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## Safety at cycle crossings

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Svensson, Åse; Pauna-Gren, Jutta

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LUND UNIVERSITY

PO Box 117  
221 00 Lund  
+46 46-222 00 00

**Safety at cycle crossings – the relationship between motor vehicle drivers' yielding behaviour and cyclists' traffic safety**

Åse Svensson, Transport and Roads, Lund University, Lund, Sweden [ase.svensson@tft.lth.se](mailto:ase.svensson@tft.lth.se)

Jutta Pauna-Gren, Trafikverket, Sweden [Jutta.Pauna-Gren@trafikverket.se](mailto:Jutta.Pauna-Gren@trafikverket.se)

## **Abstract**

With a high share of motor vehicles yielding to crossing cyclists, cyclists' waiting time decreases and their level of service increases. The main aim of this paper is to study how this propensity to yield is connected to the traffic safety situation for cyclists at cycle crossings in a Swedish context. In a previous study, motor vehicle drivers' yielding behaviour was studied at 65 cycle crossings with different signage. In the present study, seven of these crossings were selected and yielding data at these locations were complemented with accident data, studies of traffic conflicts, and cycle flow. In addition, a questionnaire on road users' perceptions of yielding rules at cycle crossings was distributed. The analyses showed that the conflict frequency per crossing cyclist decreased with increased propensity to give way i.e. cyclists' traffic safety increases with motor vehicle drivers' propensity to yield. The analyses further showed that motor vehicles drivers' propensity to give way increased with increased cycle flow and that the conflict frequency per crossing cyclist decreased with increased cycle flow. A conclusion from the analysis is that signage alone at cycle crossings does not likely affect the traffic safety situation at the location, but it is rather the combination of signage, type of location, cycle flow, yielding behaviour, and motor vehicle speed, where some factors most likely covary, that is important. An interesting indication that should be researched further is that the perceived unclear rules at cycle crossings might contribute to an increased propensity to yield and thus an increase in traffic safety.

**Keywords:** cycle; crossing; yielding; flow; safety; conflicts

## **1 Introduction**

The present study aims at analysing the relationship between motorists' yielding behaviour and cyclists' safety at cycle crossing and the possible influence of road users' perceptions of the yielding rules at cycle crossings.

### **1.1 The importance of safety and other qualities**

Safety is of great concern when planning for cyclists. Among road users being treated in Swedish hospitals for at least 24 hours, cyclists are now the biggest group; around 2900 cyclists per year, compared to the second largest group, car drivers and passengers, with around 2100 per year (Trafikanalys, 2014). Furthermore, 45% of those who are seriously injured and 40% of those who are

very seriously injured in traffic are cyclists (Trafikanalys, 2014). According to hospital data, 80% of the injured cyclists were involved in solo accidents. Nevertheless, according to police and hospital data, collisions between cyclists and motor vehicles are still the primary cause for cyclists' fatal injuries (Niska and Eriksson, 2013; CROW, 2007). About half of these injuries occur at crossing accidents (Niska and Eriksson, 2013) with a fairly equal share between cycle crossings and other types of intersections (Niska et al., 2009; CROW, 2007).

A Swedish enquiry was appointed by the Swedish government in 2009 with the assignment to "increase cycling and make cycling safer. It was found that it is important to increase cyclists' accessibility and level of service in order to increase cycling, but cycling must be safe and must be perceived as being safe and secure (SOU 2012:70). This study pointed to the importance of promoting designs of the traffic environment that, if possible, maximize all these qualities. The same statement about other qualities being important when planning for cyclists is found in CROW (2007), but this Dutch cycle design manual clearly states that these other qualities should not come at the expense of safety. According to CROW (2007), these other requirements are for instance "directness in time" and "comfort", two concepts dealing with preventing delays in the cycle network and at intersections by enabling cyclists to cross without stopping and giving priority to cycle flows.

Lindelöw presented a literature survey in 2009 on factors affecting the level of cycling. The studied publications were assessed with regard to validity, trustworthiness, and statistical significance, and the review concluded that the most important factors affecting the level of cycling were – in addition to habit and external factors (e.g. climate, weather conditions, time of day, and errand) – travel-specific factors such as distance, travel time, safety, perceived risk, security), and maintenance (Lindelöw, 2009). Yang et al (2015) point at the importance of short delays for cyclists by concluding that cyclists' likelihood of riding through a red light depends on waiting time and cyclists' individual speeds. Brosseau et al. (2013) presents corresponding results for pedestrians and waiting time and shows that short delays are just as important for pedestrians and cyclist as for car traffic. Börjesson and Eliasson (2012) show that cyclists have high values of travel time savings and high valuation of improved cycling speeds and comfort.

## 1.2 Level of service and safety

To the author's knowledge there is limited research on the relationship between cyclists' level of service and safety. As referred to above it is clearly pointed out in the Dutch cycle design manual that "these other qualities" (as for instance improved level of service) should not come at the expense of safety (CROW, 2007). Also above, Yang et al (2015) on the other hand highlight the problem of long delays increasing the propensity to cycle against red light i.e. causing risky behaviour. A study of 65 cycle crossings in Sweden (Pauna et al., 2009) showed that the share of motor vehicle drivers yielding to crossing cyclists is rather high irrespective of the type of cycle crossing or which party is obliged to yield. On average, 58% of motor vehicle drivers yielded to crossing cyclists. But depending on location, signing, etc. the propensity to yield at a specific cycle crossing in the data set varied between 23 and 97%. As analyses of safety were not part of this study, it is not possible to relate yielding rates i.e. cyclists' level of service, to traffic safety.

