Identifying conflict clusters of cyclists at a roundabout by automated traffic surveillance

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Abstract Cyclists are more likely to be injured in fatal crashes than motorised vehicles. To gain detailed and precise behavioural data of road users, i.e. trajectories, a measuring campaign was conducted. Therefore, a black-spot for accidents with cyclists in Berlin, Germany was selected. The traffic has been detected by a fully automated traffic video analysis system continuously for twelve hours. The video surveillance system is capable of automatically extracting trajectories, classifying road user types and precise determining and positioning of conflicts and accidents. Additionally, pre-conflict and pre-accident situations could be analysed to provide further in-depth understanding of accident causation. The evaluation of the measuring campaign comprised the investigation of traffic parameters, e.g. traffic flow, as well as traffic-safety related parameters based on Surrogate Safety Measures (SSM). Furthermore, the spatial and temporal distributions of conflicts involving cyclists were determined. As a result, three possible conflict clusters could be identified, of which one cluster could be confirmed by detailed video analysis, showing conflicts caused by right turning vehicles.

NOTATION

$b_{\max}$	Maximum Braking Deceleration
C2C	Car to Car Communication
C2I	Car to Infrastructure Communication
DLR	*German Aerospace Center*
DRAC	Deceleration Rate to Avoid Crash
MV	Motorised Vehicle
PDM	Probability Density Map
SOFM	Self-organising Feature Map
SSM	Surrogate Safety Measures
TCT	Traffic Conflict Technique
TTC	Time to Collision
VRU	Vulnerable Road User

INTRODUCTION

The number of cyclists in urban areas of Germany is rising. Rethinking in transport mode selection leads to a changing modal split as well as new road safety challenges. The number of accidents involving cyclists has been steadily increasing within the last years. In Berlin 7,699 accidents involving cyclists were reported in 2014 (+10.7% compared to 2013). Thereof 639 cyclists were seriously injured (+1.3% compared to 2013) and 12 cyclists died. The high vulnerability is reflected in a high crash severity: almost one out of four road fatalities in Berlin was a cyclist and 72.1% of all accidents involving cyclists resulted in physical injuries. Responsibility for 42.1% of cycling accidents laid at the driver's door. 49.1% of cycling accidents have been caused by cyclists. The main causes for accidents caused by cyclists were (i) use of wrong lane, (ii) insufficient safety distance, (iii) wrong behaviour when entering the traffic flow and (iv) inadequate speeds. The main causes for accidents involving cyclists caused by car drivers were wrong behaviour when turning and entering the traffic flow as well as ignoring the right of way [1].

Accident data bases provide comprehensive information about cycling accidents. However, there is a lack of knowledge about safety related road user behaviour, particularly interactions between cyclists and cyclists as well as between cyclists and other road users at particular places and conditions. Detailed knowledge in this regard is expected to improve the identification of systematic deficits in road design, traffic control, road surface markings and other factors. In addition, not much is known about the parameters that lead road users to behaviour that fosters critical situations. Additional data on road user behaviour and their interactions can be obtained by automated video analysis providing trajectories of road users based on spatiotemporal sensors, e.g. cameras, radar systems, or laser scanners. Road user trajectories enable extended analysis of traffic parameters, road use and conflicts. An appropriate automated video analysis system is being developed by the German Aerospace Center (DLR) [2-5]. Research topics in this context are, e.g. investigations of correlations between accidents, critical situations, traffic parameters (e.g. traffic volume, density), and topological features of road space.

A measuring campaign at a prominent black spot for cycling accidents in Berlin (Moritzplatz, 25 cycling accidents reported in 2014) was conducted to evaluate the automated video analysis system. Based on the detected trajectories of individual road users several SSMs quantifying the criticality of the recorded road user interactions have been determined. Spatiotemporal distributions of clusters with high conflict potential could be identified by aggregation.

