When do drivers yield to cyclists at unsignalized roundabouts? Empirical evidence and behavioral analysis

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Submitted in July 2014 for presentation at the 94th Transportation Research Board Annual Meeting and publication in the Journal of Transportation Research Record

5295 words (Abstract + Text +References) +6 figures & tables (6 X 250) = 6795 words

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Abstract

Cycling popularity has shown an increasing trend during the last decades in many cities of Europe and USA because of its environmental and health benefits. However, cyclists are frequently involved in traffic accidents, especially, when they interact with vehicles at unsignalized intersections. There is still lack of evidence and analysis on how such interaction is performed. This paper explores empirical evidence of the vehicle-bicycle interaction on a typical Swedish roundabout, and provides insights into factors influencing car drivers' yielding decisions when they interact with cyclists. The vehicle-bicycle interaction was divided into group categories (*Non-Conflict*, *Conflict*, *Yield*, and *Non-Yield*) and their speed differences were analyzed by group. Furthermore, logistic regression was applied to model behavioral aspects of such interactions. The observed data showed a higher and significant speed variation among vehicles, whereas bicycles exhibited lower variation across the groups. The modelling results revealed that the yielding probability decreased when the speed of the vehicle was higher. On the other hand, the bicycle speed had little impact on drivers' decision to yield. More importantly, the results showed that the yielding probability was significantly increased by the proximity of the cyclist to the conflicting zone. The results indicated that the yielding rate of drivers can be improved by keeping vehicles' speed under 20 km/h, by which drivers have the capacity to detect and yield to cyclists in the studied facility.

Keywords: Vehicle-bicycle interaction, roundabout, yielding behavior, logistic regression models.

1. INTRODUCTION

Bicycling, as a non-motorized mode, is becoming increasingly relevant in transport planning because of its potential benefits for energy, environment and health. Researchers and public authorities consider bicycling as a mode of transport and cyclists as travelers. Thus bicycling is no longer considered only a recreational activity. In Stockholm, the number of cyclists has shown an increasing trend in the last decade, especially for trips towards the inner City *(1)*. In addition, a number of bicycling sharing systems (*BSS*) have been introduced (and become popular) in many cities around the world, overcoming some of the problems related to bicycling and providing means for one-way trips supporting public transport systems *(2, 3)*. However, bicycling safety is still the focus of attention and requires a better understanding of bicycling needs and relationships with other modes of transport. Especially, the interaction with motorized vehicles is a crucial aspect for the public, practitioners and researchers.

Vehicle-bicycle interactions can be divided into three main types, depending on the interaction as follows:

- Longitudinal interaction (Vehicle-bicycle interaction next to links). This situation happens when cyclists travel on bicycle lanes or paths next to the traffic stream. Safety considerations are mainly the width of the bicycle lane/path, vehicles' speed, and vehicle and bicycle volumes *(4, 5, 6, 7)*;
- Mixed interaction (Vehicle-bicycle longitudinal interaction within links). This interaction occurs when drivers and cyclists share the road without any physical barrier to divide the travel modes. Safety considerations are the road width, overtaking opportunities, lateral lane position, vehicle and bicycle speeds and volumes *(8, 9)*.
- Crossing interaction (Vehicle-bicycle interaction at crosswalks). Two types of crossings can be considered: signalized and unsignalized intersections. At signalized intersections, traffic lights allow for separation of primary conflicts. The remaining secondary conflicts e.g., vehicle turning right or left and cyclist heading through, may lead to serious conflicts/accidents. On the other hand, at unsignalized crossings (including roundabouts) priority rules govern vehicle-bicycle interactions. Normally, at these unsignalized crosswalks, cyclists have priority above vehicle traffic according to the traffic regulations in Sweden. However in reality, such *"priority"* is also based on expectations and assumptions *(10)* i.e., the expectation that the driver has detected the approaching conflicting cyclist and the driver being able or willing to give way. Studies in Sweden have shown that drivers' yielding rate to cyclists is on average 58 % *(11)*. Consequently, there is still a large proportion of drivers who do not comply with the *"expectation"* to yield to cyclists. Other studies have shown that the yielding rate decreases as the speed of the vehicle increases due to the fact that the driver has less time to detect and react to the presence of cyclists *(12)*.