Perhaps available research in an adjacent area of research, pedestrian crossings, may shed some light into the issue. In year 2000 obligatory yielding to pedestrians who are on or entering pedestrian

crossings (zebra crossings) was introduced in Sweden with the aim of increasing pedestrians' level of service. Before- after-studies showed that pedestrians' level-of-service had increased (waiting time had decreased and motor vehicle drivers' propensity to yield had increased) but the number of pedestrian injuries had increased (Thulin and Obrenovic, 2001; Thulin, 2007). Within brackets it might be worth mentioning that still today, pedestrians' crossing at marked pedestrian crossings is a safety problem (e.g. Eriksson et al., 2014). To summarize, in the case of pedestrians it seems as if increased level of service not necessarily is connected to increased safety. The question that unavoidably emerges is possible implications for cyclists on cycle crossings; how is the relation here regarding cyclists' level of service (car drivers' propensity to yield) and cyclists' safety?

### **1.3 The aspects of uncertainty, yielding rules and safety**

Again with reference to the results of changed yielding rules at pedestrian crossings, there is an ongoing discussion on whether the increased risks at pedestrian crossings after changed yielding rules might be due to changes in pedestrian behaviour. Could it be that pedestrians – now with a presumably stronger feeling of priority – tend to enter pedestrian crossings without looking properly? Such psychological effects due to “uncertainty” and “feeling of priority” have been indicated in other studies. Kaparias et al. (2012) presented a study indicating lower speeds at shared space solutions, and their survey data showed that the car drivers' feeling of uncertainty enhanced their alertness and led to lower speeds. Sakshaug et al. (2010) conducted a study comparing integrated and separated designs of roundabouts regarding cyclists' passages, and they showed that uncertainty at separated roundabouts regarding yielding rules might bring about more cautious behaviour resulting in increased propensity for car drivers to yield and thus to increased safety. Svensson (1998) and Svensson and Hydén (2006) compared signalised and non-signalised intersections. They showed that increased safety at the non-signalised intersections might be due to the feeling of having to interact, i.e. a feeling of uncertainty regarding other road users' propensity to yield, and that decreased safety at signalised intersections might be due to the phenomenon of delegating responsibility to the signal, i.e. a reduced feeling of uncertainty about who is to yield when “I have a green light”. Again, what importance might aspects of uncertainty based on road users' perceptions of the yielding rules at cycle crossings, have when it comes to yielding and safety at cycle crossings?

## **2 Aim and research questions**

To increase cycling, i.e. to make cycling an attractive transport mode, cycling must be safe and must be perceived as safe. It must also be acknowledged, however, that qualities such as comfort, efficiency, and reduced delay / waiting times – qualities that so far have been very much reserved as values and preferences of drivers of motorised vehicles – are also valid for cyclists. Based on the results above, it might be concluded that motor vehicle drivers' increased propensity to give way might improve safety, but it might also be the other way around as the case with the changed yielding rules at pedestrian crossings, i.e. safety might decrease. Yet another indication from the studies above is that uncertainty about yielding rules might increase safety, i.e. that a feeling of priority is not good for traffic safety. Thus, this paper – which studies safety at cycle crossings in

connection to motor vehicle drivers' yielding behaviour – seeks to answer the following research questions:

- Is it always conducive to good traffic safety for cyclists if motor vehicle drivers' propensity to give way is high?
- How does the propensity to yield affect safety and how might the signage, road markings, and cycle flow influence yielding and safety?
- How might road users' expectations of yielding contribute to explaining yielding behaviour and safety?

The overall aim of this paper is to study how the propensity to yield is connected to the traffic safety situation for cyclists at cycle crossings and the influence of signage and road users' perceptions of the yielding rules.

### 3 Introduction to the study

In a previous study (Pauna et al., 2009), referred to earlier and which is the starting point for this study, 65 cyclist crossings were studied regarding motor vehicle drivers' propensity to give way to crossing cyclists and the influence of vehicles' approaching speeds. The studied cycle crossings were all non-signalised. None of the crossings were raised or marked differently from the road surface in terms of colour or material. They did, however, differ regarding the presence of signage in the road and the presence and location of give-way signposts. Please note that when give-way signposts are present they are facing the motor vehicle drivers and not the cyclists on the cycle crossing. Please also note that this study examines the situation at cycle crossings before the change of regulations in September 2014. Altogether, six different types of cycle crossings were identified, all representing the most common designs of cycle crossings in Sweden:

- Type 1: Cycle crossing with give-way signpost located before the cycle crossing and presence of signage in the road indicating a cycle crossing,
- Type 2: Cycle crossing with give-way signpost located after the cycle crossing and presence of signage in the road indicating a cycle crossing,
- Type 3: Cycle crossing with no give-way signpost but with presence of signage in the road indicating a cycle crossing,
- Type 4: Cycle crossing with no give-way signpost and no presence of signage in the road indicating a cycle crossing,
- Type 5: Cycle crossing with give-way signpost located before the cycle crossing but without presence of signage in the road indicating a cycle crossing,
- Type 6: Cycle crossing with give-way signpost located after the cycle crossing but without presence of signage in the road indicating a cycle crossing.

The results showed that the propensity to yield was somewhat higher with the give-way signpost located before (73%) rather than after the crossing (71%), and crossings with road markings indicating a crossing had higher yielding shares (66%) compared to those without road markings (52%). The propensity to yield was low at locations without any give-way signposts at all (46%), and was at its lowest when road markings were also missing (42%). The results further showed that the share of motor vehicle drivers yielding to crossing cyclists is rather high irrespective of the type of cycle crossing or which party is obliged to yield. On average, 58% of motor vehicle drivers yielded to

crossing cyclists. This is a very high percentage especially in light of the fact that the cyclist is always obliged to yield to motor vehicle drivers even if there are a few situations where the cyclist and the motor vehicle driver have a joint responsibility. In addition, the results showed that the propensity to yield decreased with higher speeds, which is in line with previous research (Jonsson and Hydén, 2007).