RELATED WORK

The present study builds off the work of similar previous approaches in the fields of conflict technique and video analysis. In [6] a fully automated video based detection system is described, which allows the analysis of traffic situations before and after introducing measures to improve traffic safety. This framework was further developed in [6], where SSMs and their probability density distributions with regard to different conflict types are automatically determined. Similar video based systems for automated traffic situation detection and interpretation were proposed in [8-10]. More or less all of the publications in this area emphasize the great chances of video based detection systems, but also the challenges and problems arising mainly from the video technique, e.g. occlusions of the vehicles, weather and illumination conditions.

In [11] safety related indicators of conflict analysis and their suitability for the determination of the conflict severity and the determination of safety risks in traffic areas are discussed. Existing indicators are extended and refined. Besides the more common SSMs as Time to Collision (TTC) or Deceleration Rate to Avoid the Crash (DRAC), the authors consider braking intensities and sudden swerving as important safety aspects.

In [12] cyclist-vehicle conflicts and accidents are analysed at two different roundabouts in Lund, Sweden, with regard to different interaction types, e.g. entering motorist and circulating cyclist, motorist and cyclist exiting in parallel, etc. One result of this study was that some of the conflicts seemed to be correlated to accidents and others were not. They assumed that specific interaction types lead to different conflicts or accidents, e.g. interactions of circulating vehicle and entering cyclists can probably develop to a parallel conflict or accident. The authors state that the results should be treated with caution, since they are not significantly validated due to only 90 hours of video material and a rather high false alarm rate of the automated video analysis system between 20% and 90%, which was because of systematic and random affections by weather conditions, optical occlusions of the vehicles.

In [13] two different approaches were developed and tested for the automated detection and classification of atypical traffic situations. As a result of this study a multi-dimensional probability density map (PDM) approach was estimated superior to the employment of a self-organizing feature map (SOFM) for the problem. In case of the PDM approach, the typicality of trajectories was assessed by a quantification of their deviance from a normal trajectory, where normality was defined by a distribution obtained from set of reference trajectories. In [14] similar methods were applied to analyse traffic offenses of cyclists at an intersection. In [3] these methods were applied for detecting critical and atypical situations at an ungated level-crossing.

Generally, when talking about conflicts detected by automated systems as a valid safety indicator, one must take into account the detection process, which underlies errors. Therefore in [15] the error rates of such detected conflicts based on the sensors these detections are dependent on. A calculation scheme for error rates of automated video based detection of critical situations was developed. It was shown for a stationary road side detector that the false positive rate, which means the rate of detected critical situation that are actually not critical, is four to five times higher than the true positive rate (real critical situations). This leads to the conclusion that studies known from literature, stating there is correlation between conflicts and accidents, should be considered with scepticism as long as no reliable information on error rates, the sensor systems set-up, etc. are provided.

In [16], road user trajectories were estimated software-aided to analyse the interactions of vulnerable road users (VRU) and motorised vehicles (MV) and to compare the traffic safety of signalised and non-signalised intersections. Although these results may not apply for conflicts, there exist several accident-based studies with focus on cyclists. These studies present amongst other things typical crash scenarios and reasons for them. For instance in study [17] it was observed, that many collisions of cars and cyclists occurred between right-turning cars or cars crossing from the left and cyclists. As a reason for the accidents caused by cars, the missing glance over the shoulder was stated. Another study [18] examined accidents of cyclists with focus on turning vehicles and cyclists travelling straight ahead. In 90% of all accidents the vehicle driver caused it. Though, accidents were benefitted by cyclists, e.g. by driving illegally on sidewalks. Accidents occurred noticeably frequently when vehicles turn right and the cycle lane is more than 2 m away from the street in combination with an obstacle.

METHODOLOGY

Video based situation detection

The automated video analysis system used for the present study is capable to detect and classify road users and track them in real world coordinates using adaptive filters (e.g. Extended Kalman or particle filters) yielding trajectories with a maximal temporal resolution according to the framerate of the camera [3]. Different software modules realise the detection and the processing of trajectories (see Figure 1): (i) The image data acquisition (video server) yields image sequences of the surveillance area; (ii) detection and classification algorithms yield vehicle counts and their modal classification (e.g. car, bus, or bicycle); (iii) tracking algorithms yield trajectories of road users; finally, (iv) traffic situations (e.g. normal, atypical or critical) are classified by trajectory level algorithms, eventually (v) triggering the recording of specific types of situations.

