Evaluation of user behavior and acceptance of an on-bike system

Published Version:
Prati, G., Marín Puchades, V., De Angelis, M., Pietrantoni, L., Fraboni, F., Decarli, N., et al. (2018). Evaluation of user behavior and acceptance of an on-bike system. TRANSPORTATION RESEARCH PART F: TRAFFIC PSYCHOLOGY AND BEHAVIOUR, 58, 145-155 [10.1016/j.trf.2018.06.005].

Availability:
This version is available at: https://hdl.handle.net/11585/650298 since: 2018-11-20

Published:
DOI: http://doi.org/10.1016/j.trf.2018.06.005

This is the final peer-reviewed accepted manuscript of:

Prati, G., Marín Puchades, V., De Angelis, M., Pietrantoni, L., Fraboni, F., Decarli, N., … Dardari, D. (2018). Evaluation of user behavior and acceptance of an on-bike system. Transportation Research Part F: Traffic Psychology and Behaviour, 58, 145–155. https://doi.org/10.1016/j.trf.2018.06.005

The final published version is available online at:

https://doi.org/10.1016/j.trf.2018.06.005

Evaluation of User Behavior and Acceptance of an On-Bike System

Gabriele Prati[a], Víctor Marín Puchades[a], Marco De Angelis[a], Luca Pietrantoni[a], Federico Fraboni[a], Nicolò Decarli[b], Anna Guerra[b], & Davide Dardari[b]

[a]Department of Psychology, University of Bologna, Viale Europa 115, 47521 - Cesena (FC) - Italy

[b]Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi" (DEI), via Venezia, 52, 47521 - Cesena (FC) - Italy

Corresponding author

Gabriele Prati, Dipartimento di Psicologia, Università di Bologna, Viale Europa 115, 47521 Cesena (FC), Italy; Tel.: +39 0547338507; fax +39.0547338503 (fax). Email: gabriele.prati@unibo.it.

Abstract

In this study, users' acceptance of an on-bike system that warns about potential collisions with motorized vehicles as well as its influence on cyclists' behavior was evaluated. Twenty-five participants took part in a field study that consisted of three different experimental tasks. All participants also completed a follow-up questionnaire at the completion of the three-task series to elicit information about the acceptance of the on-bike system. In the experiment phase, participants were asked to ride the bicycle throughout a circuit and to interact with a car at an intersection. Participants completed three laps of the circuit. The first lap involved no interaction with the car and served the purpose of habituation. In the second and third laps participants experienced a conflict with an incoming car at an intersection. In the second lap, the on-bike device was not activated, while in the third lap, participants received a warning message signaling the imminent conflict with the car. We compared the difference in user's behavior between the second lap (conflict with a car without the warning of the on-bike system) and the third lap (conflict with a car with the warning of the on-bike system). Results showed that, when entering the crossroad, participants were more likely to decrease their speed in case of warning of the on-bike system. Further, the on-bike system was relatively well accepted by the participants. In particular, participants did not report negative emotions when using the system, while they trusted it and believed that using such technology would be free from effort. Participants were willing to spend on average 57.83€ for the system. This study highlights the potential of the on-bike system for promoting bicycle safety.

Keywords: cycling, safety, willingness to pay, evaluation, technology acceptance, on-bike device

1. Introduction

Bicycle use is an alternative and complementary mode of transportation and is recognized to have individual health benefits (Götschi, Garrard, & Giles-Corti, 2016; Kelly et al., 2014) as well as societal benefits such as reduction in traffic congestion, air and noise pollution, and fossil fuel consumption (de Nazelle et al., 2011; Macmillan et al., 2014; Xia, Zhang, Crabb, & Shah, 2013). However, the adoption of cycling for transportation has been slowed due to safety concerns and because bicyclists are considered vulnerable road users (Wegman, Zhang, & Dijkstra, 2012), or better, minority road users (Prati, Marín Puchades, & Pietrantoni, 2017).

Collisions involving motor vehicles account for the majority of the recorded bicyclists' crashes resulting in serious injuries and fatalities in police and hospital records (Chong, Poulos, Olivier, Watson, & Grzebieta, 2010; Nicaj et al., 2009; Prati, De Angelis, Marín Puchades, Fraboni, & Pietrantoni, 2017; Rosenkranz & Sheridan; Rowe, Rowe, & Bota, 1995; Sze, Tsui, So, & Wong, 2011). Although different factors account for bicycle–motorized vehicle collisions, the central role played by the behavior both of the cyclist and the driver of the opponent vehicle involved in the collision has been ascertained (Prati, Marín Puchades, De Angelis, Fraboni, & Pietrantoni, 2017). Based on that, it has been suggested the adoption of an on-bike system that informs cyclists about potential collisions with approaching vehicles (Prati, Pietrantoni, & Fraboni, 2017). However, to our knowledge, bicyclist's behavior and acceptance of an on-bike system that warns about potential collisions have not been yet evaluated. This paper aims to address this gap in knowledge by examining bicyclist's behavior and acceptance of an on-bike system.

The acceptance of intelligent transport systems has been conceptualized and operationalized in different ways (e.g., Huth & Gelau, 2013; Payre, Cestac, & Delhomme, 2014;

