A hierarchical modelling framework for vehicle-bicycle interactions at roundabouts

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A Hierarchical Modelling Framework for Vehicle-bicycle Interactions at Roundabouts

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ABSTRACT

This paper introduces a framework to model vehicle-bicycle interactions at unsignalized roundabouts. Based on discrete choice theory, a probabilistic model of two hierarchical levels is proposed to represent the driver yielding decision process. The first level models the probability of conflict whereas the second level quantifies the probability of yielding given that a conflict has occurred. A case study is introduced for evaluation of the proposed methodology using real data observed at a typical Swedish roundabout. The results show that the conflict probability is influenced differently depending on the user, cyclist or driver, arriving to the interaction zones. The yielding probability is negatively correlated with the speed of the vehicle when the driver makes decision. The model estimation results also suggest that the relative position of bicycle has larger impacts than its speed i.e. the closer the bicycle is to the conflict zone the greater the impact is on the driver decision. Finally, the empirical analysis also indicates that vehicle speed less than a threshold value shall lead to a high yielding rate, and therefore safer situation at the roundabout.

Keywords: Vehicle-bicycle interaction, cyclist safety, yielding behavior, unsignalized intersection, roundabout, hierarchical logit model, maximum likelihood estimation.

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1 INTRODUCTION

Cyclists are vulnerable road users, and cycling safety is an essential concern in traffic planning. Especially, the interaction with motorized vehicles has attracted lot of attention. According to the literature, speed is the key factor for serious and fatal outcomes in vehicle-bicycle accidents [1], and Minikel [2] points out that higher vehicles' speed, higher traffic volumes, and the presence of heavy vehicles are detrimental to cyclist safety. At unsignalized intersections governed by priority rules (e.g., four-leg intersections, T intersections, and roundabouts) the interaction between car drivers and cyclists is normally based on expectations. The expectation is that drivers yield to cyclists and pedestrians traversing the crosswalk. However, Bjorklund [3] states that sometimes the expectations of the road users can be wrong: some fail to look for a specific road user (e.g. failing to give way) and some miss to look in some specific direction. T-junctions are examples where car drivers usually fail to fulfill other road users' expectations. For instance, when coming from the connecting street and turning right at T-junctions, drivers pay more attention to cars coming from the left and little attention to cyclists and pedestrians on the right. At priority intersections in Sweden, the expectation relies on car drivers who are responsible to yield (give way) to any other road user traversing the crosswalk [4]. However, drivers' yielding behavior to cyclists at priority intersections is still subject of investigation. For instance, Summala et al., [5] conducted a study where priority rules changed in Finland enforcing car drivers to yield to cyclists. They concluded that changes in the yielding priority influence differently road users' behavior depending on the characteristics of the bicycle crossing. In another investigation, [6] studied car drivers' yielding behavior due to the presence of bicyclists at roundabouts. They collected data by means of video recordings from 6 different roundabout layouts in Finland, Sweden and Denmark. The main differences were the size of the central island (13-16 m and 40 m) and the location of the crossing (adjacent or set back 6 m). Large central islands provided for a lower approaching vehicle's speed. They found that in average 13 % of the drivers did not look to the cyclists when approaching from the right. The yielding rate is higher when the crossing is adjacent to the roundabout compared to when the crossing is set back 6 m from the roundabout. More importantly, they also report that vehicles of high speed fail to look for cyclists and contribute to drivers not yielding to cyclists.

Another important concern in safety studies is that drivers may fail to fulfil other users' expectations due to lack of attention (e.g. driver does not realize the presence of the cyclist due to limited vision accessibility or disturbance from cell phone usage) or misinterpretation (cyclists often assume that drivers are aware of their presence although drivers may have not seen the cyclists). This has been documented in the traffic safety literature as 'looked-but-failed-to-see-errors' [7]. For instance, in an in-depth study of vehicle-bicycle collisions, [8] analyzed 188 accidents from 4 different cities. They found that a large percentage of the collisions (37 %) neither the driver nor the bicyclist had time to yield. They report two mechanisms underlying the collisions as follows: allocation of attention and unjustified expectations. The most frequent accident reported was with vehicle turning right and bicyclist approaching from the back of the driver on the right side of the vehicle. From these collisions, only 11 % of the drivers noticed the cyclist before impact because drivers looked to the left during the critical phase. On the other hand, cyclists did notice the vehicle (68 %) and 92 % believed that driver would yield as expected.

