cm wide bicycle lane marking was present, it began longitudinally at -16 m, continuing to the intersection, with its lateral center at -3.0 m when the lane was narrow, and at -

2.6 m when it was wide. This geometry is illustrated for the different conditions (1-8) in Figure 14.

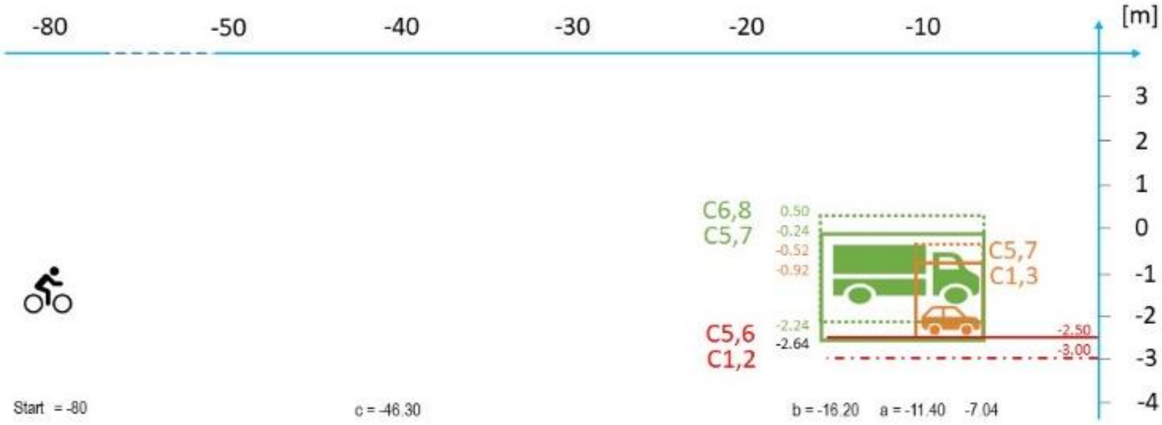

Figure 14 The geometry of the experimental setup, seen from above, with indication of the different conditions 1-8 (indicated as C1-C8)

Upon arrival participants were given oral and written information about the test before giving an informed consent. After that they were asked to fill in a pre-questionnaire including demographics and questions regarding their cycling habits. The participants were then introduced to the bicycle simulator and completed a practice scenario to get used to the simulator. During the test scenario, participants cycled 8 times through variants of an intersection according to the conditions in Table 8. A test leader was sitting behind the cyclist throughout the test and asked questions as the participant stopped after each intersection. These were open-ended questions regarding why he or she chose that position to stop, and what it felt like to stop there. The answers were entered directly into a spreadsheet document to facilitate merging with simulator data. After the test, there was a post-questionnaire with questions regarding the test, self-rated performance and the simulator.

4.3 **Results**

The most significant difference of longitudinal stop position was between the two straight opposites, condition 4 (Narrow-No Cycle Lane Marking- Truck) and condition 5 (Wide- Cycle Lane Marking- Car), see Figure 15. For condition 4, the average stop position was behind the truck, and for condition 5 it was next to the car, which corresponds to the verbal expressions of being visible and avoiding the “dead angle”. This suggests an effect of vehicle type. The choice of stop position of course also affected the speed measures at different points.

The increased caution associated with the presence of a truck is motivated and in line with previous statistics and studies showing that cyclist moving with the traffic is at high risk and especially in a shared lane (Kim et al., 2007) and with large vehicles present. (Ackery, McLellan, & Redelmeier, 2011; Vandenbulcke, Thomas, & Panis, 2014).

Looking at verbal responses, "Truck" has the most negative remarks (41) and condition 4 dominates with 34 negative remarks, whereof "Truck" was most frequent. There were only a few (5) negative remarks for "Car", which strongly supports the influence of vehicle type on the cyclists' decisions about where to place themselves. Positioning oneself either ahead or behind the motor vehicle are strategies mentioned in conjunction with reasons such as obtaining a good overview, providing high visibility, avoiding the "dead angle", and to be prepared for the vehicle turning right without use of indicators, which is one of the most frequent types of bicycle – motor vehicle collisions (Kaplan & Prato, 2013; Kim et al., 2007; Preusser, Leaf, DeBartolo, Blomberg, & Levy, 1982; Räsänen & Summala, 2000).

As described above, at condition 4 (Narrow-No Cycle Lane - Truck), the average longitudinal stop position was behind the truck, Figure 15. This was significantly farther behind the stop line compared to for condition 5-7. The latter all have the wider lateral space in common, which shows the effect of this factor.