Van der Laan, Heino, & De Waard, 1997; Vlassenroot, Brookhuis, Marchau, & Witlox, 2010; Wolf & Seebauer, 2014). Van der Laan et al. (1997) proposed a standardized checklist to assess drivers' acceptance of new technology. The Van der Laan scale comprises two dimensions, one denoting the usefulness of the system, and the other one designating satisfaction associated with the system. Among the theories and models of user acceptance of information technology, Venkatesh, Morris, Davis, and Davis (2003) described and analyzed different underlying basic concepts in behavioral models, such as the Theory of Planned Behavior (TPB; Ajzen, 1991), the motivational model (Vallerand, 1997), the Technology Acceptance Model (TAM; Davis, 1989; Davis, Bagozzi, & Warshaw, 1989), and the Social Cognitive Theory (Bandura, 1986), that can be applied to the acceptance of technology. Based on these acceptance models, Venkatesh et al. (2003) developed a unified model named the Unified Theory of Acceptance and Use of Technology (UTAUT). In the UTAUT, four core determinants of intention to use the technology are conceptualized: (1) performance expectancy (e.g., perceived usefulness and trust from the TAM); (2) effort expectancy (e.g., perceived ease of use from the TAM); (3) social influence (e.g., subjective norm from TPB); and (4) facilitating conditions (e.g., perceived behavioral control from the TPB). Osswald, Wurhofer, Trösterer, Beck, and Tscheligi (2012) developed and extended the UTAUT with the Car Technology Acceptance Model (CTAM) that unifies several models of technology acceptance. Specifically, they added four further direct determinants of intention to use the technology besides those included the UTAUT: perceived safety (e.g., users' beliefs about the degree to which the system can affect the safety), anxiety (e.g., anxious or emotional reactions when it comes to use the technology), self-efficacy (e.g., belief in users' ability and competence to use a technology), and attitude toward using technology (e.g., overall affective reaction upon using a system). While the Van der Laan scale is focused on users' perception, the target variable of CTAM and UTAUT is the intention to use/ usage behavior. User-acceptance may also include an assessment of the price people are willing to pay or sell the technology (e.g., Huth & Gelau, 2013; Payre et al., 2014; Son, Park, & Park, 2015; Vlassenroot et al., 2010; Wolf & Seebauer, 2014). Based on the above description of the approaches to investigate the acceptance of a new technology, the first aim of this work was to investigate potential users' acceptance of an on-bike system that warns about potential collisions with motorized vehicles. Information about users' acceptance of an on-bike system was collected using the Van der Laan scale as well as measures of intention to use the technology, perceived usefulness, perceived ease of use, attitude toward technology, facilitating conditions, anxiety, perceived safety, trust, social influence, willingness to pay (WTP) and willingness to accept (WTA). We did not collect information about self-efficacy because the system does not require any ability and competence to be used.

In addition to users' acceptance, device assessment in road safety also requires an evaluation of the technological solution effectiveness in terms of users' behavior (Bordel et al., 2014; Son et al., 2015). For instance, in the field of advanced driver assistance systems, the effectiveness of forward collision warning system as well as lane departure warning system was investigated in terms of improvements in driving safety behavior (e.g., Ben-Yaacov, Maltz, & Shinar, 2002; Blaschke, Breyer, Färber, Freyer, & Limbacher, 2009). To this end, the second aim of the study was to investigate cyclists' behavior in response to the triggering of the device.

2. Method

2.1 Ethical Considerations

The data collection procedure complied with the Research Ethical Code of the Italian Association of Psychology. All participants were asked to provide written informed consent prior to their inclusion in the study. Specifically, we informed participants about (1) the purpose of the study and its characteristics (e.g., duration and procedures); (2) their right to decline to participate, and to withdraw participation at any time without penalty; (3) potential risks, discomfort or adverse effects associated with the study (e.g., the risks associated with this research are the same as what they face every day while riding a bicycle); (4) any potential research benefits; (5) any data collected during the study that personally identifies them would have been treated with confidentiality; (6) incentives for participation; and (7) an explanation of the proper person to contact for questions about the research, its findings, and research participants' rights.

2.2 Participants

Twenty-five participants (21 female, 84%) aged between 19 and 57 years (M = 23.80, SD = 9.22) took part in the study. The median family monthly income of participants was between 2,000.00 and 3,000.00€ (range = 1,000.00-4,500.00€). Ten participants (40%) do not usually cycle, while nine (36%) cycle once a week, three (12%) twice a week, one (4%) three times a week, and two (8%) four or more times a week. The mean percentage of use of motorized vehicles on the basis of various travel purposes was 37.29% (SD = 25.62) with a range between 0 and 80%.

2.3 Measures

2.3.1 Acceptance

We measured acceptance focusing on both user's perceptions and intention to use the system. Thus, we used the scale from Van der Laan et al. (1997), as well as measured the constructs included in the CTAM with the scales from Osswald et al. (2012) and Ghazizadeh, Peng, Lee, and Boyle (2012). The Van der Laan et al. (1997) scale includes nine semantic differential items representing different attitudes toward the system. Participants were asked to rate on a five-point scale (from 2 to +2) what level of these adjective continuums they attributed to the evaluated system. The items are grouped into two scales, one indicating the usefulness of the system, and the other the satisfaction resulting from the use of the technology. An example of two opposite adjectives for an item measuring the usefulness of the system is "Effective/Superfluous," whereas an example of the satisfaction scale is "Pleasant/Unpleasant." Cronbach's index of internal consistency for the usefulness and satisfaction subscales was .94 and .80, respectively. A total of 30 items were used to measure the variables involved in the CTAM. Participants were asked to express their degree of agreement to the 30 items on a five-point Likert scale (1 = *strongly disagree*; 5 = *strongly agree*). Reliability (Cronbach's alpha) and descriptive statistics of the scale items are reported in Table 1. To measure Trust in the system, we used one item of the scale by Ghazizadeh et al. (2012). The item was "I think I can depend on the innovative technology." For the rest of the constructs, we adapted the scales used by Osswald et al. (2012) to the cycling context. Thus, to measure Performance expectancy, we used a four-item scale, an example of which would be "The system would be useful while cycling." The scale used to measure Effort expectancy also comprised four items. One example is "I find the system easy to use." Four items were used to measure Attitudes toward the technology, and an example of item would be "Using the system is a good idea." We used two items to measure Social influence. An example of one of them would be "I would be proud to show the system to people who are close to me." The three items of the scale of Facilitating conditions were used. An example of them is "I have the knowledge necessary to use the system." Anxiety was measured using three of the items of the scale, for instance, "I have concerns about using the system." The three items of the Behavioral intention to use the system scale were used. One example of it is “Given that I had access to the system, I predict that I would use.” Regarding the Perceived safety, we used the six-item scale. An example of item would be “I believe that using the system is dangerous.”

2.3.2 Willingness to pay and willingness to accept

We measured WTP by asking them to indicate the maximum amount of money they would be willing to pay for it (Simonson & Drolet, 2004). To measure the WTA, we asked the amount of money for which they would sell the system if they had it in their possession (Simonson & Drolet, 2004).

2.3.3 Risk perception of mixed traffic

Three items of the fear of traffic scale from Chataway, Kaplan, Nielsen, and Prato (2014) were used to measure risk perception of mixed traffic. An example of item would be “I feel unsafe due to the proximity of cars behind me.” A five-point Likert scale ranging from 1 = *never* to 5 = *always* was used.

2.3.4 Position, speed, and trajectory

To realize an experiment capable of revealing the behavior of cyclists in the absence and presence of an on-bike system, an ad-hoc technology was used to collect the necessary data. The idea was to record the trajectory of the cyclist during the experiment and to analyze it off-line to determine its speed in several portions of the path and to analyze the trajectory contour (e.g., if deviations were present when approaching the intersection and/or the car, or after the activation of the warning of the on-bike system).