The decision process of a driver to yield has not been understood thoroughly in the literature. Therefore, the main objective of this paper is to develop a theoretical framework to model the driver-cyclist interaction process when they approach a conflicting zone. The rest of the paper is organized as follows: section 2 presents a theoretical framework using a probabilistic approach to model the driver decision process; section 3 illustrates the proposed methodology through an application in modeling vehicle yielding probability at a typical roundabout in Stockholm using actual data collected at the junction; section 4 discusses the corresponding results and analysis, and finally, section 5 concludes the paper.

2 METHODOLOGY

2.1 Yielding decision process

The vehicle-bicycle interaction is triggered by the collision course in which the vehicle and bicycle would have been involved if current trajectories had been maintained heading to a common crossing area, called a conflict zone (*CZ*). In order to avoid a collision due to the conflicting trajectories, a “negotiation” begins upstream the *CZ* between the driver and the cyclist which are defined here as the interaction zones (*IZ*). Figure 1 describes the general vehicle-bicycle interaction as the driver and cyclist approach to the conflicting zone. Drivers have the responsibility to yield and once they perceive a conflict with a cyclist, car drivers need to make a decision at a certain point whether to yield or not. The decision point varies across drivers and factors influencing such decision include driver behavior, attitudes, and intersection characteristics. Among other factors, the vehicle and bicycle speeds and relative positions of the interacting subjects are important predictors, which may give insights into the yielding decision process. Consequently, the decision process to yield during vehicle-bicycle interaction comprises two states or levels as follows:

1) A conflict event (*C*) is perceived.
2) A yielding event (*Y*) is observed.

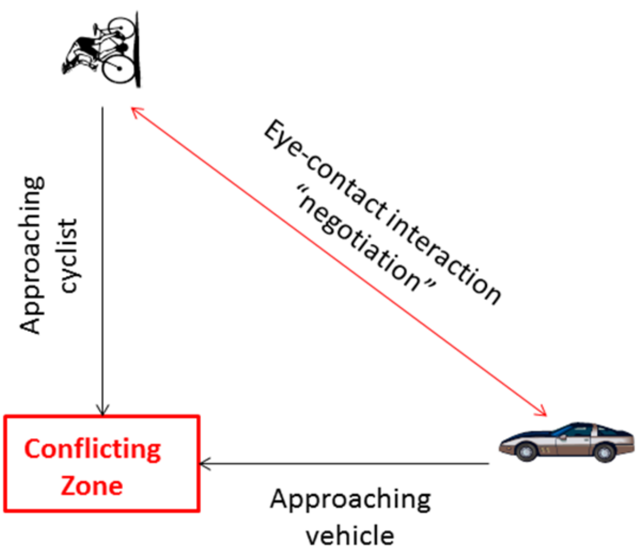


Figure 1. General vehicle-bicycle interaction zones at roundabouts.

Another important aspect of the yielding decision process is the actual possibility that the driver is able to stop the vehicle to yield to the cyclist i.e., the driver is able to react by braking and stopping the vehicle before the crossing. During vehicle-bicycle interaction, drivers need not only to pay attention to the crosswalk but farther into the sidewalk or bicycle path/lane to check for the possible presence of cyclists and be able to decrease their speed or come to a full stop if needed. The distance where the driver begins screening for cyclists can be considered as the point where the decision process begins. If a cyclist is detected, the driver decides whether it is possible to yield, depending on, among other factors, the vehicle speed, bicycle speed, the vehicle and bicycle relative distances to the crossing. Therefore, the vehicle-bicycle interaction can be represented by at least two states as stated before. A conflict (*C*) state and a yielding (*Y*) state, given that a conflict has occurred. This two-stage process is described in Figure 2 and used to determine the model structure.