### 3.1 Study sites

From the 65 sites seven sites were selected for safety studies in this paper (Figure 1-4). Thus, all cycle crossings are level with the road surface, non-signalised, not marked differently from the road surface in terms of colour or material, and with cyclists traveling in both directions. The initial intention was to cover the six different types of cycle crossings with regard to the presence or absence and the location of signage in the road and give-way signposts. In further discussions with the Swedish Transport Agency (Transportstyrelsen), it was, however, decided to prioritize sites with a design and signage where the yielding rules might be difficult for road users to interpret. It was further of importance to include sites with different levels of yielding proportions. Because it was decided to assess traffic safety based on conflict studies (this choice of method is discussed below) and to be able to conduct these within existing time and budget restrictions, another criterion for the selection of sites was a reasonably high flow of traffic. These different preconditions and criteria led to a situation where the sites selected to represent locations with low levels of yielding were somewhat skewed regarding type of cycle crossing. Locations with low levels of yielding and with reasonably high flows of traffic are all located on road sections or at intersections with the cyclists crossing the main road. Almost all other sites where the cyclists cross the road intersecting the main road have a level of yielding that is around the average or higher irrespective of type of intersection (3-arm, 4-arm, or roundabout). There are a few exceptions among these “other” sites with low levels of yielding, but here the results were uncertain due to small numbers of observations. These sites were therefore excluded from the final selection because they would require unreasonably long observation periods when conducting conflict studies. Based on all these different considerations, the following seven sites were selected for safety studies in this paper.

Two of the sites, Eskilstuna and Svanevägen in Lund, are Type 1 sites, i.e. the yielding sign is located in front of the marked cycle crossing (Figure 1). These sites are henceforth referred to as Type 1(E) and Type 1(S). Type 1(E) is located at a roundabout. Type 1(S) is located at a 3-arm intersection with give way regulation and the cycle crossing crosses the road intersecting the main road.

Two of the sites, Växjö and Baravägen in Lund, are Type 2 sites, i.e. the yielding sign is located after the marked cycle crossing (Figure 2). These sites are henceforth referred to as Type 2(Vx) and Type 2(B). Type 2(Vx) is located at a roundabout. Type 2(B) is located at a 3-arm intersection with give way regulation and the cycle crossing crosses the road intersecting the main road.

Two of the sites, Kristianstad and Västerås, are Type 3 sites i.e. there is no yielding sign at all at the marked cycle crossing (Figure 3). These sites are henceforth referred to as Type 3(K) and Type 3(Vs). Type 3(K) is located at a 4-arm intersection with give way regulation but the cycle crossing, unlike Type 1 and Type 2 above, crosses the main road. Type 3(Vs) is located at a 3-arm intersection with give way regulation and also here the cycle crossing crosses the main road.



The seventh and last site, Gävle, is a Type 6 site, i.e. the yielding sign is located after the unmarked cycle crossing (Figure 4). This site is henceforth referred to as Type 6(G). Type 6(G) is located at a roundabout.



Figure 1: Type 1 site.



Figure 2: Type 2 site.



Figure 3: Type 3 site.



Figure 4: Type 6 site.

### 3.2 Methods

**Motorists' yielding behaviour:** Here an interaction is defined as a situation at a cycle crossing where a motor vehicle driver (here most often a car driver) and a cyclist are moving on a collision course and one of the road users must adapt its speed in order to avoid a collision. The road user that lets the other road user cross first is the yielding party. Throughout this paper, *share of yielding* or *yielding propensity* is always reported in terms of share of *motorists* yielding during interactions. The observations were conducted at site by trained observers. Each site was studied for six hours during a weekday divided into two hours in the morning (07.30–09.30), two hours in the middle of the day (11.30–13.30), and two hours in the late afternoon/evening (15.00–17.00). For each interaction the observer registered in a protocol the process of the interaction, if it was the motor vehicle driver or the cyclist that yielded, etc. in this way could the share of motor vehicle drivers yielding be calculated. The total number of interactions exceeded 100 at all selected sites. The data on yielding (Table 1) was extracted from the results in Pauna et al. (2009).

Table 1: Number of observations (interactions) and share of motor vehicle drivers yielding at the different sites (Pauna et al., 2009).

Site	Number of observations (interactions)	Share of motor vehicle drivers yielding (%)
Type 1(S)	162	81
Type 1(E)	100	58
Type 2(B)	106	60
Type 2(Vx)	129	86
Type 3(K)	135	30
Type 3(Vs)	118	28
Type 6(G)	132	52

**Safety – The Swedish Traffic Conflicts Technique:** Cyclists’ risks at the seven sites were assessed based on the Swedish Traffic Conflicts Technique (TCT) (Hydén, 1987). A conflict is defined as “an observable situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged.” The severity of a conflict is based on two variables: Time-to-Accident (TA) and Conflicting Speed (CS). TA is the time from the start of the evasive action until the collision would have occurred if the road users had continued with unchanged speeds and directions. CS is the speed of the vehicle taking evasive action at the moment just before the evasive action starts. Observers were trained for a week, and conflict studies were then conducted at the seven sites. The aim was to do 5 days of conflict registrations at each site with 6 hours of registration per day for a total of 30 hours. Due to bad weather, this was reduced to 28 hours at Type 1(E) and Type 6(G) and to 22 hours at Type 2(B). In the analysis, only the serious conflicts were included because these have been shown to have a correlation with injury accidents (Hydén, 1987).