The common technology used for positioning (i.e., trajectory estimation) is the global navigation satellite system (GNSS), among which the global positioning system (GPS) is the most famous implementation. However, such widely adopted positioning solutions do not provide a sufficient accuracy for analyzing the trajectory of a bike and for exactly determining its speed. For this reason, a new technology was employed for the experiments. In particular, a so-called real-time locating system (RTLS) developed by the University of Bologna has been adopted (Dardari et al., 2017). Such RTLS is composed of a certain number of reference radios placed in known positions in the environment, namely anchors. The anchors act as the satellites in the GNSS, thus collecting measures with respect to a moving radio, namely tag, whose trajectory estimation is the goal of the system. In our case, such tag was placed on the moving bike, i.e., the target of the experiment. Five anchors were placed on several points along the bicycle path of the experiment so that a positioning accuracy < 50 cm could be guaranteed. In the left portion of Figure 4, a map of the environment is depicted with the anchors nodes represented by a square green marker.

This innovative RTLS is able to guarantee such accuracy thanks to the adoption of a particular radio technology, called ultra-wide band (Gezici et al., 2005). The main characteristic of this approach is given by the capability of determining, exploiting ad-hoc processing techniques, the distance between two radios; such distance is computed from the measurement of the radio signal propagation time between the transmitting and receiving antennas. Once the distances between the tag and the anchors are inferred, a localization algorithm is used to uniquely determine the tag’s position in the considered reference system.

In a second phase, an off-line processing tool can reproduce the bicycle trajectory in the map. In the left portion of Figure 4, the bike trajectory is shown with circle markers. The colors of them represent the points in which the HMI was active (red) or not operative (cyan). On the right portion of Figure 4, the speed of the bike is shown. Starting from the raw trajectory data, several features could be extracted to assess the users' behavior during the experiment. In particular, the more significant ones that we have adopted are listed in the following:

- Average speed: the average speed of the cyclist during the entire path of the experiment.
- Average speed pre-intersection: the average speed of the cyclist in the seven meters before the intersection. Computed in both the cases of simple conflict without the on-bike system and with the system activated (second and third laps).
- Average speed post-intersection: the average speed of the cyclist in the seven meters after the intersection. Computed in both the cases of simple conflict without the on-bike system and with the system activated (second and third laps).
- Average speed pre-HMI: the average speed of the cyclist in the three seconds before the activation of the HMI. Computed only in the lap with the on-bike system activated (third lap).
- Average speed post-HMI: the average speed of the cyclist in the three seconds after the activation of the HMI. Computed only in the lap with the on-bike system activated (third lap).
- Angle post-intersection: the angle between the trajectory point corresponding to seven meters after the intersection and the trajectory point corresponding to the beginning of the intersection. Since before the intersection the trajectory is expected to be almost straight, a large angle indicates a deviation from the normal path. Computed in both the cases of simple conflict without the on-bike system and with the system activated (second and third laps).

- Angle post-HMI: the angle between the trajectory point corresponding to three seconds after the activation of the HMI and the trajectory point corresponding to the activation of the HMI. Computed only in the lap with the on-bike system activated (third lap).

Notice that, in the experiment tasks, the HMI was manually activated. However, the adoption of such a positioning technology could pave the way to the deployment of a practical on-bike system to warn automatically the bicyclists. In fact, if the RTLS is able to estimate with high accuracy the position of every road user, especially when approaching the intersection, an early warning could be delivered when a potential conflict is detected. Technical details about the implementation of such kind of solution can be found elsewhere (Dardari et al., 2017).

2.4 Procedure

Participants were contacted during the lessons of the course in Social Psychology hosted by the Faculty of Political Sciences of the University of Bologna, in Forlì, Italy. A researcher explained the study during the lessons and students were invited to contact the researcher by email showing their interest in participating and stating their preferred date to take part in the study. The course allowed students the possibility of obtaining course credits by participating in the field test or by performing another type of assignment. Participation in the study involved one day and lasted around 45 minutes. The study consisted in three phases: (1) pre-experiment survey; (2) experiment tasks; and (3) post-experiment survey. Next, we explain each one of the phases.

2.4.1 Pre-experiment survey

In this phase, participants were welcomed in a facility nearby the experiment circuit, and were asked to complete the informed consent form. After having signed the written informed consent, each participant was asked to fill out a brief questionnaire containing questions about bicycle use and socio-demographic data (e.g., family income, gender). Once the survey was completed and the previous participant had finished, they were accompanied to the circuit.

2.4.2 Experiment tasks

The main task undertaken by the participants consisted in riding the bicycle throughout the circuit and interacting with a car at an intersection. The circuit was oval and contained an intersection equipped with the reference nodes to estimate the position of the bicycle (Figure 1). The car that interacted with participants was always driven by the same researcher to minimize differences in trajectories and speed. To keep a safe distance between the car and the participants, we established a landmark that the car could not surpass in each scenario. Moreover, we established the zone of the road that participants could use on the basis of the side from which the car approached the intersection. For this, we placed conspicuous and colorful cones on the road surface to ensure that the participants would not cycle too close to the car landmark. Figure 1 shows how the cones where placed for each one of the situations.

There were two different conflicts between car and bicycle at intersection, involving distinct car maneuvers. All the participants had to go through each one of them. In one conflict, the car popped out from behind a small truck conveniently parked on the left side of the intersection when the participant was approaching (Figure 2). The other conflict involved the car coming from the opposite direction and turning left and eventually stopping to yield to the participant (Figure 3). Moreover, there were two conditions that regarded the use of the system: the first one without the system, and the second one, in which the system was switched on and the participants were warned of the incoming hazard. The conditions always followed the same order, whereas the two conflicts were randomly counter balanced in ordering across participants to eliminate the order and sequence effects of passing through one conflict with the car before the other.

Before taking part in the different conditions, participants were provided with a helmet and were instructed to ride the bicycle through the circuit. They were told that they would share the road with a vehicle, and that all the situations were controlled so that the vehicle would not surpass a minimum distance threshold from them to avoid any contact. Moreover, they were asked to respect the road rules and to behave as they would do outside of the experiment. Then, they were instructed to stop when they were requested to and were told that they would be shortly interviewed about the latest laps then. Once the experimenter had ensured that the instructions were well-understood and effectively addressed any doubts and uncertainties about the study, participants were asked to start cycling.