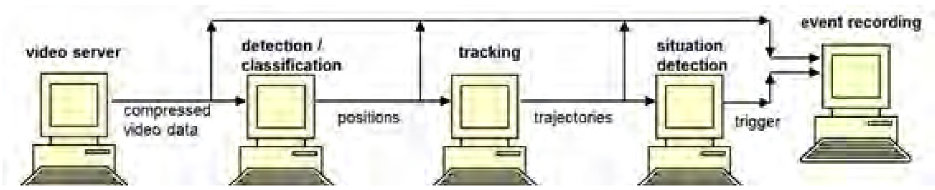

Figure 1. Process chain for situation detection (from [3]).

Surrogate Safety Measures for conflict analysis

Conflict situations between two interacting road users can be quantified by several SSMs. Indicators take into account the spatial or temporal distances of different road users, e.g. TTC, distance to collision, probabilistic indicators (e.g. collision probability), DRAC, or maximum braking deceleration. Approximately 30 indicators are described in the literature [19-21].

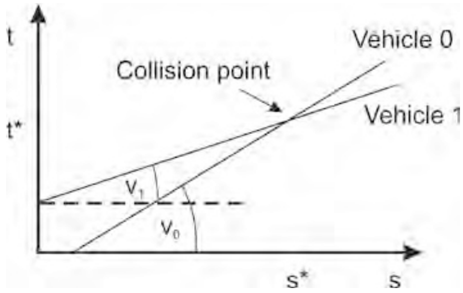

Figure 2. Schematic representation of conflicting trajectories of two vehicles

Time To Collision (TTC)

The TTC quantifies the remaining time to a potential collision of two interacting vehicles, if they would not change their speed and direction, see Figure 2: If the speeds v_0 and v_1 would remain constant, the vehicles would collide at time t^* at location s^*. Given the net distance Δs and the speed difference Δv of the vehicles, then:

$$TTC = t^* = \frac{\Delta s}{\Delta v} = \frac{\Delta s}{v_1 - v_0} \qquad (1)$$

TTC-values of below 1.5 seconds are generally assumed to indicate critical situations [20-22].

Deceleration Rate to Avoid the Crash (DRAC)

The DRAC quantifies the necessary deceleration for the following vehicle to avoid an upcoming collision given a constant velocity of the leading vehicle. It can be calculated from kinematic considerations according to Figure 2. If Δs is the net distance between the vehicles and Δv the speed difference, then:

$$DRAC = \frac{\Delta v^2}{2\Delta s} = \frac{\Delta v}{2TTC} \qquad (2)$$

The larger the DRAC value the smaller is the distance or the larger is the speed difference between the two vehicles. In the literature information differs how DRAC can be evaluated with regard to criticality. Usually, values above 3.35 m/s² for vehicles are considered as critical [23].

Braking Intensity ($b_{\max}$)

Atypical braking behaviour, e.g. intensive or frequent braking may indicate critical situations. In contrast to the SSMs, which are designed for the detection of conflicts between two road users, $\mathrm{b}_{\max}$ may also indicate single-vehicle conflicts. Let $\{\mathrm{a}\}_{1:\mathrm{n}}$ a set of all decelerations along a given trajectory within a specific area of interest, then the maximum braking intensity for each trajectory is:

$$b_{\max} = \max(\{a\}_{1:n}) \qquad (3)$$

RESULTS

Setup for the mobile automated traffic surveillance

The measuring campaign was conducted at an accident blackspot for cyclists, a four-legged roundabout located at the Moritzplatz in Berlin, Germany. The recording was conducted on July 7, 2014 from 6 a.m. to 6 p.m. (12 hours), which included the traffic peaks during the morning and the afternoon rush hours (Figure 6). The weather was warm with temperatures between 25°C and 30°C, dry, partly sunny and partly cloudy.

Characteristics of the Moritzplatz

The roundabout has four single-lane legs. Although no corresponding lane markings were present at the time of measurement, the width of the roundabout allows for two vehicles driving side-by-side. Cycle lanes with an obligation of use did exist and were separated by corresponding markings.