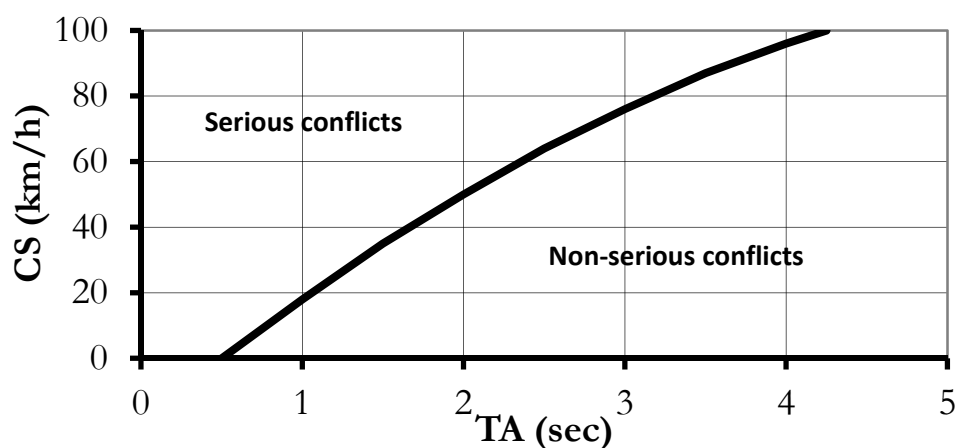


Figure 5: Definition of serious conflicts according to the Swedish TCT (Hydén, 1987).



**Safety – Data from STRADA:** The number of accidents in which a cyclist was injured were extracted from the STRADA (Swedish Traffic Accident Data Acquisition) database (Transportstyrelsen, 2015), which includes data from both the police and hospital admittance. The period was seven years of accident data.

**Cycle flow** – Because we know from other research (see Ekman, 1996; Jacobsen, 2003; Elvik, 2009; Kröyer, 2015) that the magnitude of cycle flow has an impact on safety, i.e. the safety in numbers, cycle flow was collected at each site. In connection to each hour of conflict registration, cycle flow was counted for 5 minutes. These counts were then summed up to represent an average number of cyclists per hour for the site.

**Speed** – Because the speed of motorists approaching a cycle crossing affects motorists' yielding behaviour (Jonsson and Hydén, 2007; Pauna et al., 2009), speed was measured in connection to the conflict studies. At each site, the speed was measured for 100 "free" motor vehicles when they were approximately 25 meters in front of the cycle crossing. A free motor vehicle either moves alone or is the leading vehicle in a queue or moves in a line of vehicles with at least a 3 second time gap to the vehicle in front. The reason for only choosing "free" moving vehicles is that these drivers more likely have decided their speed themselves as compared to drivers who have to adjust their speeds to the speed of vehicles in front of them. Another reason is the safety aspect – a study by Pasanen (1993) showed that all recorded pedestrian accidents involved a free-moving vehicle even though only 40% of the reference traffic consisted of free vehicles.

**Road users' perception of yielding rules** – Because road users' expectations and perceptions of yielding rules might influence their feelings of "uncertainty" or "having the right of way" and thus yielding propensity and safety (Kaparias et al., 2012; Sakshaug et al., 2010; Svensson, 1998; Svensson and Hydén, 2006), a questionnaire on this theme was developed. Because the aim was merely to get an indication of this concept, the survey was not very extensive. The questionnaire contained questions on how the respondent experiences the yielding rules at cycle crossings and questions regarding possible difficulties in understanding who is to yield. The questionnaire was distributed to 347 adult persons at car parks and cycle parks in the cities of Lund and Växjö, with roughly equal distribution to drivers and cyclists. Respondents were asked to send back the questionnaire in a pre-paid response envelope. A total of 160 complete questionnaires were sent back for a response rate of 46%. This was a small study and a small sample, but nevertheless no age group was overrepresented, there was about the same proportion of men and women, about 90% had a driving license, about 42% of the respondents drove a car at least several times a week, and 70% rode a bicycle as often.

## 4 Results

Results regarding cycle flow, motor vehicle drivers' approach speeds (mean speed and 85-perc speed), STRADA recorded accidents for 7 years, motor vehicle drivers' propensity to yield during interactions, the number of serious conflicts, and the number of serious conflicts per crossing cyclist for the seven sites are presented in Table 2. Due to the small number of STRADA accidents at the sites and the random variation inherent in small numbers, the safety analysis was based solely on the conflict data.

Table 2: Results at the different sites.

Site	Location	Cycle flow (cyclists /hour)	Mean speed (km/h)	85-perc speed (km/h)	Cycle injury accidents on crossing <sup>x</sup>	Share of motorists yielding (%)	Serious conflicts / hour	Serious conflicts / cyclist and hour
Type 1(E)	Roundabout	74	33	38	0	58	0.61	$8.2 \times 10^{-3}$
Type 1(S)	3-arm intersection *	143	31	36	5	81	0.67	$4.7 \times 10^{-3}$
Type 2(B)	3-arm intersection *	71	38	44	1	60	0.55	$7.7 \times 10^{-3}$
Type 2(Vx)	Roundabout	112	32	36	2	86	0.27	$2.4 \times 10^{-3}$
Type 3(K)	4-arm intersection <sup>y</sup>	65	48	53	3	30	0.63	$9.7 \times 10^{-3}$
Type 3(Vs)	3-arm intersection <sup>y</sup>	50	46	53	0	28	0.67	$1.3 \times 10^{-2}$
Type 6(G)	Roundabout	83	33	38	1	52	0.57	$6.9 \times 10^{-3}$

\* The cycle crossing crosses the arm with obligation to yield to traffic on the other arms

<sup>y</sup> The cycle crossing crosses the main road i.e. the other arms have obligation to yield

<sup>x</sup> 7-year accident data from STRADA

## 4.1 Speed

The mean speed and the 85-percentile speed at the sites are presented in Table 2. The speed distribution of motor vehicles approaching the cycle crossing is presented in Figure 6 below. The two Type 3 sites stand out from the rest with significant higher speeds of motor vehicle drivers approaching the cycle crossings.