A number of measures have been introduced to allow for a safer interaction. Speed reduction is one way to keep the vehicle speed under certain thresholds *(10-12)*. For instance, the introduction of speed humps before the crossing and raised crosswalks. Svensson and Pauna *(11)* reported that the yielding rate increases when the bicycle flow is higher. They also evaluated the impact of give-way signs. The yielding rate is increased when the give-way sign is located before the crossing. With the vehicle-bicycle interaction at unsignalized crosswalks still the subject of research, better understanding, through empirical evidence, of the decision process to yield and investigation of critical factors are important prerequisites towards a safer bicycling environment.

In Sweden, vehicles exiting roundabouts have the responsibility to yield to pedestrians and cyclists on the crosswalks. A recent Swedish study (11) has shown a 58 % yielding rate to cyclists. Thus there is a large percentage (>40%) of car drivers who fail to fulfil the yielding expectation. From a behavioral perspective, it is important to identify factors which might contribute to this large percentage of failures. One of the most important factors is the speed of the vehicle. According to Räsänen and Summala (13) vehicles at higher speeds have difficulties to observe cyclists, leading to a failure yield to the cyclist. At high speeds, car drivers have less time to detect cyclists, and less time to react accordingly. For instance, Summala et al., (14) investigated drivers' visual search when interacting with cyclists at T intersections governed by priority rules in Finland. They found that drivers turning right focused their attention to traffic coming from the left and scanned the right leg less frequently and also later in the process. The authors explained the behavior as one where drivers focused on the traffic on the left considered much more frequent and dangerous compared to less frequent traffic on the right during the critical phase. They evaluated the impact of speed humps on drivers' visual search and concluded that speed reduction measures can result in lower vehicle speeds and more time to focus on cyclists approaching from the right. In another study (15) an in-depth analysis of vehicle-bicycle collisions was conducted. The authors investigated and reconstructed more than 180 vehicle-bicycle accidents in Finland. In 37 % of the collision cases, both the driver and the cyclist did not realize the presence of or yielded to the other party involved. The authors identified two mechanisms underlying the collisions related directly to two-way bicycle paths and intersections govern by priority rules: i) lack of attention resulting in not detecting other road users and ii) unjustified expectations with respect to the behavior of the other road user. The most common collision involved vehicles turning right and cyclists approaching from the behind on the right side of the vehicle. An explanation was that drivers pay more attention to the traffic on the left. From these accidents, 11 % of the drivers did notice the cyclist just before impact. On the other hand, 68 % of the cyclists did notice the driver and 92 % of those cyclists believed that the driver would yield as expected.

Wood et al., *(16)* evaluated drivers' perceptions and attitudes towards cyclists. The authors reported that most of the vehicle-bicycle crashes were caused by the driver being *"not-able-to-see"* the cyclist on time to avoid the collision. They also found that cyclists overestimated the distance at which they would be recognized by a driver by almost 100%. Another important aspect of the vehicle-bicycle interaction is the "risk perception" i.e., how dangerous a traffic situation is perceived by either the cyclist or the driver. Chaurand et al. *(17)* evaluated several vehicle-bicycle common crash situations, and found that the perceived risk of an accident decreased with experience for both cyclists and drivers in such situations. They also found that the perceived risk was higher for drivers compared to cyclists in the same traffic situation.

Understanding vehicle-bicycle interactions is still an important topic for investigation. Two main subjects are identified through literature review. The right-turning driver "*maneuver*" detecting and reacting to an approaching cyclist needs further investigation. More importantly, the driver yielding decision process and its influential factors, especially at unsignalized crosswalks, should be better understood so that models and tools can be developed to facilitate the evaluation of different policies or engineering treatments for better bicycling environment. Therefore, this study aims at collecting and analyzing empirical evidence of the vehicle-bicycle interaction process at an unsignalized roundabout. Such evidence can provide insights into factors which influence drivers' behavior to fulfill other users' expectations. Specifically, the factors directly affecting the yielding decision of drivers are explored using statistical modelling approaches. The rest of the paper is organized into three main sections. Section 2 describes the data collection and analysis procedures. Section 3 presents a statistical approach to model the yielding decision process by car drivers. Section 4 presents the empirical results and discussion on the essential factors obtained by model estimation, and the paper is finally concluded in Section 5.