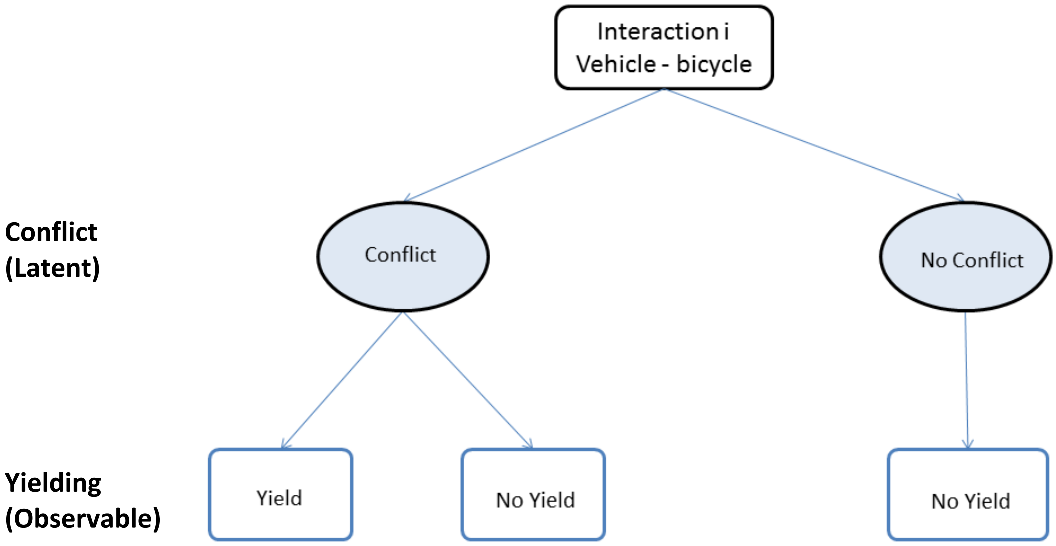


Figure 2. Vehicle yielding decision model represented by a two-stage structure.

2.2 Model structure

In the proposed model framework, the decision point depends on the condition of a traffic facility and driver attribute. For instance, at some crossings the drivers have good vision to the cycle path otherwise they may not. In principle, it can be modeled as a random variable and then identified through model estimation. However, the requirement for data collection is not fulfilled in this study. Therefore, this paper assumes a fixed decision position (distance to the *CZ* for a driver $l_n = L$) for all drivers at the traffic facility being studied.

Given the decision point of a driver, determined by the distance l_n from the *CZ*, the vehicle-bicycle interaction is then modeled by a two-level process shown in Figure 2. A conflict event must occur, though not fully observable, whenever a yielding event is observed. Since the yielding event is binary ($\text{yes} = 1$; $\text{no} = 0$;), a logit model is applied to model the vehicle-bicycle interaction process, and the yielding probability of driver n at the crossing is given by:

$$P(Y_n = 1) = P(Y_n = 1, C = 1) + P(Y_n = 1, C = 0) \quad (1)$$

where *P(Y)* is the probability of yielding and *P(C)* is the probability of conflict. The joint probability of a vehicle to yield with no conflict is zero i.e., $P(Y_n = 1, C_n = 0) = 0$; therefore, the conditional yielding probability can be represented by:

$$P(Y_n = 1) = P(Y_n = 1, C_n = 1) = P(Y_n = 1|C_n = 1) \cdot P(C_n = 1) \quad (2)$$

On the other hand, the non-yielding probability can be derived as follows:

$$P(Y_n = 0) = P(Y_n = 0, C_n = 1) + P(Y_n = 0, C_n = 0)$$
$$= P(Y_n = 0|C_n = 1) \cdot P(C_n = 1) + P(C_n = 0). \quad (3)$$

Next, the probability of a driver perceiving a conflict and the probability of having a yielding event are both represented by two different binary logit models whose utility functions are determined by the predefined predictor variables respectively. The probability of conflict by a vehicle given the driver decision point is given by:

$$P(C_n = 1) = \frac{e^{\boldsymbol{\Phi}\cdot \boldsymbol{X}}}{1+e^{\boldsymbol{\Phi}\cdot \boldsymbol{X}}} \tag{4}$$

where Φ is parameter vector and X is a vector of covariates to explain whether the conflict happens. The yielding probability is given by:

$$P(Y_n = 1|C_n = 1) = \frac{e^{\boldsymbol{\Psi}\cdot \boldsymbol{Z}}}{1+e^{\boldsymbol{\Psi}\cdot \boldsymbol{Z}}} \tag{5}$$

where **Ψ** is a parameter vector and Z is a vector of covariates that estimate the factors that explain the decision. The observed data typically include vehicle and bicycle trajectories and vehicle yielding decisions (i.e. y_n $n = 1 \dots N$). Following equations (2) and (3) the likelihood of driver making a yielding decision y_n is calculated by:

$$P(y_n) = \left(P(y_n = 1)\right)^{y_n}\left(P(y_n = 0)\right)^{1-y_n} \tag{6}$$

where y_n takes values 1 or 0 depending on driver yielding decision. In other words, if a yielding event is observed, y_n takes value 1 contributing to the yielding probability. On the other hand, if a non-yielding event takes place, y_n takes value 0 contributing to the non-yielding probability.