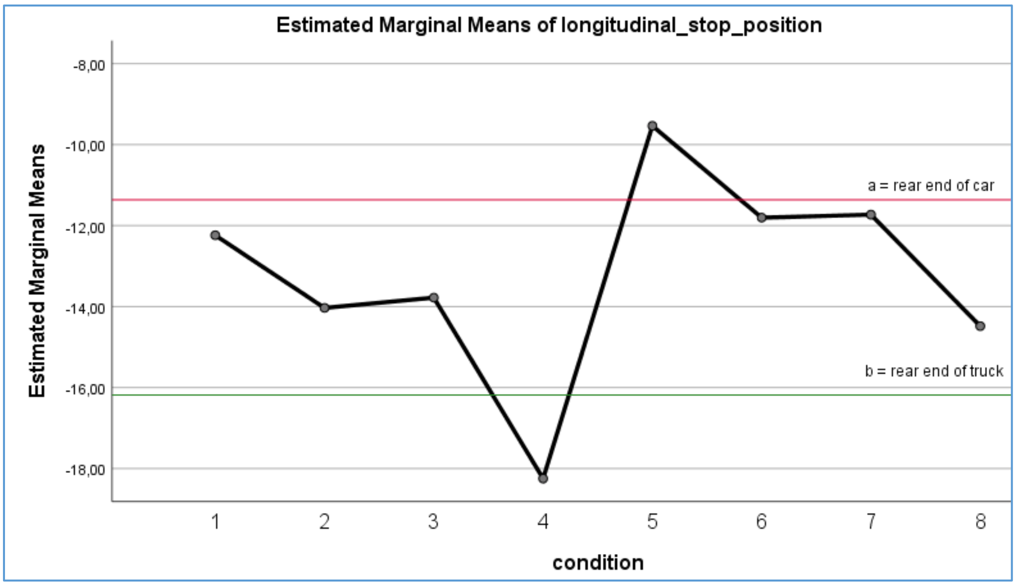

Figure 15 Estimated Marginal means of longitudinal stop position for each condition (1-8). Condition 4 (Narrow-No Lane-Truck) made participants stop farthest from the stop line and condition 5 (Wide-Lane-Car) closest.

In condition 5 (Wide- Cycle Lane - Car), participants longitudinal stop position was significantly closer to the stop line compared to all other conditions but 6 (Wide - Cycle Lane – Truck). This also demonstrates the influence of width, which is the common factor of condition 5 and 6. Further support is found amongst the verbal responses. Space constraint was the largest category of the negative remarks (37) and naturally these and mention of the fence (10) are more common in the narrow conditions (1-4). Regarding positive remarks, space and lane width (37) was the second largest category after lane markings with the bulk (32) mentions in the wide conditions (5-8). Again, this cautiousness is motivated and supported by previous literature (Ackery et al., 2011; Kim et al., 2007; Vandenbulcke et al., 2014).

Looking at the longitudinal stop position, for the conditions without road markings (3,4,7,8), the participants consequently stopped farther behind the stopping line, compared to their corresponding conditions with road marking (1,2,5,6). Even if only statistically significant at the wider lateral space and when the vehicle was a car, this consistent pattern suggests an effect of cycle lane road marking. This is supported by the verbal responses, where the dominant positive remark was relating to the presence of lane markings (56). The largest number of positive remarks was received by condition 5 (25), followed by condition 1 (19) and they both have lane markings. Further support is found amongst the negative remarks, where “No marking” was the third most common (23). This result corresponds to the previous study by Heesch and colleagues (2012), concluding that most cyclist prefer designed bicycle lanes or, even better, bicycle-only paths.

4.4 Cyclist type

Effects of cyclist type was apparent for lateral position measures, with compared to the other categories, cyclist category 1 (take it easy) stopping more to the left in most conditions. See Figure 16.