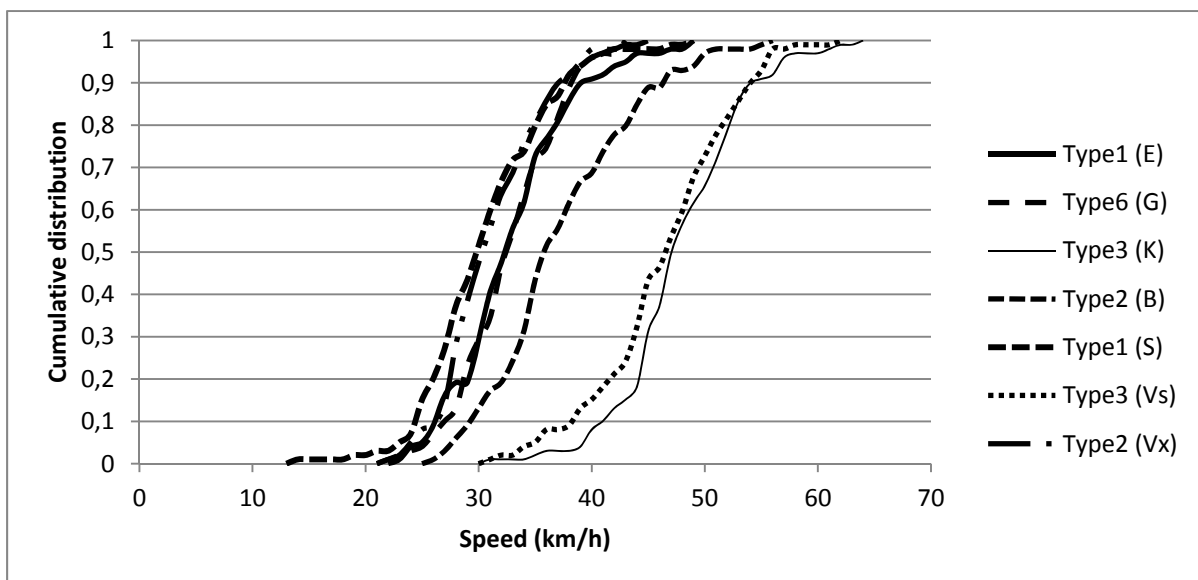


Figure 6: Speed distribution at the different sites.

## 4.2 Relationship between cycle flow, motorists' yielding behaviour and cyclists' safety

This study is based on a very small data set (seven sites). When analysing the relationships between cycle flow, yielding behaviour and cyclists' safety the main aim was therefore not to establish any exact statistical relationships but rather finding indications on likely patterns. Nevertheless, to be able to discern any patterns or trends in the data, linear and second-degree polynomial regression have been applied on the datasets. With few data points, it is most often a second-degree polynomial that fits the best, but these do on the other hand less often produce good explanations for the relationship. Here safety is analysed as number of serious conflicts per crossing cyclist and per hour. The reason for this is that this provides a description of the risk that each and every crossing cyclist is facing (Ekman, 1996).

### 4.2.1 Relationship between cycle flow and motorists' propensity to yield

Figures 7 and 8 show that the propensity to yield increases with increasing cycle flow. A second-degree polynomial regression produces the best fit ( $R^2=0.85$  as compared to 0.75). However, none of the relationships produce good explanations. The polynomial regression bends off and reaches a maximum of 85% propensity to yield at around 130 cyclists per hour. The straight line produces a 100% propensity to yield at around 150 cyclists per hour.

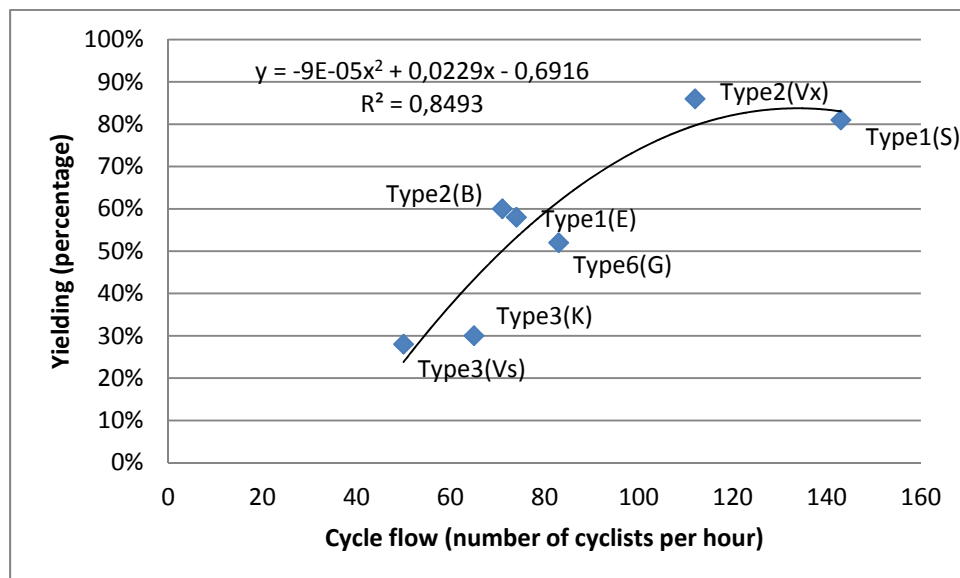


Figure 7: Relationship between cycle flow and motorists' propensity to yield. Second-degree polynomial regression.