Participants completed three laps of the circuit. The first lap involved no interaction with the car and served the purpose of habituation to the bicycle and of checking the correct understanding of the path that the participants had to follow. The second and third laps involved the participants interacting with the car, keeping the scenarios in the order previously assigned to each one of them. In the second lap, the on-bike device was not activated, while in the third lap, participants received a warning message signaling the conflict with the car. Such a message was delivered by a simple HMI composed of an audio alert (a buzzer beeping) and a visual alert (a LED blinking). The HMI was activated manually by a researcher only in the last lap, a few meters before the bike was approaching the intersection where the conflict with the car took place. At the end of each lap, a researcher stopped each participant to ask about the thoughts of the interaction with the car, the risk perceived in it, and how severe the potential consequences seemed. In addition to this, on the third lap, participants were asked about whether they had reacted differently from the second lap, and if so, how.

2.4.3 Post-experiment survey

The questionnaire was filled out in the same nearby facilities where the pre-experiment survey was conducted, and participants were accompanied there by a researcher once the experiment tasks were completed. The questionnaire included the measures of acceptance described above.

2.5 Statistical Analysis

To calculate the *p*-value for non-parametric tests, we used the exact method which gives us an exact significance value and is preferred for small samples. To compare two conditions when the same participants take part in each condition, we used the Wilcoxon signed-rank test.

3. Results

3.1 Acceptance of the On-Bike System

Means and standard deviations for key study variables are shown in Table 1. The mean score for the Intention to use the system was 3.99 with a standard deviation of 1.28, meaning that the participants reported a high level of acceptance of the system. Regarding the determinants of the intention to use the system, the mean score for anxiety were below the midpoint of 3.00, whilst the mean scores for the other measures, especially perceived ease of use and trust, were particularly above the midpoint of 3.00, indicating that most study participants reported that the on-bike technology does not evoke anxious or emotional reactions and is perceived as free of effort and trustworthy. Concerning the willingness to pay for the on-bike system, participants were willing to spend on average 57.83€, *SD* = 43.06€, min = 5.00 max = 200.00. In terms of willingness to accept, the mean lowest price for which participants were willing to sell the on-bike system was 43.73€, *SD* = 31.59€, min = 0.00€ max = 150.00€. WTP was statistically higher than WTA; W_s = 39.50, *z* = -2.03, *p* = .043, *r* = -.43.

Table 1 also shows inter-correlation among key study variables. Risk perception of mixed traffic was not related to the other variables. WTP was associated with WTA only. WTA was not associated with other variables except for trust. Behavioral intention to use was associated with the other measures, especially perceived safety, trust, and attitude toward technology. Perceived usefulness was related significantly to all variables except perceived ease of use.

Table 2 shows results from the van der Laan scale. The results of the items 3, 6, and 8 were mirrored. After having mirrored these items, all numbers had a positive value, denoting the positive part of the bipolar continuum (ranging from -2 to +2) with a neutral zero reference point. Participants perceived the on-bike system as very useful (item 1), good (item 3), effective (item 5), assisting (item 7), and raising alertness (item 9). The mean score for the usefulness scale (*M* = 1.40, *SD* = 0.81, *Mdn* = 1.60) was significantly higher than the mean score for the satisfying scale (*M* = 0.90, *SD* = 0.74, *Mdn* = 1.00); W_s = 29.00, *z* = -3.32, *p*< .001, *r* = -.66.

3.2 Evaluation of User's Behavior and Perceptions in Response to the On-Bike System

We compared the difference in user's behavior between the second lap (conflict with a car without the warning of the on-bike system) and the third lap (conflict with a car with the warning of the on-bike system). Considering the average speed both before and after the conflict, we have found that the average speed without the warning of the on-bike system (*M* = 14.23, *SD* = 3.28, *Mdn* = 12.71) was not statistically different from the average speed with the warning of the on-bike system (*M* = 14.05, *SD* = 2.91, *Mdn* = 14.01); W_s = 126.00, *z* = -.98, *p*= .339, *r* = -.20.We then compared the difference in speed before and after entering the crossroad with the warning of the on-bike system with the same before-after difference without the warning of the on-bike system. The mean score for the before-after difference without the warning of the on-bike system (*M* = 1.38, *SD* = 2.30, *Mdn* = 0.30) was significantly lower than the mean score for the before-after difference with the warning of the on-bike system (*M* = 2.05, *SD* = 2.28, *Mdn* = 1.10); W_s = 237.50, *z* = -2.02, *p* = .043, *r* = -.40. This indicates that, when entering the crossroad, participants were more likely to decrease their speed in case of warning of the on-bike system. We also compared the difference in the trajectory before and after entering the crossroad with the warning of the on-bike system with the same before-after difference without the warning of the on-bike system. The before-after difference in trajectory without the warning of the on-bike system (*M* = 4.88, *SD* = 4.13, *Mdn* = 3.70) was similar to the before-after difference in trajectory with warning of the on-bike system (*M* = 6.54, *SD* = 6.29, *Mdn* = 4.10); W_s = 203.50, *z* = -1.10, *p* = .278, *r* = -.22. This indicates that, when entering the crossroad, participants were not more likely to change their trajectory in case of warning of the on-bike system. Finally, the average speed before the warning of the on-bike system (*M* = 16.64, *SD* = 2.30, *Mdn* = 13.60) was statistically higher than the average speed after the warning of the on-bike system (*M* = 12.80, *SD* = 3.99, *Mdn* = 13.60); W_s = 69.00, *z* = -2.52, *p* = .010, *r* = -.50. This indicates that participants were more likely to ride slowly after the warning of the on-bike system.

In addition to the data regarding user's behavior, we have also collected information on users' risk perception following each conflict (with and without the warning of the on-bike system). The perception of risk regarding the conflict without the warning of the on-bike system (*M* = 2.04, *SD* = 0.54, *Mdn*= 2.00) was statistically lower than the perception of risk regarding the conflict with the warning of the on-bike system (*M* = 2.64, *SD* = 0.86, *Mdn*= 3.00); *Ws* = 221.00, *z* = -2.79, *p* = .007, *r* = -.56. In addition, the perceived consequences of the conflict with the warning of the on-bike system (*M* = 3.12, *SD* = 0.73, *Mdn*= 3.00) were statistically more severe than the perceived consequences of the conflict without the warning of the on-bike system (*M* = 2.76, *SD* = 0.88, *Mdn*= 3.00); W_s = 56.00, *z* = -2.19, *p* = .045, *r* = -.44.