Therefore, the likelihood function of obtaining the observed decisions over all drivers is represented by the joint probability of observing N vehicle-cyclist interacting events.

$$P(y_1 \dots y_N) = \prod_{n=1}^{N}\left(P(y_n = 1)\right)^{y_n}\left(P(y_n = 0)\right)^{1-y_n} \tag{7}$$

Based on the equations (2)-(3), the log-likelihood function can be further expressed as:

$$\mathcal{L} = \sum_{n=1}^{N} \log\left(\left(P(y_n = 1)\right)^{y_n}\left(P(y_n = 0)\right)^{1-y_n}\right) \tag{8}$$

By replacing the corresponding logit models (5)-(6), the final log-likelihood function becomes:

$$\mathcal{L} = \sum_{n=1}^{N} \log\left(\left\{\frac{e^{\Psi\cdot z}}{(1+e^{\Psi\cdot z})}\cdot\frac{e^{\Phi\cdot x}}{(1+e^{\Phi\cdot x})}\right\}^{y_n}\left\{\frac{1}{(1+e^{\Psi\cdot z})}\cdot\frac{e^{\Phi\cdot x}}{(1+e^{\Phi\cdot x})}+\frac{1}{(1+e^{\Phi\cdot x})}\right\}^{1-y_n}\right). \tag{9}$$

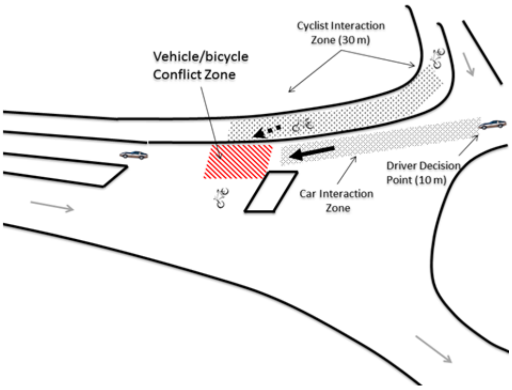
Therefore, by maximizing the likelihood function, both the model parameters for observed yielding event and hidden conflict event could be identified.

3 CASE STUDY

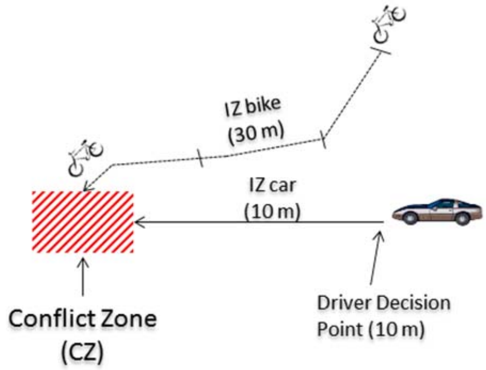
3.1 Data description

The data used in the case study was collected in the autumn 2013 by means of video cameras comprising 2 hours of video recordings during the afternoon peak from 16 to 18 hours. Weather conditions were clear and dry. A video analysis program was used to extract yielding behavior and corresponding useful information. For model estimation purposes, both vehicle and bicycle trajectory data as well as cyclist and driver characteristics are ideally required as they interact towards the conflict zone. Because of the limitation of obtaining trajectory data from the current image software as well as lack of cyclist and driver characteristics information, the proposed method assumes a fixed decision point where all drivers will make decision, and final estimated models will not consider cyclist and driver characteristics.