In 2014, 25 cycling accidents have been reported officially. The three road sections captured by the video recording system have traffic volumes between 15,000 and 22,000 motorized vehicles on average per day (Figure 3). Official numbers of cyclists were not available.

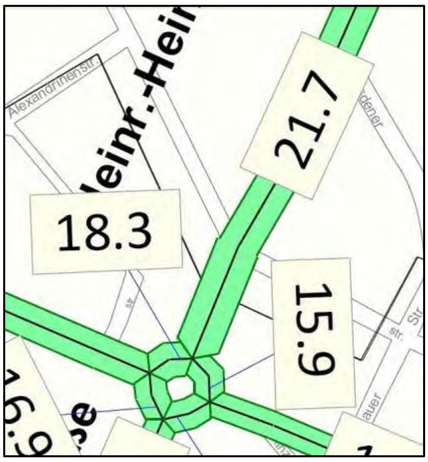

Figure 3. Traffic volumes (MV) in 1,000 vehicles/day of the three captured road sections at Moritzplatz [24].

Measuring setup

As shown in Figure 4, the Urban Traffic Research Car (UTRaCar), a mobile laboratory of the DLR, was installed on the inner part of the roundabout for observation of traffic in northeast direction into and from the street Prinzenstraße. The UTRaCar is equipped with an extendible pole of twelve meters height and a working station capable of processing video images in real-time to obtain trajectories of moving objects in captured traffic scenes. The camera used in this survey acquired images with a resolution of 1,340 x 1,040 pixels at a frequency of 20Hz.

Figure 4. UTRaCar at the Moritzplatz. a Photograph of the setup at the measuring day.

In Figure 5(a) the field of view of the camera is shown. Detected were road users either entering to Prinzenstraße in north-east direction or remaining in the roundabout as well as road users entering the roundabout from Prinzenstraße. In Figure 5(b) the ortho-photo of the same part of the roundabout is shown including trajectories of the road users (coloured) and their predictions (grey) within the next two seconds.

Figure 5. Camera image showing the field of view (a)

The evaluation of the measuring campaign comprises the investigation of traffic parameters, e.g. traffic volume, mean speed as well as temporal and spatial frequency distributions of critical interactions between bicycles and other road users (using TTC , DRAC, and b_{max}). Other road users respectively non-cyclists were motorized vehicles (MV).

Cyclist shares

Altogether 20,167 road users were detected within the twelve hours of the survey (3,451 cyclists and 16,716 non-cyclists). The share of cyclists of all road users varied between 10% and 30% (17.1% on average) per hour (see Figure 6).

Cyclist volumes

From the 3,451 cyclists in total, 573 cyclists passed the field of view during the morning peak be-tween 9 a.m. and 10 a.m. and 528 cyclists were counted during the afternoon peak between 5 p.m. and 6 p.m. The minimal hourly volume of 219 cyclists was counted between 8 a.m. and 9 a.m.

Cyclist speeds

For each bicycle trajectory point the instantaneous speeds were determined. The raw positions were filtered by a Kalman filter [3] to obtain speed and acceleration data and to reduce noise. The trajec-tories have a temporal resolution of 0.05 s corresponding to the 20 Hz image repetition rate of the camera. The individual mean speeds of cyclists in free flowing traffic (e.g. between 6 a.m. and 7 a.m.) are shown in Figure 7(a). The diagram in Figure 7(b) shows the mean speeds in dense traffic (be-tween 2 p.m. and 3 p.m.).