4. Discussion

The aim of the present study was to investigate users' acceptance of an on-bike system that warns about potential collisions with motorized vehicles as well as its effect on cyclists' behavior. User's acceptance was evaluated using the Van der Laan et al. (1997) scale, willingness to pay/sell, and measures of the CTAM questionnaire. For what concerns the Van der Laan et al. (1997) scale, the items from the satisfying sub-scale were rated also positively but not as good as the usefulness sub-scale-items. Based on the mean scores in the scales of the CTAM questionnaire, the system did not provoke anxiety among the participants but it was considered trustworthy, safe, easy to use, useful, and controllable in average. Moreover, behavioral intention to use the system was related to all the variables included in the CTAM model and trust. Correlation parameters entail that the perceived safety (i.e., the degree of belief about how the use of the system influences well-being), the attitudes toward the use of technology (Osswald et al., 2012), and the trust in the system are what is most crucial to the intention to use the on-bike system.

According to the results, WTP had a mean value of 57.83€ with a standard deviation of 43.06€, while WTA had a mean value of 43.73€ with a standard deviation of 31.59€. The present findings suggest that the price of the on-bike system should be kept relatively low. Otherwise, incentives should be considered to ensure large scale deployment of this on-bike system. The non-significant correlations of the WTA and WTA with the behavioral intention to use the on-bike system suggest that there might be other factors which can prevent or facilitate the usage of the systems. In other words, participants may value the on-bike system but the intention to use does not increase as the value increases. Huth and Gelau (2013) have found a low correlation (though significant) between willingness to pay for the advanced rider assistance systems and the usage intention. Further research is needed to investigate this issue. Although WTA is usually higher than WTP (Horowitz & McConnell, 2002), we have found that the WTP was higher than the WTA. In other words, if participants were in possession of the system, they would be willing to sell it for less. One possible explanation for that is that they were asked to deem the price at which they would sell it when the system had been gifted to them. Thus, a lower price than that of the purchase could be expected since they did not have to pay for it. Nevertheless, previous research has shown that when people are asked to act as decision makers who provide valuations for others, WTP exceeds WTA (Ackert, Church, & Dwyer Jr., 2007). In the present study, the elicited valuation may be influenced by perspective or role: participants may have provided valuations for the group of cyclists that are perceived as “others” or outgroup members (Prati, Marín Puchades, & Pietrantoni, 2017). In this situation, people care about fairness which can be defined as an aversion to inequity by comparing their material payoff relative to the payoffs of others.

Regarding the user’s behavior and perceptions after the use of the system, whereas the average speed and the trajectory with and without the system were not different, the speed difference before and after the intersection was higher when the system was being used. In addition to this, the speed before the warning of the system was higher than that after. This indicates that the activation of the system lead users to reduce their speed at the intersection, therefore, leaving it at a lower speed. These differences in speed caused by the system could be explained by the fact that the conflict was perceived as riskier and with potentially more severe consequences when the system was switched on. According to risk adaptation theory (Koornstra, 2009), individuals adapt their behavior to their perceived risk, therefore, when the system warned the users about the conflict, making it more salient, their risk perception might have increased leading them to adapt their behavior by reducing speed and thus risk perception.

4.1 Practical Implications

Starting from the results and with a clear focus on the behavioral intention to use the system correlates, it is possible to draw some implications for the users, designers, and researchers. Results showed that trust, perceived safety, and attitude toward technology were the most important correlates of behavioral intention to use the system. Trust is an issue of major relevance for the success of the technology. Walker, Stanton, and Salmon (2016) claim that the users are extremely sensitive to the performance of the system, and Hancock et al. (2011) showed that the performance of the system was the major predictor of the development of trust in technology. Moreover, false alarms are the most important types of system failure and affect trust in the system (e.g., Geels-Blair, Rice, & Schwark, 2013). For the designers, this means that special attention is needed in the development of a highly reliable risk assessment algorithm. Moreover, the process by which user’s trust in the system is developed is strictly related to the relationship between the user’s reliability on the system and the effective system’s capabilities (Fallon, Murphy, Zimmerman, & Mueller, 2010). This means that throughout the direct experience of the system, the user can easily reframe his/her level of trust in the system, thus potentially leading to system disuse (i.e., lack of trust in the whole system or a specific controller) or misuse (i.e., over-trust in the system; Khastgir, Birrell, Dhadyalla, & Jennings, 2017). Based on this premise, it is fundamental to promote a coherent description of the system in terms of performance, how the system works and why the user should rely on the system. As it emerged in our study, the more coherent the information is with the capabilities and limitations of the system, the more appropriate will the calibration of trust be (Khastgir et al., 2017).

The latter practical implication is related to another key factor for the intention to use the system, that is, the attitude toward the use of technology. Since this construct reflects the user's beliefs about the system, its usage and its effects, marketing strategies coherent with capabilities, functionalities, and limitations of the system could be crucial for the diffusion of on-bike devices. Thus, it is important to identify and involve the potential early adopters, targeting the marketing strategies to technology-friendly cyclists.

It has been also shown that the on-bike device enhances cyclists' perception of risk in certain situations through its warning, which consequently leads to a reduction of cyclists' speed. This means that the HMI of such devices should be designed in a way that facilitates risk awareness, thus increasing the perceived severity of consequences of the collision. User's behavioral responses to the on-bike system support this argument. In fact, as shown in the results, users approached the intersection by reducing their speed which, as a result of increased perceived safety. As already proposed in previous research (Fraboni, Marín Puchades, De Angelis, Prati, & Pietrantoni, 2016; Summala, Pasanen, Räsänen, & Sievänen, 1996), reducing speed when approaching an intersection can be extremely helpful for road users to have more time to detect the environment and the potential risks, and to react appropriately. Therefore, the system interface should enhance the cyclist's perception of the actual risk. Future research could explore how users' behavior changes in response to several warnings with diverse levels of urgency. More research is also needed to explore cyclists' perception after a conflict and their attribution of the perceived risk, be it caused by the situation or by the technology.