2. DATA COLLECTION AND ANALYSIS

2.1 Vehicle-bicycle interaction zones

Generally, in Sweden, teamwork is promoted among drivers within the traffic system to account for a polite and safer interaction. Unsignalized crosswalks are normally governed by priority rules. Drivers exiting a roundabout have the responsibility to give way to any other road user traversing the crosswalk. Normally, before drivers reach the crosswalk, they are expected to monitor further upstream into the sidewalk or road for the possible presence of cyclists. Similarly, cyclists are expected to look for vehicles as they approach the crosswalk to ensure a safe crossing. Due to the different dynamics, the vehicle-bicycle interaction comprises two important zones:

- A conflict zone (*CZ*) where the vehicle and bicycle trajectories meet or cross with potential collision if trajectories are sustained.
- An interaction zone (*IZ*) where the driver and the cyclists begin to interact or negotiate to avoid a potential collision.

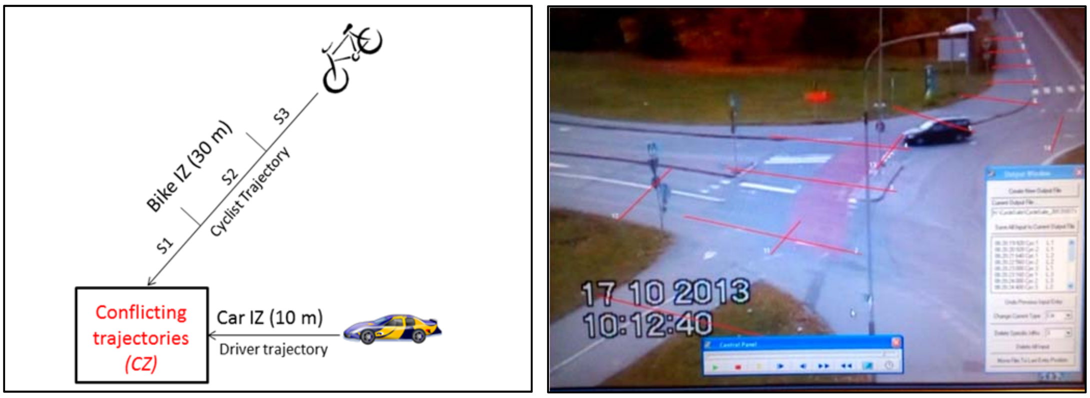
The *CZ* zone is often painted at priority intersections (including roundabouts) and can be considered the whole crosswalk. Therefore, the *CZ* is a common and overlapping area for both vehicle and bicycle. On the other hand, different vehicle and bicycle dynamics, such as speed, acceleration, reaction times and braking forces, imply that drivers and cyclists begin monitor each other at different locations from the *CZ*. Therefore, two different interaction zones are defined correspondingly:

- Car *IZ* begins at the *CZ* and extends further into the roundabout.
- Bike *IZ* begins at the *CZ* and extends further upstream into the sidewalk or bicycle path/lane.

Each *IZ* has different lengths due to different vehicle and bicycle kinematic forces. The Car *IZ* zone extends up to 10 m from the *CZ*. Due to the specific geometry of the studied roundabout, the driver has full visual coverage over the sidewalk at 10 m distance from the *CZ*. The driver can detect the presence of cyclists, and is able to react and decide to fulfill the yielding expectation or not. Therefore, the location is considered as the decision point for drivers and may vary among different facilities. On the other hand, the bike *IZ* extends up to 30 m from the *CZ*, divided into 3 segments of 10 m each. The segments are defined as *S1*, *S2* and *S3* (see Figure 1(a)).