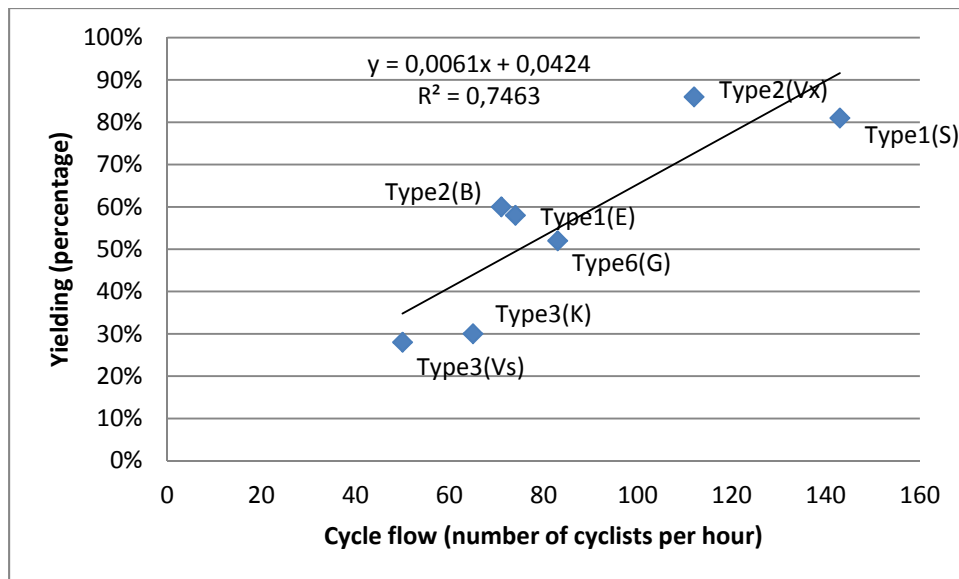


Figure 8: Relationship between cycle flow and motorists' propensity to yield. Linear regression.

#### 4.2.2 Relationship between propensity to yield and conflict risk per crossing cyclist

The analysis (Figure 9 and 10) shows that the conflict frequency per crossing cyclist decreases when the propensity to yield increases. Both the straight line and second-degree polynomial fit the data well ( $R^2 = 0.87$ ). A straight line might be preferred, however, because it produces zero risk per crossing cyclist when the yielding propensity reaches 100%.

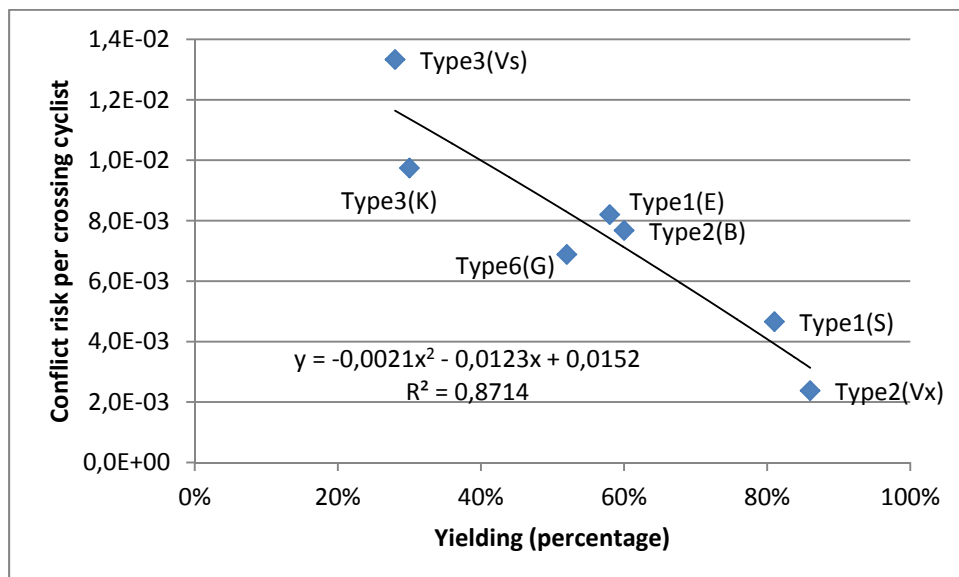


Figure 9: Relationship between propensity to yield and conflict risk per crossing cyclist. Second-degree polynomial regression.