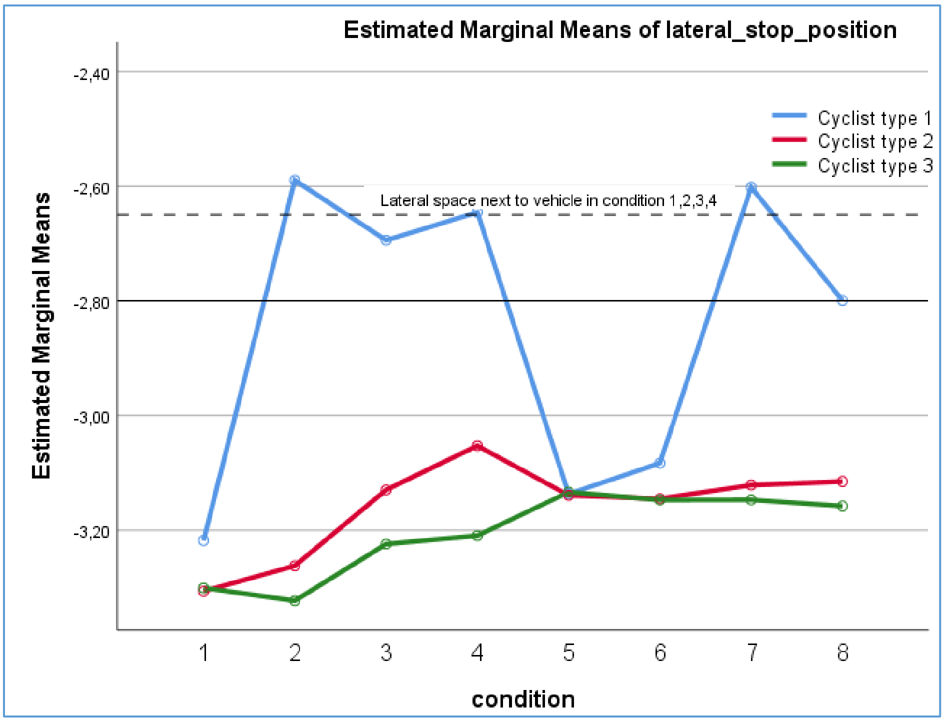

Figure 16 Estimated marginal means for lateral stop position displayed by category. Cyclist type 1 (blue line) stops significantly more to the left compared to cyclist type 2 (red line) and 3 (green line).

Also, participants in category 3 (faster than most people), compared to participants in category 1, stop more to the right. The effect of cyclist type has been shown in previous studies conducted at VTI (K. Kircher, Nygårdhs, Ihlström, & Ahlstrom, 2017; Katja Kircher, Ihlström, Nygårdhs, & Ahlstrom, 2018) and this is an important factor to include when designing an infrastructure. As can be expected, there was an effect of cyclist type on cycling speed, since participants were categorized after self-rated cycling speed compared to others.

5. Discussion

The present project has been able to identify important issues of relevance concerning interaction between cyclists and motor vehicles. This was achieved by through literature reviews, analyses of historic accident information, field observations and a bicycle simulator study. Important knowledge for improving the interaction between cyclists and motor vehicles at intersections was formed. The findings confirm that the way the road and cycling infrastructures at intersections is designed contributes to how cyclists and motor vehicles interact at points of conflict.

Findings from the literature study revealed that how road and cycling infrastructures are designed at intersections contributes to how road users interact at points of conflict. Analyses of the Swedish accident database revealed that most of the accidents between cyclists and motor vehicles at intersections occurred in broad daylight and at good weather condition, that these accidents mainly involved passenger cars, that cyclist accidents with buses constitutes the highest injury severity, and that one in every twenty-cyclist accident with trucks resulted in a cyclist fatality.

The simulator study revealed an increased caution associated with the presence of a truck and that positioning oneself either ahead or behind the motor vehicle are strategies to obtain a good overview, providing high visibility, avoiding the "dead angle", and to be prepared for the vehicle turning right without use of indicators.

Placing cyclists and motor vehicle drivers close (where they are visible to one another) at intersection areas was found to produce positive results according to the findings from the literature review and the observational study. This was found to increase the level of presence awareness for both road users. Though cyclists were found to feel more uncomfortable with the solution as they feel unsafe and more exposed (majority of the cyclists in the observational study preferred separated cycling infrastructure), they tend to be more careful and attentive in this traffic situation. Conversion of separated cycling infrastructure to a cycling lane 20 – 30m before an intersection (i.e. one directional lane) was found in the literature review to enhance interaction at intersections, as motor vehicle drivers will only have to expect cyclists from one direction. This is also assumed to make detection easier by object detector sensors in motor vehicles, for better interaction. This solution also has the potential to prevent cyclists from entering the intersection from the wrong directions as observed in the observational study.

Confidence level among cyclists was found to vary, which affects their interaction with motor vehicles. The level of confidence of random cyclists in traffic is difficult for random motor vehicle drivers to perceive or know as different cyclists behaved differently depending on their cycling confidence in traffic, which eventually affects their interaction outcome. In the simulator study, lack of space was revealed as a large factor for feelings of discomfort, which was also reflected in the stopping position being closer to the stop line. Results from the simulator study also showed that lane markings improved the feelings of comfort even more.