2.2 Data collection

To investigate drivers' yielding behavior to cyclists, vehicle and bicycle trajectories are needed. Information on the presence of yielding events is also crucial for the analysis. As a result, data acquisition to analyze drivers' yielding decisions is an intensive and tedious task. One way to ease and overcome such difficulties is by video recordings and data extraction using image processing. During the data collection, vehicle-bicycle interactions at a typical roundabout in Stockholm were observed. The data was collected on a weekday in the autumn 2013 during the afternoon rush hour (16:00 – 18:00). Weather conditions were normal, dry, and clear. Video equipment was used to capture vehicle-bicycle interactions. A mast tower of 15 m in height with 2 cameras was installed and configured to visually cover the conflict and interaction zones. The video cameras saved the images for post processing. The study area was a one-lane roundabout located near Stockholm University. A video analysis program, called SAVA (18), was used for data extraction. After image calibration, the program allows for drawing of virtual lines on the film so that moving objects can be traced as they traverse the study area. A log file is created with subject ID and timestamps at each virtual line. Afterwards the speed can be derived from the time and distance recorded. From video observations, the yielding events were also identified, based on drivers' deceleration or speed adaptation to let a cyclist traverse safely the crosswalk. Figure 1(b) shows the film analysis with some virtual lines drawn.



a) Conflict trajectories and *IZ's* b) SAVA area screenshot

c) Drivers' sight vision at 10 m d) Cyclists' sight vision at 30 m

FIGURE 1 Vehicle-bicycle interactions and data collection approach.

2.3 Event Groups

When a vehicle exits a roundabout and passes through the bicycle crossing, the following events may happen:

- *Non-Conflict*: the driver does not encounter any cyclist, thus crossing freely and leaving the *IZ* and *CZ* zones without any interruption.

- *Conflict*: the driver interacts with cyclist due to potential collision.

It is assumed that there is *Conflict* if vehicle and bicycle are simultaneously in their respective *IZ*. Moreover, the arrival time difference (*ATD*) between the vehicle and the bicycle at the boundary of each interaction zone is the key variable to establish a *Conflict* event. Larger *ATD* values imply that it is less likely that the trajectories of the vehicle and bicycle meet at the *CZ*. On the other hand, shorter *ATD* values indicate that it is likely that a *Conflict* is perceived by the driver. From video observations and based on the *ATD* values at the boundaries of each *IZ*, a threshold of 5.5 seconds was identified as a threshold between *Non-Conflict* and *Conflict* events. Based on this threshold observations are classified into the following events:

- $Non - Conflict$ $(ATD > 5.5\ seconds)$
- $Conflict$ $(ATD \leq 5.5\ seconds)$

Furthermore, in the conflict situation, a car driver may have two options:

a. Car driver yields to the interacting cyclist or
b. Car driver passes through the *IZ* and *CZ* zones without yielding to the interacting cyclist.

Therefore, a *Conflict* leads to two subsequent events:

- $Non - Yield$ $(if\ driver\ does\ not\ yield\ given\ ATD \leq 5.5\ seconds)$
- $Yield$ $(if\ driver\ yields\ given\ ATD \leq 5.5\ seconds)$

Finally, the vehicle-bicycle dataset can be classified into 4 groups as follows: *Non-Conflict, Conflict*, *Yield* and *Non-Yield* groups for vehicles and bicycles. In the bicycle case, *Yield* refers to a cyclist interacting with a driver who does yield and, similarly, for the other groups.