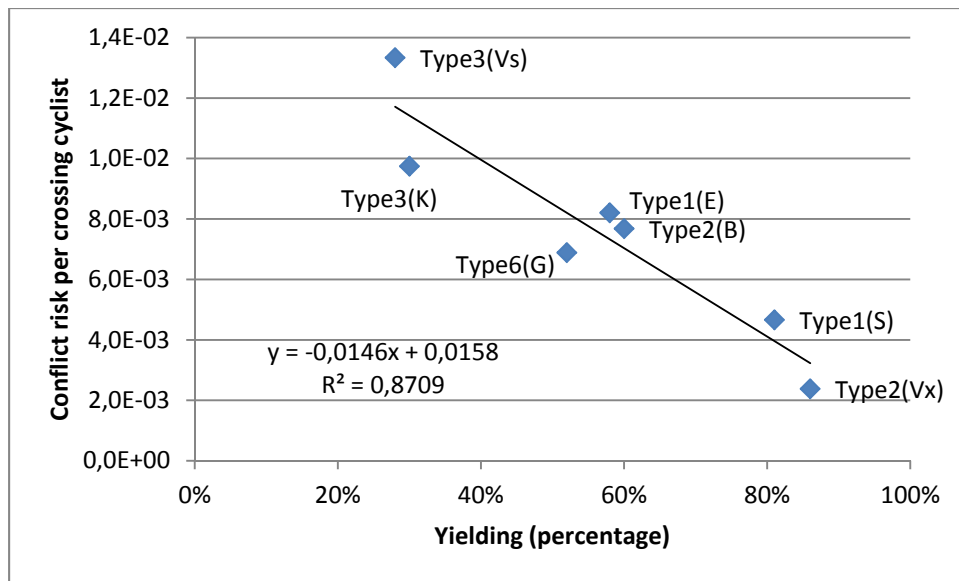


Figure 10: Relationship between propensity to yield and conflict risk per crossing cyclist. Linear regression.

#### 4.2.3 Relationship between cycle flow and conflict frequency per crossing cyclist

The analysis shows that the conflict risk per crossing cyclist decreases with increasing cycle flow, i.e. cyclists' risks decrease when their exposure increases, which is supported by previous research (e.g. Ekman, 1996; Jacobsen, 2003; Elvik, 2009; Kröyer, 2015). It is the second-degree polynomial that produces the best fit ( $R^2 = 0.97$  as compared to 0.70). But again, none of the relationships produce good explanations. The polynomial regression curve bends off and has a minimum conflict risk per crossing cyclist at 120 cyclists per hour. The straight line produces zero conflict risk per crossing cyclist at around 160 cyclists per hour.

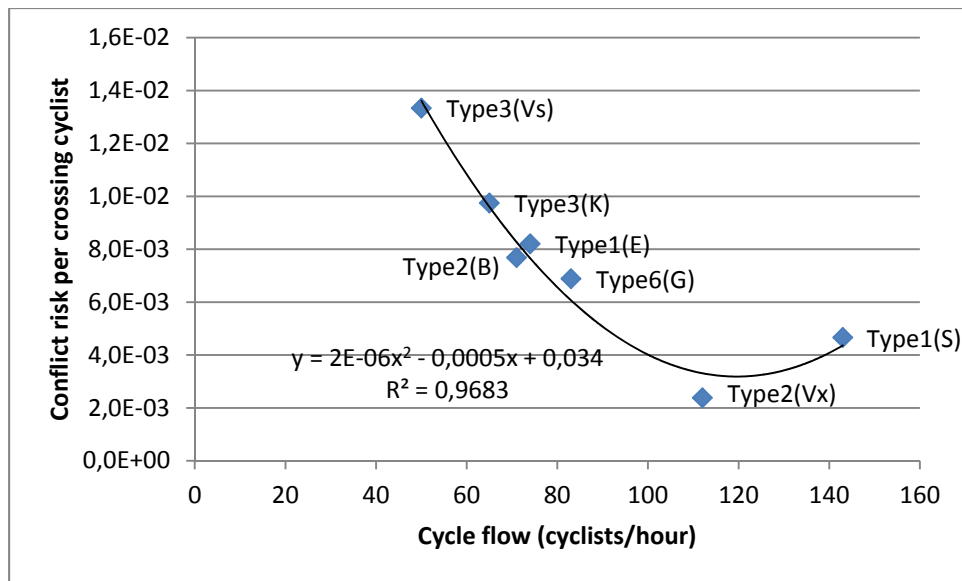


Figure 11: Relationship between cycle flow and conflict frequency per crossing cyclist. Second degree polynomial regression

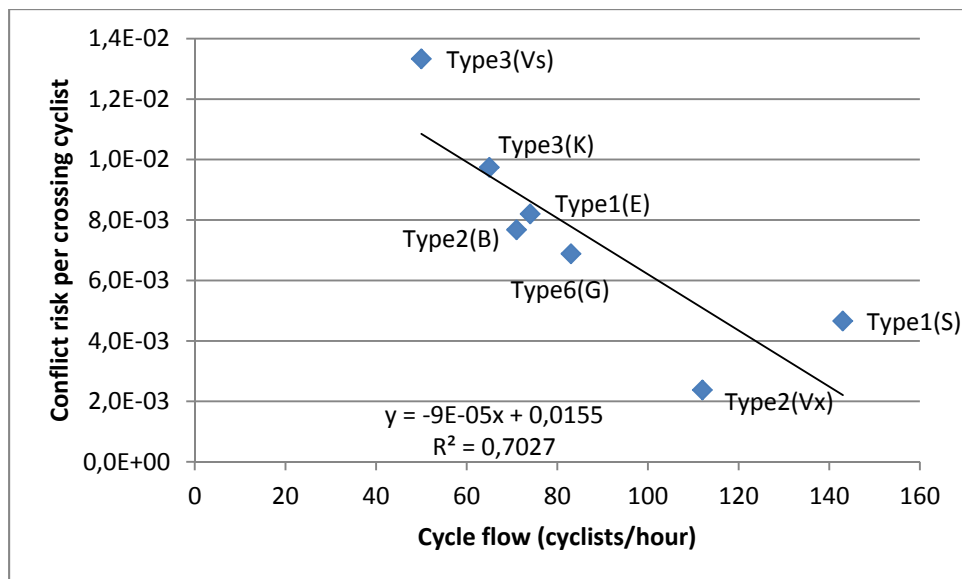


Figure 12: Relationship between cycle flow and conflict frequency per crossing cyclist. Linear regression.