In suburban areas, roundabouts are normally the place where vehicle-bicycle interaction takes place regularly. When attempting to exit a roundabout described in Figure 3(a), drivers primarily consider the traffic in the incoming entry lane, though they have priority over that traffic stream. Afterwards, drivers have a clear sight into the sidewalk to detect the presence of cyclists upstream on the sidewalk or bicycle path. Thus the decision to yield takes place few meters away from the *CZ*. Therefore, based on the geometric conditions of the studied roundabout, drivers' decision point was set to 10 meters away from the *CZ*. See Figure 3(b). This distance allows drivers a clear sight upstream the sidewalk, and allows them to react to the presence of cyclists accordingly as shown in Figure 3(c). The cyclist is traced at 3 points with a space of 10 meters in between. Figure 3(d) illustrates the cyclist's approaching view at 30 m away from the *CZ*. Consequently, the car *IZ* is 10 meters long, whereas the bike *IZ* is 30 m long comprising 3 segments or regions of 10 meters. It is assumed that there is vehicle-bicycle interaction whenever a driver and a cyclist are in their interaction zones (mainly because of the limitations of the available data). For instance, if a vehicle arrives at the car *IZ* and there is no cyclist in the bike *IZ*, no conflict event occurs (hence no yielding event). On the other hand, if there are vehicle and bicycle in the interaction zones simultaneously, a conflict event may take place.



a) Roundabout layout



b) Conflict and interaction zones

c) Driver's view at 10 m

d) Cyclist's view at 30 m

Figure 3. Roundabout layout, interaction zones and road users' views.

3.2 Utility for vehicle-cyclist conflict event

Since logistic regression is applied to model the binominal probability of conflict, the system utility is represented by $V = \phi \cdot X$ where ϕ is parameter vector and X is vector of explanatory variables. A number of explanatory variables can be used to capture the probability of a conflict. The arrival-time at the boundary of each interaction zone is used as the key covariate. Besides, the conflict probability is found affected by whether the car or the bicycle arrives first at the interaction zone. It is expected that the impact of the arrival time difference (*ATD*) between the car and the bicycle explains the probability of conflict. Given the interaction zone boundaries and the difference of vehicle and bicycle dynamics, it is assumed that the shorter the difference of the arrival time is, the stronger the conflict should be. Two variables are introduced as follows:

$$\chi_1^{ATD} = \max(0, T_{car} - T_{bike}) \tag{10}$$

$$\chi_2^{ATD} = \min(0, T_{car} - T_{bike}) \tag{11}$$

where χ_1^{ATD} represents the case when the bicycle arrives first with only positive values by definition, T_{car} is the vehicle arrival time, and T_{bike} is the bicycle arrival time at the *IZ* boundary respectively; and χ_2^{ATD} denotes the situation that the vehicle arrives first at the boundary of the interaction zone. So the utility of conflict in equation (4) is thus represented by:

$$V_{conf} = \Phi \cdot X = \phi_0 + \phi_1\chi_1^{ATD} + \phi_2\chi_2^{ATD} \tag{12}$$

Table 1. Summary of explanatory variables used for estimation of conflict probability.

Parameter	Variable	Unit	Description
ϕ_0	-	-	Constant
ϕ_1	χ_1^{ATD}	Sec	Arrival time difference when bicycle arrives first.
ϕ_2	χ_2^{ATD}	Sec	Arrival time difference when car arrives first

Table 2. Summary of variables used in the yielding estimation.

Parameter	Variable	Unit	Description
ψ_0	-	-	Constant
ψ_1	V_{car}	Km/h	Instantaneous speed of a vehicle at the start of the *IZ* zone
ψ_2	R_1	dummy	1 if the bike is in *Region 1* (0-10 m) when the car arrives at decision point, else 0
ψ_3	R_2	dummy	1 if the bike is in *Region 2* (11-20 m) when the car arrives at decision point, else 0
ψ_4	R_3	dummy	1 if the bike is in *Region 3* (21-30 m) when the car arrives at decision point, else 0
ψ_5	V_{bike}	Km/h	Bicycle velocity measured with reference to the car at 10 m away from conflict zone

3.3 Utility for yielding event

Provided that a conflict has occurred, the driver needs to make a decision with two possible mutually exclusive outcomes i.e., yield or not yield to the conflicting cyclist (see Figure 2). The vehicle speed at the moment that driver makes decision (fixed at 10 meters away from the *CZ)* is applied in modeling binomial probability of yielding. Other predictor variables include the relative speed and position of the bicycle with respects to the vehicle at the decision point. Table 2 summarizes the predictor variables that are included in our study. The system utility for the logistic regression on yielding is then modeled by

$$V_{yield} = \Psi \cdot Z = \psi_0 + \psi_1 z_1 \cdots\cdots + \psi_5 z_5 \tag{13}$$

Where, $\boldsymbol{\Psi}$ is a parameter vector and *Z* is a vector of explanatory variables. Certainly, site geometric characteristics play an important role in the yielding process (e.g., 1-lane, 2-lane facilities; raised or non-raised crosswalks; painted, non-painted bicycle lanes; angle of intersecting approaches; road and sidewalk width and gradient, etc.). However, data from different facilities are needed to account for such variability, which is limitation for this study.