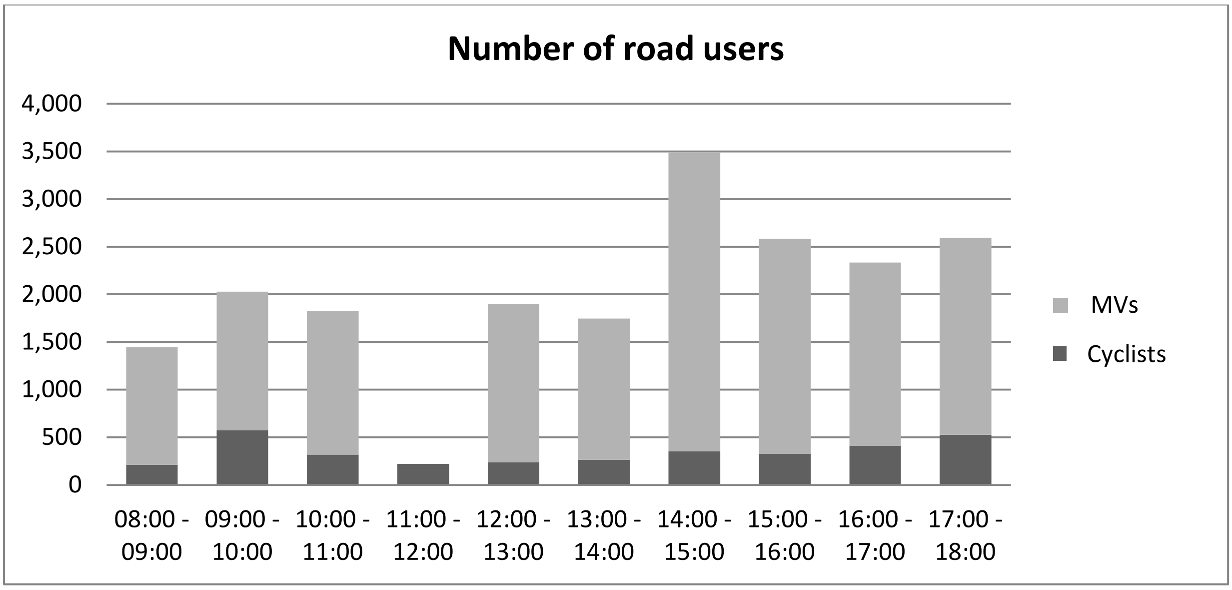

Figure 6. Number of road users per hour.

The most frequent speeds in free flow were 5.5-6 m/s (18-19.8 km/h), whereas in dense traffic 4.5-5 m/s (16.2-18 km/h). Speed values of less than 0.5 m/s arose from stopping cyclists. Regarding the whole time of the survey the 95-percentile was below 10 m/s (36 km/h). The extreme speed values of more than 10 m/s are obviously implausible and were classified as erroneous detections and were not considered throughout the evaluation. These implausible values suggest current shortcomings of the video analysis system that need to be solved.

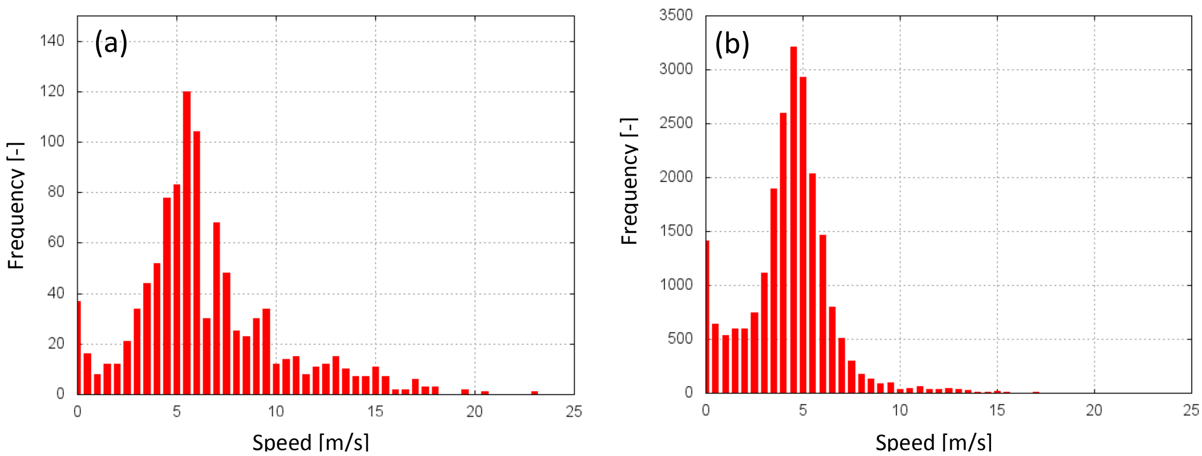

Figure 7. Cyclist speed distribution in free flow 6 a.m.-7 a.m. (a) and in dense traffic 2 p.m.-3 p.m. (b)