2.4 Data analysis results

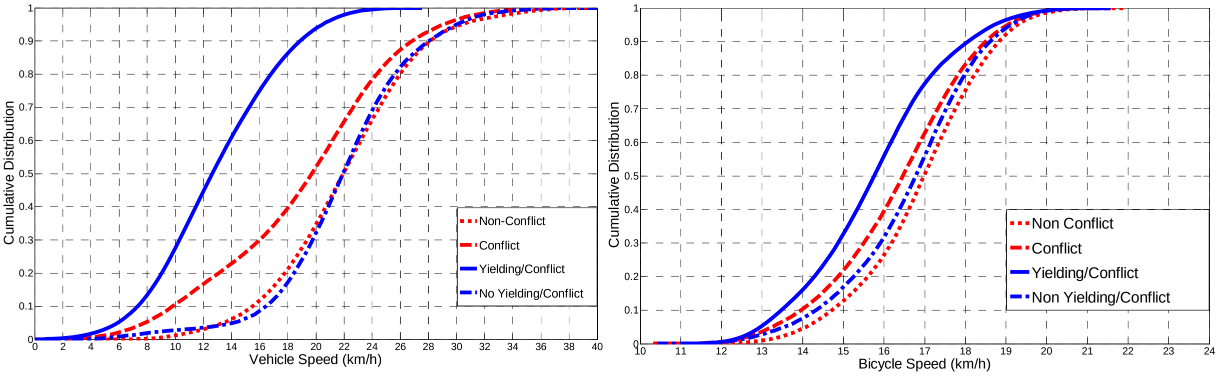
Table 1 summarizes descriptive statistics about various measures of interest. The mean vehicle speed difference between *Non-Conflict* and *Conflict* groups is 2.90 km/h($t = 2.55$). As expected, vehicles interacting with bicycles have lower speed in comparison to *Non-Conflict* (free) vehicles. The mean vehicle speed difference between the *Conflict* and *Yield* groups is 6.16 km/h ($t = 11.88$). Naturally, yielding vehicles present the lowest mean speed of all vehicle groups since they adapt the speed to let cyclists traverse the crosswalk safely. It was expected that the *Non-Conflict* group would present the highest speed given no disturbance from any cyclist. However, it is interesting to observe that the difference between the *Non-Conflict* and *Non-Yield* groups is negligible at 0.04 km/h ($t = 0.03$). In the *Non-Yield* case, it can be argued that either the driver did not detect the cyclist or the cyclist was far enough from the *CZ* thus the driver had the opportunity to go through the *CZ* before the cyclist.

TABLE 1 Vehicle and bicycle speeds by group

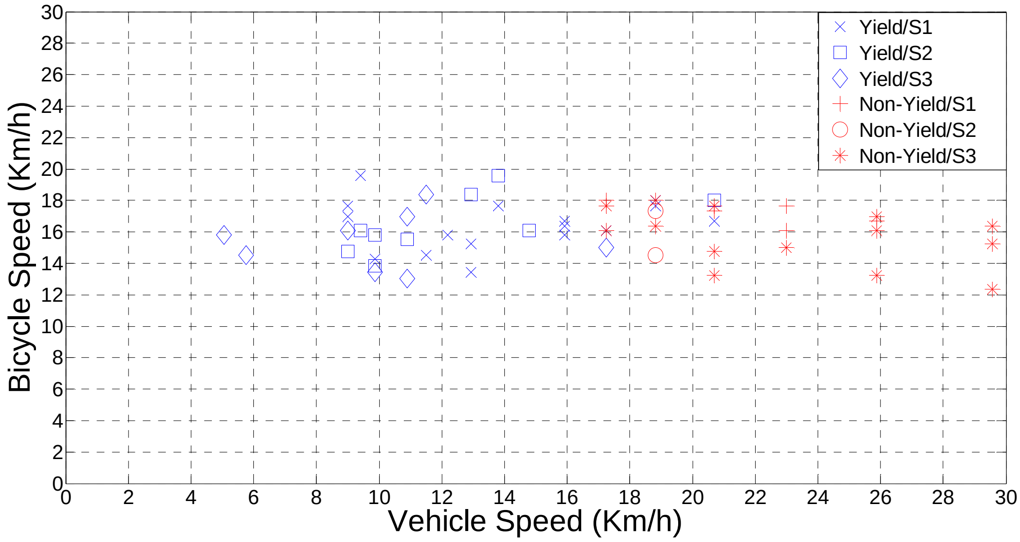
	Vehicle Speed		Bicycle Speed			
Event Groups	Mean	Stdv	Mean	Stdv	Event Sample	Yielding rate (%)
All Data	20.12	5.80	16.55	1.55	187	
Non-Conflict	21.93	4.78	16.89	1.43	70	
Conflict	19.03	6.09	16.34	1.59	117	32
Yield	12.87	3.88	15.77	1.59	37	
Non-Yield	21.89	4.65	16.61	1.53	80	

Cyclists on the other hand, present lower speed variation across the classified groups. The mean speed difference between *Conflict* and *Yield* groups is 0.57 km/h ($t = 1.39$). The speed difference is not statistically significant. This small difference can be an indication that cyclists try to impose (force) a yielding decision on drivers since cyclists are confident on their *"priority"* and do expect the driver to yield. This reveals a risky behavior from the cyclist side i.e., the cyclist is confident that the driver has detected him/her and would react to his/her presence. As mentioned in the previous section, Wood et al., (*16*) report that cyclists overestimate by twice that distance at which they would be recognized by a driver. The fastest bicycle group is the *Non-Conflict* group with mean speed of 16.82 km/h. Of course, it was expected that this group would present the highest speed since they were not disturbed by any vehicle. On the other hand, the lowest bicycle speed group is the *Yield* group with mean speed of 15.77 km/h. The speed difference between *Non-Conflict* and the *Yield* groups is small (1.05 km/h).