4 RESULTS AND DISCUSSION

The model identification approach presented by equation (6)-(9) is implemented in MATLAB. Table 3 summarizes the parameter estimation results for three different models being proposed. Model I shows that the yielding probability is mainly a function of the speed of the car. Model II relates the yielding probability to the speed of the car and the influence of proximity regions when the interacting bicycle gets closer to the *CZ*. Model III adds the speed of the cyclists in the model II.

According to the model identification results, model III presents the highest log-likelihood value compared to models I and II. However, the incorporation of the bicycle speed in model III does not provide for model improvement compared to model II. The likelihood ratio index (adjusted ρ^2) shows that model II is the best model whereas the Cox & Snell R^2 difference between model II and III is only 0.0001. In summary, the results suggest that Model II is preferred, though from the segment variables, only segment R_1 is significant at 10 %.

Table 3. Summary of the model estimation results (t-statistics in parenthesis)

Parameters		**Model I**		**Model II**		**Model III**	
		Estimate	***(t-value)***	**Estimate**	***(t-value)***	**Estimate**	***(t-value)***
Conflict Probability							
Constant	ϕ_0	4.480**	*(3.39)*	3.721**	*(2.70)*	3.720**	*(2.77)*
χ_1^{ATD}	ϕ_1	-0.665**	(-2.33)	-0.469	(-1.12)	-0.477**	(-1.20)
χ_2^{ATD}	ϕ_2	4.432**	(2.49)	3.633*	(1.94)	3.646**	(1.99)
Yielding Probability							
Constant	ψ_0	14.639**	(3.37)	19.634*	(1.72)	20.411*	(1.72)
$\mathrm{V}_{\mathrm{car}}$	ψ_1	-0.824**	(-3.48)	-1.196*	(-1.85)	-1.240*	(-1.84)
R_1	ψ_2	-	-	5.220*	(1.76)	3.298	(0.27)
R_2	ψ_3	-	-	2.911	(1,32)	0.851	(0.06)
R_3	ψ_4	-	-	0.143	(0.07)	-1.997	(-0.15)
$\mathrm{V}_{\mathrm{bike}}$	ψ_5	-	-	-	-	0.130	(0.16)
$\mathrm{LL}(\beta)$		-27.761		-22.121		-22.107	
Likelihood ratio index(corrected ρ^2)		0.6531		0.6811		0.6706	
Cox & Snell (R^2)		0.5155		0.5443		0.5444	
$\mathrm{LL}(0)$		-94.445					
No. of observation		184					
Yielding events		37					

**Statistically significant at the 5% level;

*Statistically significant at the 10% level.

4.1 Conflict probability

Model I shows statistical significant estimates whereas models II and III have ϕ_1 as insignificant. The results show that when a vehicle arrives first (negative axis values) at the interaction zone, there is a probability that a conflict is perceived by the driver if a cyclist arrives at the interaction zone within 2.0 seconds. If the cyclist arrives later, the probability of conflict is negligible, i.e., the driver does not perceive any conflicts and traverses the interaction and conflict zones undisturbed. For example, a vehicle travelling at 20 km/h (5.5 m/s) in the roundabout can completely traverse the car *IZ* within 2 seconds with no cyclist in eyesight. The probability of conflict is about 0.50 (i.e., a driver has 50 % chance to perceived a conflict situation) if a cyclist arrives at the bike *IZ* after 1.0 second. Equivalently, a driver traveling at a higher speed will not perceive any conflict since he or she is able to pass through the intersection quickly; however, drivers moving at lower speeds could certainly experience a conflict with the approaching cyclist.