Cyclist conflicts

For the identification of microscopic black spots at the roundabout temporal and spatial conflict clusters were determined. The results are based on the three indicators TTC, DRAC, and $b_{\max}$ for which the thresholds were set to 1 s (TTC), 4.5 m/s² (DRAC) and 10 m/s² ($b_{\max}$), respectively.

Altogether 252 conflicts were detected on the basis of TTC and DRAC values. The peak hour for conflicts was between 2 p.m. and 3 p.m. Table 1 lists the number of detected conflicts involving cyclists in dependence on the time of the day. It is remarkable that most of the conflicts were detected between 2 p.m. and 6 p.m. and particularly conflicts between cyclists and vehicles. There seems to be a slight correlation to traffic volume of motorized vehicles (see Figure 6 and Table 1), but no correlation to the amount of cyclists, which increases till 6 p.m. Furthermore, it can be seen the small share of conflicts among cyclists. Obviously, an investigation of the indicated correlation needs to be comprised.

Table 1. Number and percentage of cyclist-cyclist and cyclist-MV conflicts based on TTC and DRAC.

Time of day	Cyclist - cyclist conflicts	Cyclist - MV conflicts	Sum
08:00 - 09:00	2	5	7
09:00 - 10:00	4	11	15
10:00 - 11:00	0	3	3
11:00 - 12:00	0	10	10
12:00 - 13:00	0	9	9
13:00 - 14:00	2	10	12
14:00 - 15:00	6	64	70
15:00 - 16:00	12	36	48
16:00 - 17:00	9	28	37
17:00 - 18:00	7	16	23
Percentage	**16,6%**	**83,3%**	**100%**

Cyclist conflicts determined by TTC

In the following TTC based conflicts involving bicyclists are considered and plotted. For each conflict an according conflict value (e.g. TTC = 0.9s) and a conflict location (i.e. the bicyclist's position) were determined corresponding to the first time a conflict was detected. Conflict values are only calculated for the cyclist involved. If there are interacting cyclists the first one is used. The spatial resolution of the conflict points is 1 m², i.e. there is one value for each square meter. Frequent critical TTC spots are plotted with red dots, whereas less frequent spots are plotted with green dots.

In Figure 8 the detected TTC based conflict spots between 11 a.m. and 12 a.m. (a) and between 3 p.m. and 4 p.m. (b) are compared In Figure 8(b), for the latter time-interval conflicts involving cyclists occur almost exclusively at the spot where the right turning vehicles cross the path of cyclists remaining inside the roundabout while Figure 8(a) shows three different locations indicating typical conflicts. Due to manual evaluation of the corresponding video scenes after measuring conflicts, the following was concluded:

- In the conflict clusters 1 and 2 no actual conflict or surprise potential could be identified, since cyclists approaching the roundabout and cycling through it have a good view and are thus able to assess the situation on the road as well as crossing traffic participants early enough.
- In conflict cluster 3 actual conflict potential could be identified. Right turning vehicles that leave the roundabout cross the paths of cyclists that remain in the roundabout.

Figure 8. Clusters of critical TTC values between 11 a.m. and 12 a.m. (a) and between 3 p.m. and 4 p.m. (b)

Detected conflicts that could not be confirmed by manual review were assumed to be misdetections due to imprecise trajectory extraction. This indicates current deficits of the video analysis system that need to be improved.