Figures 2(a) and 2(b) plot the cumulative speed distributions for all vehicle and bicycle classified groups. Vehicle speed differences are clearly distinguished among the various groups. Especially, the difference of the *Yield* group (solid line) compared to all other vehicle groups (see Figure 2(a)). The results in Figure 2(a) suggest that the *Non-Yield* group has basically the same speed as the *Non-Conflict* group. Figure 2(a) also shows that more than 90 % of the drivers who yielded had a speed under 20 km/h. Similarly, bicycle speed profiles for different event groups are presented in Figure 2(b). Again, the *Yield* group demonstrates the lowest speed level (solid line). In addition, Figure 2(c) shows a scatter plot of vehicles versus bicycles speeds considering the cyclist's location by Segment and whether the driver yielded or not from the *Conflict* group. Interestingly, the plot indicates that low speed vehicles provide for a higher yielding rate. This result supports the idea that drivers have more time to better detect and react to the cyclist's presence at low speeds. On the other hand at high speeds, drivers do not yield as expected. The position of the cyclist plays an important role in the driver's decision according to the results. Most of the *Non-Yield* observations are with a driver at speeds above 18 km/h and cyclists in Segment 3 (>20 m). Therefore, the yielding rate decreases as the distance of the bicyclist increases.



a) Vehicle speeds by groups. b) Bicycle speeds by groups.



c) Vehicle vs. bicycle speeds by group and segment.

FIGURE 2 Vehicle and bicycle cumulative speeds by groups and scatter plot.

3. MODELING THE PROBABILITY OF YIELDING

The data analysis in the previous section provides useful insights on the yielding probability. The substantial difference between free vehicles and those interacting with bicyclists for example, indicates that the yielding probability is significantly affected by vehicle speed. The speed of the bicycle had a relatively small impact according to lower variation among the groups. Additionally, the proximity of the cyclists to the conflict zone should have some impact on drivers' yielding decisions. The analysis in this section aims at developing a model that identifies the important factors that explain these decisions. The explanatory variables considered are summarized in Table 2.

TABLE 2 Variable descriptions

Parameter	Variable	Unit	Description
β_0	-	-	Constant
β_1	V_{car}	Km/h	Instantaneous speed of a vehicle at the start of the Car *IZ* zone (decision point 10 m)
β_2	$Segment\ 1$	dummy	1 if the bike is in *Segment 1* (0-10 m) when the car arrives at decision point, else 0
β_3	$Segment\ 2$	dummy	1 if the bike is in *Segment 2* (11-20 m) when the car arrives at decision point, else 0
β_4	$Segment\ 3$	dummy	1 if the bike is in *Segment 3* (21-30 m) when the car arrives at decision point, else 0
β_5	V_{bike}	Km/h	Bicycle velocity measured with reference to the car at 10 m away from conflict zone

Logistic regression, a statistical approach appropriate for modeling binary response data was used to estimate the model (similar approaches have been used to investigate the vehicle and pedestrian interactions (*19*)). The probability of yielding, given that vehicle-cyclist conflict takes place, is given by:

$$P(Y = 1|X) = e^{U(X)} / 1 + e^{U(X)} \quad (1)$$

U(X) is the systematic utility function of the decision to yield given by:

$$U(X) = X \cdot \beta = \beta_0 + \beta_1 x_1 + \dots\dots + \beta_5 x_5 \quad (2)$$

where, $\beta = [\beta_0\ \beta_1 \dots \beta_5]^T$ is a vector of parameters and $X = [x_1\ x_2 \dots x_5]^T$ a vector of explanatory variables that determine the final yielding probability. *Y* is a yielding event. The models, with different specifications, were estimated using SPSS *(20).*