On the other hand, when a bicycle arrives first (positive axis values) at the interaction zone, there is probability of conflict up to about 14 seconds. For example, at the speed of 10 km/h (2.7 m/s) the cyclist takes 11-12 seconds to reach the *CZ* thus a driver arriving later can still catch up with the cyclist in a collision course resulting in a conflicting event. In Figure 4, model I shows a conflict probability up to 11 seconds and models II and III indicate a conflict probability up to 14 seconds. At about 7.0 seconds in model I and 8.0 seconds in models II and III, the results estimate a conflict probability of 0.5, indicting that a driver has 50 % chance to perceive a conflict situation with the approaching cyclist. The probability of conflict is very high, almost 1, for the case when a vehicle arrives within 4 seconds after a bicycle arrival.

The results show as well that the estimated conflict probabilities do not change when the bicycle speed is included in the estimation. Model II has almost the same probabilities compared to model III, though ϕ_1 is not significant. Therefore, the speed of the bicycle has practically no impact when it is included in the estimation. On the other hand, the impact of the cyclist proximity is important with a shift upwards and to the right on the conflict probability. This is clearly seen in model I (without regions) compared to model II (with regions).

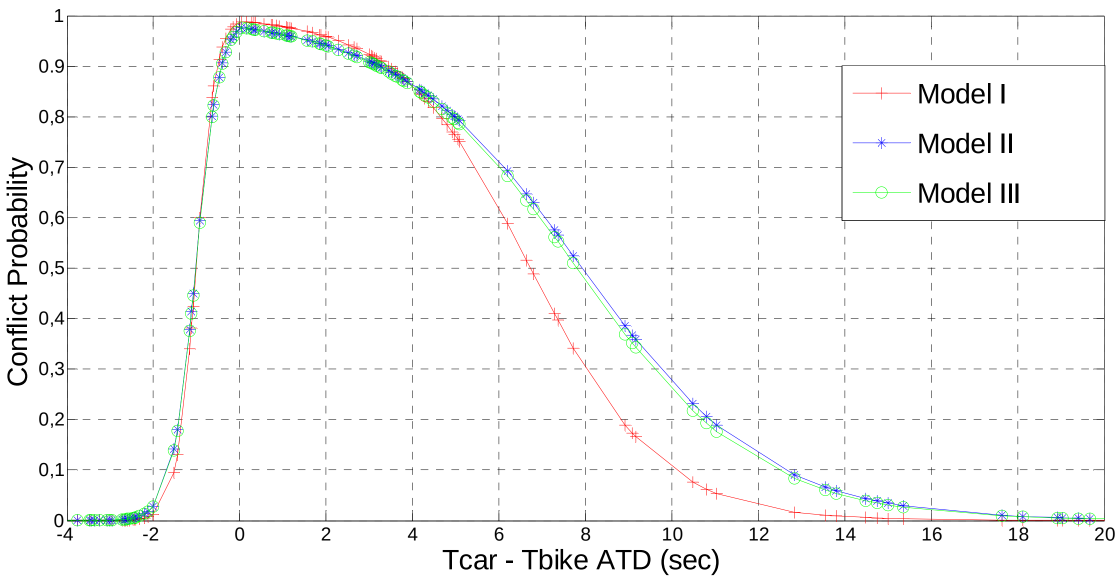


Figure 4. Probability estimates for the conflict events.

4.2 Yielding probability

The results in Table 3 show that the speed of the vehicle is negatively correlated with the yielding probability in all models as expected i.e., higher car speeds result in lower probabilities to yield. At higher speeds drivers have less time to detect for cyclists and react accordingly. This is very much in accordance with the findings of [6]. Figure 5 plots the results of the models. The results suggest that there is a probability that a yielding event takes place if the speed of the vehicle is under 20-22 km/h, given that a conflict has occurred. The yielding probability estimates for model I differs from models II and III which are fairly similar. Model I shows yielding probabilities up to 22 km/h indicating that vehicles with higher speeds yield to cyclists compared to models II and III which shows yielding probabilities up to 20 km/h. Although the segment variables in models II and III are not significant (only ψ_2 in model II at 10%), the proximity of the cyclist agree with a priori expectations i.e. the closer the cyclist is to the *CZ*, the higher the yielding probability should be. Thus the closer the cyclist is to the *CZ* the higher the influence is on the driver. In model II; *Region 1* (R_1) presents the highest impact on the yielding probability. The presence of a cyclist within 10 m from the *CZ* induces drivers moving at higher speed to yield which is increased by 5.22 km/h compared to the situation where there is no interacting cyclist. *Region 2* (R_2) shows an increase as well in the yielding probability; however, the impact is lower compared to the previous region since the cyclist is farther away (11 – 20 m from the *CZ*). The cyclist's presence in this region induces drivers travelling at higher speed to yield which is increased only by 2.91 km/h compared to the situation where there is no approaching cyclist. Interestingly, *Region 3* (R_3) shows an increase of 0.14 km/h which is probably interpreted as some drivers may decide to go through the *CZ* before the cyclist gets there since the cyclist is far between 21-30 m away. During the video inspections it was observed that some drivers speed up instead once a cyclist was detected in R_3. Consequently, according to the segment results, R_1 and R_2 have a positive and important impact on the driver yielding decision and might point out a threshold distance for such impact (In our case 20 m according to the setup of the cyclist track). Nevertheless, the impact of cyclist presence in R_3 is not negligible. But the impact is smaller and might be in the opposite direction reducing the yielding probability. On the other hand, the speed of the bicycle was expected to increase the yielding probability and according to the results the bicycle speed has a very small impact on the driver yielding decision when it is incorporated in the estimation. Correlation with segment variables may play a role for the results.