#### 4.2.4 Road users' perceptions of yielding rules at cycle crossings

Analysis of the questionnaires showed that approximately half of the respondents perceived that the yielding rules for interactions between motor vehicle drivers and cyclists worked badly or rather badly, and the other half perceived that the rules worked well or rather well. Seventy-one per cent of the respondents agreed at least to some extent with the statement "I think it is difficult to know who is to yield to who when motor vehicle drivers and cyclists are on intersecting courses".



## 5 Discussion and conclusions

This research investigated how motorists' propensity to yield is connected to the traffic safety situation for cyclists at cycle crossings. To assess safety, conflict studies according to the Swedish Traffic Conflicts Technique (Hydén, 1987) were conducted. In the analyses safety is analysed as number of serious conflicts per crossing cyclist and per hour. Yielding data was extracted from the previous study (Pauna et al., 2009). In addition speeds, cycle flows and road users' perceptions of yielding rules at the cycle crossings were collected.

Empirical evidence is generated from a relatively small data set of seven sites. We must therefore be very cautious about drawing any firm conclusions. With more data the analyses had possibly been able to provide clearer relationships and better explanations. Still the seven sites represent the most common designs of cycle crossings in Sweden. Thus, the results are very relevant, at least in a Swedish context.

The results showed that motorists' propensity to yield increased with increasing cycle flow. This might be interpreted in terms of shifting the power balance a bit from motorist traffic to cyclists when many cyclists are involved. The polynomial regression produced the best fit with acceptable correlation ( $R^2=0.85$ ) but not good enough explanation. It might be argued that a more "preferable" shape would be one showing a relationship that bends off and slowly reaches a 100% propensity to yield at very high cycle flows. The results further showed that the conflict frequency per crossing cyclist decreases when the propensity to yield increases. Both the linear and polynomial regression produced acceptable correlations ( $R^2 = 0.87$ ) but a straight line might be preferred, because it produces zero risk per crossing cyclist when the yielding propensity reaches 100%. The results also showed that the conflict risk per crossing cyclist decreases with increasing cycle flow, i.e. cyclists' risks decrease when their exposure increases, which is supported by previous research (e.g. Ekman, 1996; Jacobsen, 2003; Elvik, 2009; Kröyer, 2015). The second-degree polynomial produced the best fit with good correlation ( $R^2 = 0.97$ ), but not good enough explanation. It might be argued that a more "preferable" shape would be one showing a relationship that bends off and slowly approaches zero conflict risk per crossing cyclist when cycle flows are very big.

Coming back to the main research question on how motorists' propensity to yield is connected to the traffic safety situation for cyclists at cycle crossings, we have despite a small data set shown that there seems to be a relationship between higher propensity to yield to crossing cyclists and fewer serious conflicts per crossing cyclist. Other factors as cycle flow, motorists' approaching speeds and road users' perceptions of yielding rules at cycle crossings are shown not only to influence yielding behaviour and safety but might be rather vital parts of the explanation.

What possible conclusions might then be drawn regarding the types of cycle crossing and their relations to safety? The initial study (Pauna et al., 2009) shows, for instance, that Type 1 crossings, with the yield sign located in front of the cycle crossing, in general result in a higher share of motorists yielding to crossing cyclists than is the case at Type 2 crossings in which the yield sign is located after the cycle crossing. In the present study we are able to show that locations with higher degree of yielding are also safer. This does not, however, imply that it is possible to draw the conclusion that all Type 1 crossings are safer than Type 2 crossings. The reason is that the different types of cycle crossings do not form a specific pattern when the different relationships to safety are analysed. (In the next section we come back to why this is different for the Type 3 crossings.) For

Type 6 crossings it is not possible to talk about a pattern as there is only one Type 6 site in the study. Aspects that also seem to influence safety are the share of motorists' yielding, cycle flow, and motor vehicle speed at the specific location, aspects that in addition seem to covary.

As described in section 3, the selected cycle crossings are unfortunately not random regarding their share of yielding, speed, cycle flow, or in terms of their location in the street network. When selecting the seven sites from the initial 65 locations it became obvious that locations with low levels of yielding and with reasonably high flows of cyclists are all located on road sections or at intersections with the cyclists crossing the main road (Type 3). Almost all other sites where the cyclists cross the road intersecting the main road (Type 1, 2, and 6), have a level of yielding that is around the average or higher irrespective of type of intersection (3-arm, 4-arm, or roundabout). It is therefore not surprising that the both Type 3 crossings form a specific pattern in all of our analyses, including lower cycle flow, lower share of motorists yielding, higher motor vehicle speeds, and higher conflict risks per crossing cyclist. The previous study (Pauna et al., 2009) shows that motorists' speeds influence their propensity to yield, and previous research shows a clear relationship between speed and safety (e.g. Kröyer, 2015). A Type 3 crossing might therefore be a cycle crossing that is not perceived as safe and, if possible, is avoided by cyclists which in turn results in low cycle flows, low propensity to yield, and reduced traffic safety.

As part of future work, the indication that it might be the perception of unclear rules at cycle crossings that increases the propensity to yield and thus increases traffic safety, ought to be further explored. This is especially important as we today have new and "clearer" yielding rules at speed secured cycling crossings in Sweden, with motorised traffic being obliged to yield to crossing cyclists. With the new rules, we have a similar situation as with the "clear rules" at Swedish pedestrian crossings, namely, that we also introduce new expectations among the road users with regard to who has the right of way and who is to yield, which is completely different from the former "ordinary cycle crossings" studied in this paper where road users are very uncertain about the rules. Could it be that potential negative effects due to stronger expectations about who is to yield / go first are reduced or eliminated with the lower speeds at the raised crossings? Hopefully this will be studied thoroughly before these new crossing designs are implemented on a larger scale.

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