4. RESULTS

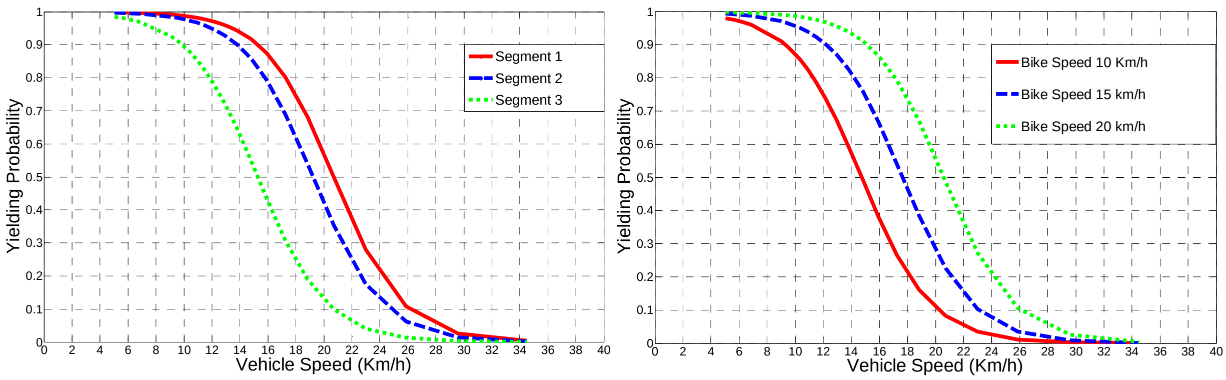
The results of logistic regression are presented in Table 3. The a priori expectation was that higher speeds of the vehicle and bicycle lead to lower yielding probabilities. It was also expected that cyclists closer to the *CZ* zone would have greater impact on the driver. The model estimation results support the initial hypotheses. For instance, the speed of the vehicle is negatively correlated to the yielding event as it was expected. Therefore, a vehicle with high velocity has lower chance to fulfil the yielding expectation. At high speeds, drivers have less time to detect and react to the presence of an interacting cyclist. This finding is also in line with previous literature such as (*12*, *15*).

The impact of the proximity of the cyclist approaching the *CZ* agrees with the expectations as well. A cyclist in Segment 1 imposes higher yielding probabilities which increases by 4.890 compared to the case where there is no cyclist. Thus if a driver encounters a cyclist near the *CZ*, the driver is more likely to give way according to the results; whereas, if the cyclist is in Segment 2, the impact on the yielding probability is slightly lessened and the probability to yield is only increased by 4.289. Figure 3(a) exhibits that there is still a small chance (10 %) to yield when the vehicle speed is up to 26 km/h and 25 km/h for Segment 1 and Segment 2 respectively. Of course, if the driver fails yielding the cyclist is expected to do so and wait for the driver to avoid a collision. Consequently, Segment 1 and 2 show a sustained influence on drivers' yielding decisions hence the presence of the cyclist up to 20 m away from the *CZ* has a strong impact on car drivers. On the other hand, the presence of the cyclist in Segment 3 shows a relatively lower impact on the yielding probability (2.680). Figure 3(a) shows that a driver whose speed is 20 km/h and detecting a cyclist in Segment 3 has only 10 % probability to yield. The impact of the distance of the bicyclist from the *CZ* needs further investigation. For example, bicyclists far away may impact drivers in the opposite direction by encouraging them to accelerate instead of yielding, as it was observed in the video recordings.