4.2 Limitations and Recommendation for Future Research

Notwithstanding the above-mentioned results, the current study is not free from limitations that could reduce generalizability of findings. Those limitations are mainly related to characteristics of the sample. First, the sample size is relatively small (n = 25), and second, the sample lacks variability in terms of gender and social status, since most participants are female university students. Since the participants voluntarily agreed to participate in the test, the present study could be subject to self-selection bias. Another issue regards the participants' bicycle use shares. In fact, most participants did not use bicycle (40%) or cycle only once a week (36%). Bicycle use shares could greatly influence participants' reactions when encountering a motorized vehicle on the road, since not using the bike frequently could imply lower levels of cycling skills, experience, confidence with the specific mean of transportation and low self-efficacy when dealing with dangerous situations. Future research regarding on-bike warning systems should address those issues, specifically recruiting a higher number of participants, and maximizing the variability of sample characteristics, possibly using multiple methods to recruit people. Furthermore, future studies should focus on controlling for multiple variables such as bicycle use, cycling skill and self-efficacy, when assessing cyclists' reactions to warnings and their interaction with safety systems. Regarding participants' evaluation of WTP and WTA, it is important to consider that Italian university students formed the sample. This could have negatively affected the economic value given to the device, meaning that both WTP and WTA could increase. To obtain more accurate values, future researches and producers' market surveys should extend the sample to all the potential users.

4.3 Conclusions

The present study contributes to existing literature examining bicyclist's behavior and acceptance of an on-bike safety system through three different experimental tasks. According to the results of Van der Laan scale, participants rated to be satisfied with the interaction with the system and found it to be quite useful. It is interesting to note that variables such as perceived safety, attitudes toward the use of technology and trust on the system have the strongest correlations with the user's intention to use the system. To explain behavioral differences when using the system, compared to when it is switched off, we drew on the risk adaptation theory, explaining that the system has the potential to make risks more salient for participant and, thus, prompting them to adapt their speed accordingly. The present study provides recommendations for future research, as well as suggestions and implications for designers and marketing practitioners.

Acknowledgements

Funding: This work was supported by the European Commission under the Horizon 2020 Framework Programme (2014–2020). Project XCYCLE (contract number: 63597).

References

Ackert, L. F., Church, B. K., & Dwyer Jr., G. P. (2007). When the shoe is on the other foot. *Public Finance Review, 35*(2), 199-214. doi:doi:10.1177/1091142106292776

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Ben-Yaacov, A., Maltz, M., & Shinar, D. (2002). Effects of an in-vehicle collision avoidance warning system on short- and long-term driving performance. *Human Factors, 44*(2), 335-342. doi:10.1518/0018720024497925

Blaschke, C., Breyer, F., Färber, B., Freyer, J., & Limbacher, R. (2009). Driver distraction based lane-keeping assistance. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(4), 288-299. doi:http://dx.doi.org/10.1016/j.trf.2009.02.002

Bordel, S., Somat, A., Barbeau, H., Anceaux, F., Greffeuille, C., Menguy, G., . . . Gallenne, M.-L. (2014). From technological acceptability to appropriation by users: Methodological steps for device assessment in road safety. *Accident Analysis & Prevention, 67*, 159-165. doi:http://dx.doi.org/10.1016/j.aap.2014.01.016

Chataway, E. S., Kaplan, S., Nielsen, T. A. S., & Prato, C. G. (2014). Safety perceptions and reported behavior related to cycling in mixed traffic: A comparison between Brisbane and Copenhagen. *Transportation Research Part F: Traffic Psychology and Behaviour, 23*, 32-43. doi:http://dx.doi.org/10.1016/j.trf.2013.12.021

Chong, S., Poulos, R., Olivier, J., Watson, W. L., & Grzebieta, R. (2010). Relative injury severity among vulnerable non-motorised road users: Comparative analysis of injury arising from bicycle–motor vehicle and bicycle–pedestrian collisions. *Accident Analysis & Prevention, 42*(1), 290-296. doi:http://dx.doi.org/10.1016/j.aap.2009.08.006

Dardari, D., Decarli, N., Guerra, A., Al-Rimawi, A., Marín Puchades, V., Prati, G., . . . Pietrantoni, L. (2017). High-Accuracy Tracking Using Ultrawideband Signals for Enhanced Safety of Cyclists. *Mobile Information Systems*, *2017*, 13. doi:10.1155/2017/8149348

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly, 13*(3), 319-340. doi:10.2307/249008

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, *35*(8), 982-1003.

de Nazelle, A., Nieuwenhuijsen, M. J., Anto, J. M., Brauer, M., Briggs, D., Braun-Fahrlander, C., . . . Lebret, E. (2011). Improving health through policies that promote active travel: A review of evidence to support integrated health impact assessment. *Environment International*, *37*(4), 766-777. doi:10.1016/j.envint.2011.02.003

Fallon, C. K., Murphy, A. K. G., Zimmerman, L., & Mueller, S. T. (2010, 17-21 May 2010). *The calibration of trust in an automated system: A sensemaking process.* Paper presented at the 2010 International Symposium on Collaborative Technologies and Systems.

Fraboni, F., Marín Puchades, V., De Angelis, M., Prati, G., & Pietrantoni, L. (2016). Social influence and different types of red-light behaviors among cyclists. *Frontiers in Psychology, 7*(1834). doi:10.3389/fpsyg.2016.01834

Geels-Blair, K., Rice, S., & Schwark, J. (2013). Using system-wide trust theory to reveal the contagion effects of automation false alarms and misses on compliance and reliance in a simulated aviation task. *The International Journal of Aviation Psychology*, *23*(3), 245-266. doi:10.1080/10508414.2013.799355

Gezici, S., Tian, Z., Giannakis, G. B., Kobayashi, H., Molisch, A. F., Poor, H. V., & Sahinoglu, Z. (2005). Localization via ultra-wideband radios: A look at positioning aspects for future sensor networks. *IEEE Signal Processing Magazine, 22*(4), 70-84. doi:10.1109/MSP.2005.1458289

Ghazizadeh, M., Peng, Y., Lee, J. D., & Boyle, N. L. (2012). Augmenting the technology acceptance model with trust: Commercial drivers' attitudes towards monitoring and feedback. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56*(1), 2286-2290. doi:doi:10.1177/1071181312561481

Götschi, T., Garrard, J., & Giles-Corti, B. (2016). Cycling as a part of daily life: A review of health perspectives. *Transport Reviews, 36*(1), 45-71. doi:10.1080/01441647.2015.1057877

Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y., de Visser, E. J., & Parasuraman, R. (2011). A meta-analysis of factors affecting trust in human-robot interaction. *Human Factors, 53*(5), 517-527. doi:10.1177/0018720811417254

Horowitz, J. K., & McConnell, K. E. (2002). A review of WTA/WTP studies. *Journal of Environmental Economics and Management, 44*(3), 426-447. doi:http://dx.doi.org/10.1006/jeem.2001.1215

Huth, V., & Gelau, C. (2013). Predicting the acceptance of advanced rider assistance systems. *Accident Analysis & Prevention, 50*, 51-58. doi:http://dx.doi.org/10.1016/j.aap.2012.03.010

Kelly, P., Kahlmeier, S., Gotschi, T., Orsini, N., Richards, J., Roberts, N., . . . Foster, C. (2014). Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. *International Journal of Behavioral Nutrition and Physical Activity, 11*, 132. doi:10.1186/s12966-014-0132-x

Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2017). Calibrating trust to increase the use of automated systems in a vehicle. In N. A. Stanton, S. Landry, G. Di Bucchianico, & A. Vallicelli (Eds.), *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World®, Florida, USA* (pp. 535-546). Cham: Springer International Publishing.