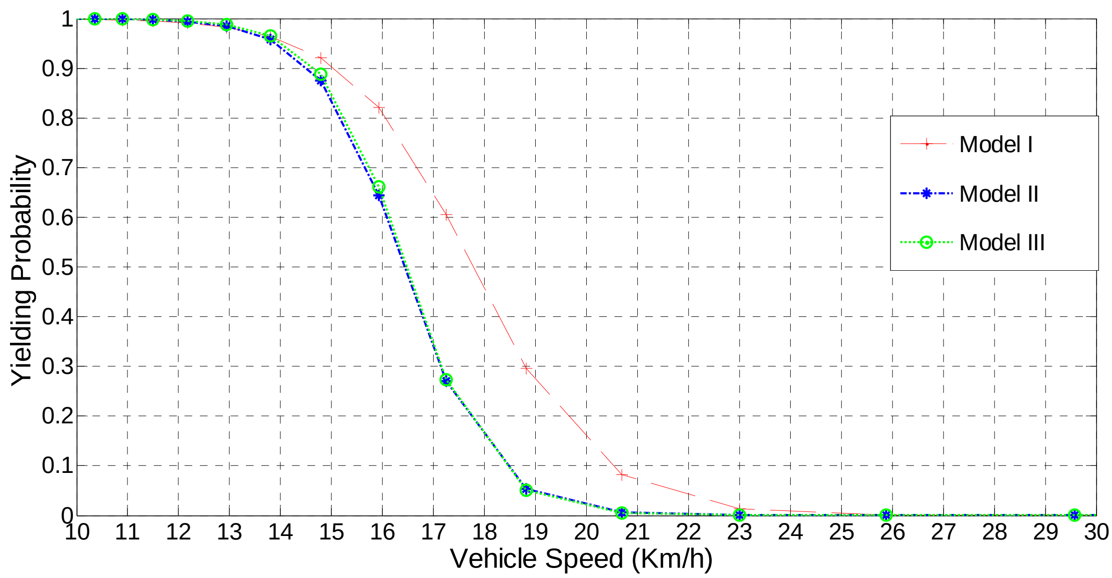


Figure 5. Probability estimates for the yielding events.

5 CONCLUSIONS AND RECOMMENDATIONS

The paper proposes a two-level framework to model drivers' yielding decisions. Level 1 is treated as a latent state and captures conflict probabilities while level 2 models the yielding probabilities. According to the results the most important factors influencing drivers' yielding decisions are: i) the speed of the vehicle and ii) the relative position of the cyclist to the *CZ*. Surprisingly, the impact of the cyclist speed is small and might have an impact in both directions increasing or decreasing the yielding probability depending on the bicycle relative position. For instance, a slow cyclist further away encourages a driver to speed up instead of giving way to the cyclist. This behavior indeed can cause accidents if the driver misjudges the situation. The conflict probability depends on whether the driver or the cyclist arrives first at the *IZ* zones. For instance, if the vehicle arrives first, there is a probability that a conflict is perceived if a cyclist enters the interaction zone within 2.0 seconds later. In the other case when the cyclist arrives first, there is a probability of conflict even if the car arrives up to 12-14 seconds later.

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