Cyclist conflicts determined by DRAC

In Figure 9(a) the histogram of the DRAC-based conflict detection is shown for the whole day. The histogram has its global maximum at 2.5 m/s^2 <= DRAC < 3 m/s^2. Although braking intensities above 5 m/s^2 are realistic, the DRAC values above 5 m/s^2 are seen as numerical artefacts after post-processing and manual review of the video scenes and are thus neglected. Indeed, in field braking experiments [25] maximum braking decelerations of about 5 m/s^2 were found. Due to the defective-ness of the DRAC values no threshold for critical values is applied here. Instead, all detected values are shown.
The intensities and locations of the DRAC based conflicts are presented in Figure 9(b). Again, manual conflict video evaluation showed that only conflict indications that are located where vehicles turn right leaving the roundabout and cross the marked cycle lane correspond to real conflicts.

Cyclist conflicts determined by Maximum Brake Intensity b_{max}

The conflict clusters determined by maximum decelerations of each of the cyclist trajectories are similarly located as the conflicts clusters determined by TTC and DRAC and thus not visualised here. Again, three clusters with high frequency of cyclist breaking operations were identified. The maximal deceleration was approximately 5 m/s^2.

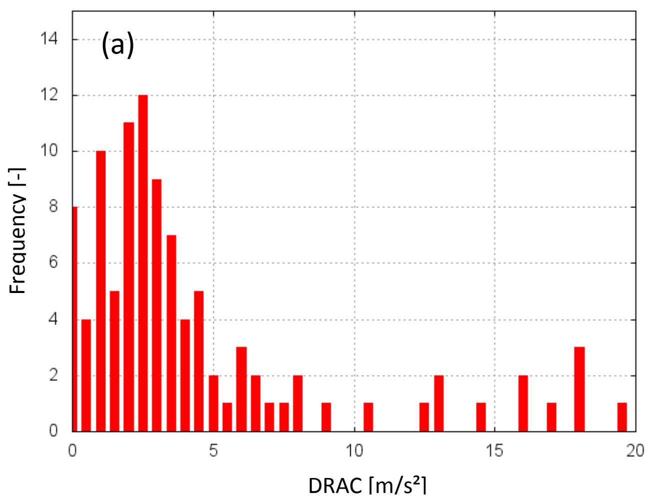

Figure 9. Histogram of DRAC values of cyclists detected between 6 a.m. and 6 p.m (a) .

DISCUSSION

Temporal distribution of cyclist conflicts

In Berlin, most cycling accidents in 2014 occurred in the peak hours with highest traffic volume, i.e. in the morning from 8 a.m. to 10 a.m. and in the afternoon from 3 p.m. to 6 p.m. [1]. With respect to conflicts in this study the most conflicts were detected also in the afternoon between 3 p.m. and 6 p.m., but in contrast to the temporal distribution of accidents no morning conflict peak could be identified. Consequently, there is a need of a broader data collection at more intersections and longer time periods in order to be able to draw reliable comparisons.

Spatial distribution of cyclist conflicts

Three potential hazard areas for cyclists at Moritzplatz were determined using the spatial distribution of TTC, DRAC, andb_{max}. The same hazard areas were found for all indicators independently at different times (see Figures 8 to 10).

Figure 10. Three indicated conflict areas for cyclists at Moritzplatz.

Conflict clusters 1 and 2

After manual assessment of the results the areas 1 and 2 according to Figure 10 could not be classified as conflict black spots, but false positive results. One the one hand this can be explained by the imperfection of the video analysis system, and on the other by the mentioned strongly overestimation of conflicts due to error rates as referred to [4].

Conflict cluster 3

Area 3 in Figure 10 could be identified as a real conflict cluster after manually assessing the video sequences. In several cases, when the cars turned right they ignored the right of way of the cyclists remaining in the roundabout. Several cyclists had to stop or to go for evasive actions. One reason for this behaviour could be explained by the geometry of the roundabout, which is due to the small angle between the vehicles leaving the roundabout and cyclists remaining in the roundabout. Its geometry requires the vehicle driver to do a shoulder check in many cases. Furthermore, in some cases the cyclists did not signalise their intention to turn to the right, which might have resulted in misunderstandings of the car drivers, e.g. misinterpretation of cyclists' speeds and also cyclists' directions.