Koornstra, M. J. (2009). Risk-adaptation theory. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(1), 77-90. doi:http://dx.doi.org/10.1016/j.trf.2008.08.002

Macmillan, A., Connor, J., Witten, K., Kearns, R., Rees, D., & Woodward, A. (2014). The societal costs and benefits of commuter bicycling: Simulating the effects of specific policies using system dynamics modeling. *Environmental Health Perspectives, 122*(4), 335-344. doi:10.1289/ehp.1307250

Nicaj, L., Stayton, C., Mandel-Ricci, J., McCarthy, P., Grasso, K., Woloch, D., & Kerker, B. (2009). Bicyclist Fatalities in New York City: 1996–2005. *Traffic Injury Prevention, 10*(2), 157-161. doi:10.1080/15389580802641761

Osswald, S., Wurhofer, D., Trösterer, S., Beck, E., & Tscheligi, M. (2012). *Predicting information technology usage in the car: Towards a car technology acceptance model*. Paper presented at the Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Portsmouth, New Hampshire.

Payre, W., Cestac, J., & Delhomme, P. (2014). Intention to use a fully automated car: Attitudes and a priori acceptability. *Transportation Research Part F: Traffic Psychology and Behaviour, 27, Part B*, 252-263. doi:http://dx.doi.org/10.1016/j.trf.2014.04.009

Prati, G., De Angelis, M., Marín Puchades, V., Fraboni, F., & Pietrantoni, L. (2017). Characteristics of cyclist crashes in Italy using latent class analysis and association rule mining. *PLoS ONE, 12*(2), e0171484. doi:10.1371/journal.pone.0171484

Prati, G., Marín Puchades, V., De Angelis, M., Fraboni, F., & Pietrantoni, L. (2017). Factors contributing to bicycle–motorised vehicle collisions: A systematic literature review. *Transport Reviews*, 1-25. Advance online publication. doi:10.1080/01441647.2017.1314391

Prati, G., Marín Puchades, V., & Pietrantoni, L. (2017). Cyclists as a minority group? *Transportation Research Part F: Traffic Psychology and Behaviour, 47*, 34-41. doi:10.1016/j.trf.2017.04.008

Prati, G., Pietrantoni, L., & Fraboni, F. (2017). Using data mining techniques to predict the severity of bicycle crashes. *Accident Analysis & Prevention, 101*, 44-54. doi:http://dx.doi.org/10.1016/j.aap.2017.01.008

Rosenkranz, K. M., & Sheridan, R. L. Trauma to adult bicyclists: A growing problem in the urban environment. *Injury, 34*(11), 825-829. doi:10.1016/S0020-1383(02)00389-3

Rowe, B. H., Rowe, A. M., & Bota, G. W. (1995). Bicyclist and environmental factors associated with fatal bicycle-related trauma in Ontario. *Canadian Medical Association Journal, 152*(1), 45-53.

Simonson, I., & Drolet, A. (2004). Anchoring effects on consumers' willingness-to-pay and willingness-to-accept. *Journal of Consumer Research, 31*(3), 681-690. doi:10.1086/425103

Son, J., Park, M., & Park, B. B. (2015). The effect of age, gender and roadway environment on the acceptance and effectiveness of Advanced Driver Assistance Systems. *Transportation Research Part F: Traffic Psychology and Behaviour, 31*, 12-24. doi:http://dx.doi.org/10.1016/j.trf.2015.03.009

Summala, H., Pasanen, E., Räsänen, M., & Sievänen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis and Prevention, 28*(2), 147-153. doi:10.1016/0001-4575(95)00041-0

Sze, N. N., Tsui, K. L., So, F. L., & Wong, S. C. (2011). Bicycle-related crashes in Hong Kong: Is it possible to reduce mortality and severe injury in the metropolitan area? *Hong Kong Journal of Emergency Medicine, 18*(3), 136.

Vallerand, R. J. (1997). Toward a hierarchical model of intrinsic and extrinsic motivation. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 29, pp. 271-360). San Diego, CA, US: Academic Press.

Van der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies, 5*(1), 1-10. doi:http://dx.doi.org/10.1016/S0968-090X(96)00025-3

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS quarterly, 27*(3), 425-478.

Vlassenroot, S., Brookhuis, K., Marchau, V., & Witlox, F. (2010). Towards defining a unified concept for the acceptability of Intelligent Transport Systems (ITS): A conceptual analysis based on the case of Intelligent Speed Adaptation (ISA). *Transportation Research Part F: Traffic Psychology and Behaviour, 13*(3), 164-178. doi:http://dx.doi.org/10.1016/j.trf.2010.02.001

Walker, G. H., Stanton, N. A., & Salmon, P. (2016). Trust in vehicle technology. *International Journal of Vehicle Design, 70*(2), 157-182. doi:10.1504/ijvd.2016.074419

Wegman, F., Zhang, F., & Dijkstra, A. (2012). How to make more cycling good for road safety? *Accident Analysis & Prevention, 44*(1), 19-29. doi:http://dx.doi.org/10.1016/j.aap.2010.11.010

Wolf, A., & Seebauer, S. (2014). Technology adoption of electric bicycles: A survey among early adopters. *Transportation Research Part A: Policy and Practice, 69*, 196-211. doi:http://dx.doi.org/10.1016/j.tra.2014.08.007

Xia, T., Zhang, Y., Crabb, S., & Shah, P. (2013). Cobenefits of replacing car trips with alternative transportation: A review of evidence and methodological issues. *Journal of Environmental and Public Health, 2013*, 14. doi:10.1155/2013/797312

Table 1

Reliability (Cronbach's alpha), Correlations (Kendall Rank Correlation Coefficients) Among and Descriptive Statistics for Key Study Variables