TABLE 3 Estimation results

Variable	Parameter	Model I	Model II	Model III	Model IV
$Constant$	β_0	5.762	3.591	3.547	3.530
		(29.12)	*(7.73)*	*(7.00)*	*(6.87)*
V_{car}	β_1	-0.411	-0.404	-0.408	-0.407
		(41.09)	*(23.80)*	*(22.37)*	*(21.99)*
$Segment\ 1$	β_2	-	-	4.890	7.493
				(23.77)	*(2.17)*
$Segment\ 2$	β_3	-	-	4.289	7.018
				(13.56)	*(1.71)*
$Segment\ 3$	β_4	-	-	2.680	5.266
				(7.58)	*(1.10)*
V_{bike}	β_5	-	0.236	-	-0.162
			(24.63)		*(0.27)*
$-2LL$		101.210	62.396	55.323	55.045
$Nagelkerke\ R\ square$		0.579	0.768	0.798	0.799
$Yielding\ events$		37			
$Observations$		187			

Figure 3(a) depicts the probability estimated for the Model III. The plots depict how cyclists in Segment 1 and 2 impose higher yielding rates to faster vehicles compared to cyclists being on Segment 3. Figure 3(b) exhibits the probability estimates based on Model II with the speed of the bicycle fixed at 3 levels (10, 15, and 20 km/h).



a) Cyclist Proximity b) Bicycle Speed

FIGURE 3 Yielding probabilities.

Model I and Model II have an overall accuracy of 89.9 % and 92.5 % respectively in predicting yielding decisions. On the other hand, Models III and IV have an overall accuracy of 94.1 %. Out of 37 observed yielding events, these latter models (III and IV) were able to accurately predict 30 yielding events. In the same way, these models (III and IV) successfully predicted 145 non-yielding events out of 150 non-yielding observed events and they predicted erroneously 5 yielding events which in reality were non-yielding events and predicted 6 non-yielding events which were actually yielding events. Therefore, Model III appears to have a better performance than the other models based on the *-2LL* score, *Nagelkerke R square* and *t-values* from variables included in the model.

5. CONCLUSION

Understanding driver yielding behavior and its influencing factors is important for guiding informed design, planning and even policy decisions. Apart from geometric factors and driver characteristics which also play an important role on such decisions, behavioral aspects such as the vehicle and bicycle speeds and their relative positions provide insights to better understand the decision process behind *Yield* or *Non-Yield* events. The results indicate that low speed vehicles have a high yielding rate. The *Non-Conflict* and *Non-Yield* groups presented the highest mean speed of all groups (21.9 km/h). The *Non-Yield* group can be considered as "aggressive" drivers. Another interesting result from the data analysis is the mean speed difference between the vehicle *Non-Yield* and *Yield* groups which is around 9 km/h. This result undoubtedly shows the impact of vehicle speed on the yielding decision outcome. On the other hand, cyclists seem to be very confident on their "*priority*" and try to force a yielding decision on drivers as shown in the small speed difference (1.0 km/h) between the *Non-Conflict* and *Yield* bicycle groups.

The results also show that the relative position of the cyclist is an important factor on the yielding decision. A positive impact (increased yielding rate) is reported as cyclists get closer to the *CZ.* The results also indicate that the impact is rather constant or sustained for distances up to 20 m away from the *CZ.* At a distance longer that 20 m the cyclists' impact reduces substantially. It is difficult to establish a distance threshold where the cyclist' influence ceases or changes suddenly (e.g., decreased yielding rate). It is possible that cyclists far away from the *CZ* (> 30 m) have still an impact on drivers' yielding decision yet in the opposite direction i.e., the driver detects the cyclist too far away that induces the driver to speed up instead.

The data analysis indicates that there is not much variability on bicycle's speed across the groups. The results of Model II also confirm that the cyclist speed has a small impact (0.26) on the driver yielding decision. Additionally, Model IV reveals that the inclusion of the cyclist speed in the Model does not necessarily improve the model performance. The model estimation suggests that the position of the cyclist has strong influence on the driver. This also implies that detecting the cyclist is crucial for drivers' yielding decisions. The results provide a better understanding of drivers' decision process at one-lane roundabouts. In addition, the results show that for vehicle speeds below a certain threshold (20 km/h for the studied roundabout) the yielding probability is very close to 1.

The results presented in the study reflect behavioral aspects and configuration of a typical Swedish roundabout governed by the local traffic regulations. Car drivers have the responsibility to give way to cyclists who may simply traverse the crosswalk. Therefore, the applicability of the results in other contexts, especially outside the Nordic Countries or Europe, needs further investigation and evidence.

ACKNOWLEDGMENTS

The authors would like to acknowledge the steering board of Länsförsäkring (County Insurance Company) for providing the financial support for the study.

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