CONCLUSIONS & FUTURE PROSPECTS

In this paper the results of a measuring campaign at the black spot Moritzplatz, Berlin, Germany, were discussed. The survey was intended to verify an automated video analysis system for the automated identification of potential hazardous locations with particular focus on cyclists. For this purpose, a specifically equipped measuring vehicle UTRaCar of the Institute of Transportation Systems of the DLR was used. Based on 12 hour image sequences classifications of the road users and their trajectories were obtained. These trajectories were analysed automatically as well as by manual post-processing and assessment afterwards. Quantifications of hazardous locations could be obtained by using three different indicators examining interactions and atypical behaviour of bicyclists and other road users. The following statements can be made:

- The roundabout Moritzplatz is frequented by about 15,000 to 22,000 road users per day. During the twelve hour measuring campaign 3,451 cyclists and 16,716 non-cyclists were detected. The average speed of cyclists was about 16 km/h.
- Altogether 252 conflict situations involving cyclists were automatically detected. The peak conflict hour with 70 conflicts was between 2 p.m. and 3 p.m. About 17% of all cycling conflicts comprise of conflicts between cyclists, the remaining 83% occur between vehicles and cyclists. During the data acquisition, no accidents were detected.
- The conflicts were detected and evaluated by using the indicators TTC, DRAC, and b_{max} of the Traffic Conflict Technique (TCT).
- Three spatial conflict clusters were found, but currently just one of them turned out to be a real conflict spot for this roundabout, whereas the remaining two could not be confirmed. These clusters differed with regard to their conflict potential and conflict severity: The highest conflict potential is given at the exit of the roundabout in north-eastern direction to Prinzenstraße at the crossing point of the right turning motorised vehicles and cyclists going straight.
- In order to prove (or disprove) the areas 1, 2 and 3 to be real black spots, particularly after redesigning the Moritzplatz in 2015, another measuring campaign of longer period needs to be conducted and accidents and conflicts need to be correlated.

Research issues

The research issues mentioned at the beginning of this study could be answered partially. A high potential for optimisation of the automated video analysis system, particularly the estimation of motion and tracking of cyclists was identified, since a high accuracy is a prerequisite for reliable results of indicators as previously shown by the mentioned SSMs . As a result of the lack of accuracy most of the detected conflicts could not be classified as real conflicts, because they were identified as false-positives by manual evaluation afterwards. This could be explained by (i) the current imperfection of the video analysis system and (ii) by the objectively justified strong overestimation of conflicts due to the error rates of any sensor system for safety analysis [4]. However, the determined conflict clusters are plausible and led to insights on cyclist behaviour and safety aspects.

Outlook

In the future it is planned to gather more representative and reliable data. This includes long-term measurements with different traffic states, illumination and weather conditions at different infrastructures to get more significant insights into road safety aspects, particularly of cyclists. Furthermore, it is intended to investigate and develop further conflict measures and their appropriate application for certain situations. The automated analysis system will be improved regarding automated categorization of road user types and conflict types. Moreover, it is planned to conduct automatic clustering and marking of conflict/hazardous clusters as well as to compare these clusters to accident distributions. A repetition of the survey could give insights in the effectiveness of recently implemented safety measures, since the cycle lane markings at the roundabout Moritzplatz were redesigned in August 2015 (one year after the data acquisition of this study).

Following needs of further research can be derived based on this study and related previous approaches:

- Infrastructure based detection of critical and atypical traffic situations needs to be combined with driver related information (e.g. extraction of data from Naturalistic Driving Studies) and environmental information (e.g. road condition generated from Car to Car- (C2C) or Car to Infrastructure (C2I) communication data) for a better understanding of accident causation.
- Challenges of automated video analysis need to be solved, which are affections by weather and illumination conditions and mutual occlusions of traffic participants for instance. Also, those systems have a high false positive rate which has to be corrected by an additional analysis.
- SSMs need to be adequately extended and/or combined for related traffic and safety situations. Furthermore, kinematic parameters, e.g. braking intensities and their distributions should be taken into account for conflict quantification.
- Focus is to be put on research to prevent and to mitigate accidents of VRU as they count for a high number and high severity of accidents, particularly in urban areas.
- Repetition of the campaign to assess the redesign of the lane markings at Moritzplatz.

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