	M	*SD*	α	1	2	3	4	5	6	7	8	9	10	11	12
1. Risk perception of mixed traffic	3.39	0.90	.73	—											
2. Perceived usefulness	3.71	0.82	.90	.24	—										
3. Perceived ease of use	4.22	0.97	.78	-.18	.25	—									
4. Attitude toward technology	3.80	0.83	.86	.08	.49	.48	—								
5. Facilitating conditions	3.72	0.88	.70	.04	.49	.46	.49	—							
6. Anxiety	2.05	0.99	.84	-.04	-.43	-.62	-.61	-.49	—						
7. Perceived safety	3.99	0.82	.75	-.05	.48	.31	.53	.27	-.36	—					
8. Trust	4.16	1.25	—	-.05	.38	.30	.57	.33	-.48	.42	—				
9. Social influence[a]	3.52	0.97	—	.11	.49	.36	.60	.37	-.53	.17	.49	—			
10. Behavioral intention to use	3.99	1.28	.89	-.01	.40	.35	.56	.45	-.51	.62	.63	.36	—		
11. WTP	57.83	43.06	—	.06	.12	.00	.22	.26	-.12	-.15	.24	.17	-.09	—	
12. WTA	43.73	31.59	—	-.03	.09	-.02	.28	.16	-.17	.13	.45	.03	.20	.54	—

Note. All correlation coefficients higher than .33 are significant at the .05 level. [a]Correlation between the two items was .41 ($p < .05$).

Table 2

Results from van der Laan Acceptance Scale

Item	Description	Scale	*M*	*SD*
1	Useful–useless	Usefulness	1.32	0.90
2	Pleasant–unpleasant	Satisfying	1.00	0.96
3	Bad–good	Usefulness	1.46	0.88
4	Nice–annoying	Satisfying	0.84	0.85
5	Effective–superfluous	Usefulness	1.32	0.90
6	Irritating–likeable	Satisfying	0.88	0.73
7	Assisting–worthless	Usefulness	1.44	0.87
8	Undesirable–desirable	Satisfying	0.88	1.17
9	Raising alertness–sleep inducing	Usefulness	1.48	0.96

Figure 1. Intersection with cones to restrict the zone where participants could cycle. The upper image shows the scenario in which the car comes from the opposite direction and turns left, whereas the lower picture shows the location of the cones for the scenario in which the car pops out from the left.

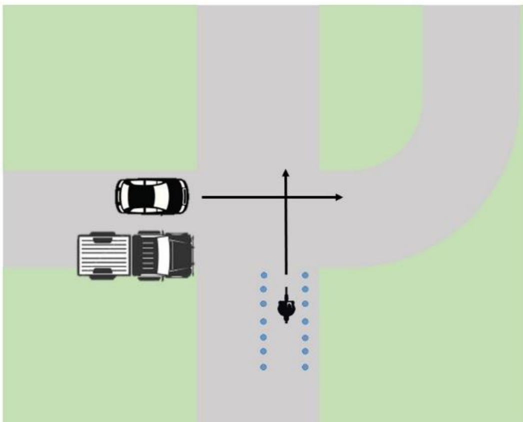

Figure 2. “Right-angle” type of conflict between car and bicycle

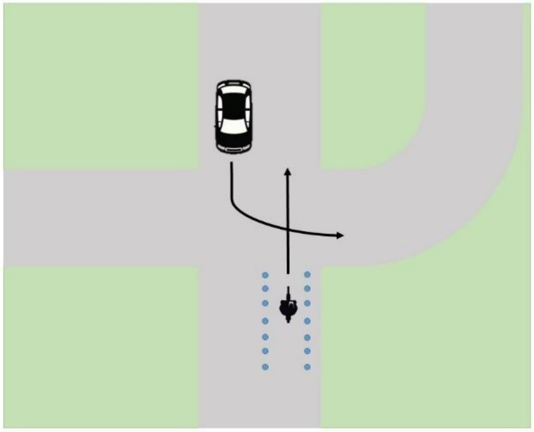

Figure 3. “Left-turn” type of conflict between car and bicycle

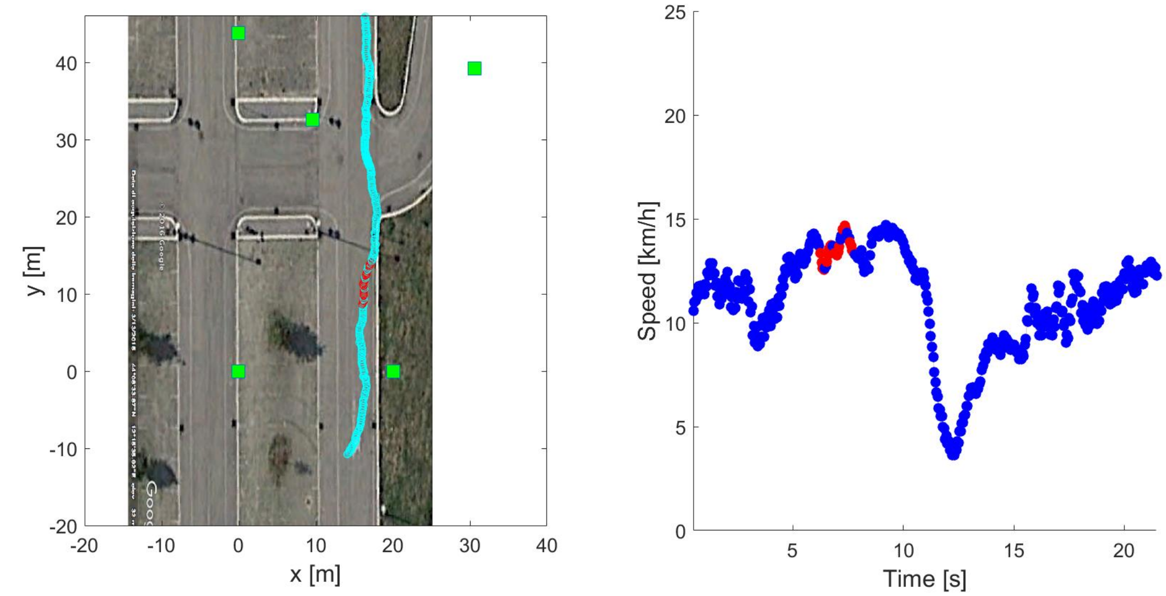

Figure 4.
Map of the environment, bike trajectory (left portion of the Figure), and recorded speed of the bike (right portion of the Figure)