The majority of the interviewed cyclists said that when arriving at an intersection just after a motor vehicle they usually pass it on its right side. This was seen in observations on sites with cycle lane or cycle path but not on sites with mixed traffic. If the motor vehicle was a heavy vehicle (bus or lorry), somewhat fewer cyclists passed it on its right side. At sites with mixed traffic (no cycle facility), compared to with cycle lane or cycle path, the cyclists' scanning behavior was more complete. At sites with cycle path, the cyclists looked for eye contact with the driver of the motor vehicle to a much larger extent than cyclists at the other two types of sites. Cyclists at sites with mixed traffic (no cycle facility) were more active in their visual search behaviour than cyclists at the other two types of sites. Also, those cyclists who passed the motor vehicle on its right side were more active in their visual search behaviour than those who did not pass the motor vehicle. The share of critical situations indicates that sites with mixed traffic (no cycle facility) is the safest solution and cycle lane solution is the least safe one.

The age, gender and the city of residence of the vehicle driver were found to affect how drivers perceive and interact with cyclists in traffic, while the driver's education level was found to have no effect on how they interact with cyclists. Other factors found to affect interaction between motor vehicle drivers and cyclists are driving frequency (which was found to affect near-miss encounters), cycling frequency among motor vehicle drivers (which was found to produce improve respect for cyclists in traffic), knowledge of traffic rules (which was found to affect perception of cyclists as well as involvement in accidents and near-miss incidents with cyclists), traffic regulation (which was found to affect the decision whether or not to yield) and motor vehicle type (with the type "bus" found to be less researched yet with more drivers having hard time with sight obstruction and longer stopping distance).

The survey on cyclist behaviour showed that cyclists are a very heterogenous group and that there is not one perfect solution suitable for all cyclists. This is supported by previous literature and also by the simulator study. The cyclist categories, which from previous studies are considered as more relevant than gender and age, were used in both the survey and the simulator study. In the simulator study, cyclists who define themselves as slower than average, show a more cautious behaviour, with a slower speed and a stop position more to the left.

6. Conclusions

Based on the findings of the various studies of the project, the following conclusions can be drawn;

1. The Swedish traffic accident database (STRADA) does not include turning movements of the road users, which is an important detail for accident analyses.
2. Cyclist behaviour at intersections, as examined in the cycle simulator, is associated with vehicle type, infrastructure (lane width and lane marking) and cyclist type.
3. Cyclist accidents with "heavy vehicles" produced the highest severity among cyclists due to vehicle weight which affects collision impact. The design of heavy vehicles makes cyclist visibility difficult for the drivers and for cyclists it hinders eye contact with the driver.
4. There are few scientific studies available on "bus" as a vehicle type, though this vehicle type was found to have caused most injury severity among cyclists.
5. Separated cycling infrastructure at intersections may make cyclists feel safer and affect their willingness to cycle. It does not however necessarily translate to safer interaction with motor vehicles. Intersection infrastructure that makes both cyclists and motor vehicle drivers visible to each other produce better and safer interactions, even if it makes cyclists feel less safe.
6. Intersection infrastructure that only allows cycling in one direction should be encouraged. This reduces the complexity for motor vehicle drivers to check for incoming out outgoing cyclist traffic and other vehicles. The infrastructure design should encourage cyclists to approach the intersection on the "right side "of the carriage way
7. One-way cycle traffic also could reduce "Look-but-failed-to-see" errors by motor vehicle drivers.
8. Vehicle driver demography (their age, gender and residency) is a major factor affecting interaction with cyclists in traffic. Elderly motor vehicle drivers are more tolerant and respectful of cyclists than younger motor vehicle drivers. Female motor vehicle drivers may be more irritated by cyclists but are less aggressive towards them, as compared to their male counterparts. Motor vehicle drivers in large cities do not perceive cyclists well in traffic and thus not tolerant of them, compared to their counterparts in smaller cities. Variation in the level of education of vehicle drivers does not affect their behaviour towards cyclists in traffic as a singular factor.
9. The findings also have relevance for the development of interaction strategy of automated vehicles since, especially at sites with cycle path, where the cyclists look for eye contact with the driver of the motor vehicle and this "contact channel" has to be replaced in a driverless car.

7. Recommendations

Based on the conclusions stated above, the following are recommendations are made;

1. Improve the available data in STRADA regarding vehicle trajectory in an accident, as this will provide more information on accident scenarios, which will enhance data analyses.
2. More scientific studies are recommended regarding safety of vulnerable road users during interaction with buses as a vehicle type, especially those used for public transport.
3. Further simulator studies should be made on "Looked-but-failed-to-see" errors by motor vehicle drivers, when converting two-directional cycle infrastructure to one-directional before an intersection.
4. The compliance with on-way traffic rule and traffic signal regulations by cyclists should be strictly enforced.
5. Research and development efforts regarding interaction strategy of automated vehicles with cyclists are needed; the cyclists' need for eye contact with the driver of the motor vehicle has to be considered.

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