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Agent-based Line-of-Sight Simulation for safer Crossings

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Abstract

Increasing in-town bicycle traffic creates a demand for safe and efficient transportation infrastructure. A significant safety aspect is crossroad layout. Existing solutions such as protected crossroads, roundabouts and standard four-way crossings are investigated in terms of viewing angles between traffic participants. An agent-based simulation helps to generate data, which is further analysed. Special attention is paid to blind spots of vehicles during turns, overall line of sight and human field of view. We can show that especially protected crossroad designs have major advantages. Standard layouts convince in terms of the analysed field of view and possible blind spots. However, they demand extensive shoulder views and head turning especially during right turns. This makes them less safe. Roundabouts show medium results. Exiting this structure always requires a right turn which is, in terms of visibility, the most dangerous action for bicycles. We conclude that protected crossroads can be recommended as the safest approach in comparison to standard and roundabout layouts. Yet, space requirements may restrict in-town realization of this design.

1 Introduction

Transportation and mobility influences everyday life on a large scale. Reducing traffic, improving its ecological impact and creating user-friendly systems are some of the major challenges of the present time. Taking Germany as an example, bicycle traffic is regarded as an essential solution to many of these aspects. Especially large cities reach infrastructural limits as growing numbers of motorized vehicles demand extensive spatial requirements [10]. At the same time, even short daily routes are traveled motorized. Despite the fact that more than half of all traffic participants *wish* to travel short routes by bicycle, only 13% use a bike daily as a means of transport. Security concerns as a major issue lead to this divergence. 63% of traffic participants demand more bicycle lanes and 55% ask for clear separation from motorized traffic [4]. In fact, most accidents in town with personal injuries and more than one participant happen between cyclists and cars. Therefore, concerns are justified, especially as cyclists are far more likely to suffer from serious injury or death [12]. Most accidents happen in connection with turning attempts at crossings. Further, they are mostly caused by disregarding right of way of other participants or overlooking them [13]. Thus, crossroads become the focus of investigation: Improved visibility and routing can have a major influence on enhancing bicycle safety. Therefore, different crossroad layouts have been developed. However, the impact of these layouts is insufficiently documented and even contradictory statements can be found [1, 5].

This research aims at providing more information about the influence of crossroad layout with a focus on visibility of cyclists by simulating car driver lines of sight.

The following section reports on simulation setup and methodology. We then continue with a description of the agents and the control logic. Section 4 describes the model for human views and lines of sight we use in the simulation. Section 5 presents and discusses the results. Section 6 concludes this short paper. The simulation can be downloaded at [8] and contains additional information on the model an agent design.

2 Simulation setup and methodology

To identify and analyze viewing angles of cars in dynamic situations, we implement an agent-based simulation (ABS) in *Netlogo* [14]. ABS are well suited to simulate behavior of interacting agents in a defined environment. Every agent behaves according to delimited patterns while reacting to the actual situation. Still, by adding randomizing variables, more organic behavior within the given rule-set is implemented. Additionally, reproducibility and comparability is secured by fixed input and output parameters for every simulation [9, 14]. The simulation consists of three crossroad designs and two agent classes. Agents are tested for a standardized four-way crossroad, a secured crossroad and a roundabout. Cars and bicycles are implemented as traffic participants. The *standardized layout* consists of a 90° crossing of two streets with a total width of 5.6 m per street and 2.8 m for a single lane respectively. Bicycle lanes have a width of 1.6 m and are located next to the street [2, 3, 11]. Both bicycle lanes and streets proceed in a straight fashion through the layout with a total length of 50 m. This layout is the most compact one as it has a total width of approximately 9 m (fig. 1a).

The second layout is designed to separate motorized traffic from cyclists during most critical turn maneuvers. These *protected crossroads* aim at reducing the danger of overlooking cyclists due to the blind spot of a vehicle and by guiding the route so that possible meeting points between traffic participants occur less often and in a decelerated way [6]. In the simulation, bicycle lanes are set apart from the street by 2.9 m to create steeper viewing angles at transitions. Further, the traffic area is smoothed at the corners since no straight bicycle lanes cross the street here. This layout as well as roundabouts need more space than standard crossings. The total width is 15.5 m (fig. 1b). The *roundabout* is realized similarly to the before mentioned protected design. However, the center is designed as an obstacle, forcing cars to turn right shortly after entering and following a circular direction. Further, all turning options become right turns in order to leave the circle even in straight or left direction. The radius of the structure is 8.4 m, width and length do not differ from the other layouts (fig. 1c).

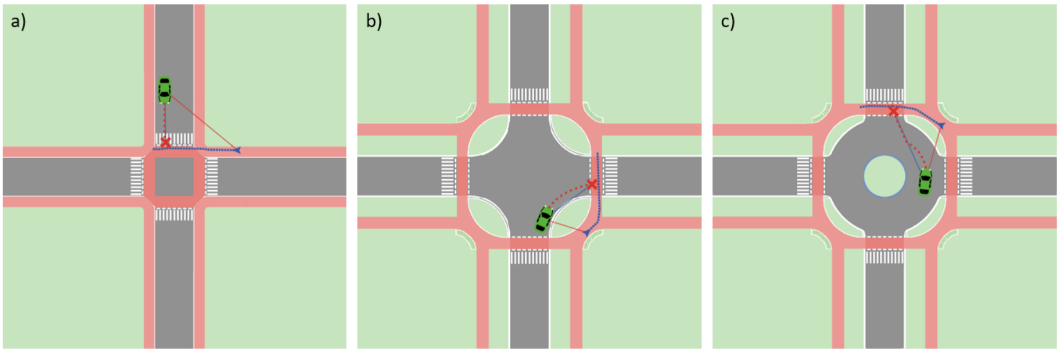

Figure 1 Standard layout (a), protected layout (b), roundabout (c) with collision detection

3 Agents and Control Logic of the Simulation

For every simulation, 1.000 *car agents* pass through the layout. They are implemented as close to real world values as possible. Dimensions, deceleration and acceleration values are chosen after most common compact cars in Germany [10]. Cars appear randomly at the edge of the layout. They are assigned to one of the possible destinations 'turn left', 'turn right', 'no turn' and behave accordingly. A randomizing variable affects driving dynamics within a threshold and creates a more organic and natural simulation. Cars keep lane autonomously and are capable of independently correcting their course while traveling. By this, every layout uses the same movement procedure and even new layouts can be designed and easily incorporated. To identify important viewing angles, car agents track all possible intersections of their own driving path with any other route. If a possible collision is detected, cars calculate the distance to the spot of collision and the respective viewing angles (fig. 1). To downsize programming scope, only one car at a time passes through the crossing. By this, right of way regulations and possible traffic congestion is omitted while increasing simulation speed. Throughout all layouts, *bicycle agents* constantly have the right of way. Thus, bicycles are implemented less complex since they have to meet less conditions. Bicycles do not have methods for accelerating, braking or detecting collisions. Instead, they move at a random speed between 10 and 18 km/h and insist on their right of way. Every 50 time-steps, a new bike appears randomly. Detecting relevant traffic participants requires the ability to estimate their future position at a possible point of collision. This can be modeled by creating a virtual path in front of each vehicle. This path is then followed by every adjacent agent. Now, agents are capable of anticipating collisions and react accordingly. For the analysed set of simulations, a total of 10,504 possible collisions is counted. As shown in figure 1, crossing virtual paths lead to a collision marker (red cross) in combination with distance calculation to this marker (blue line). At the point of an anticipated collision, the car agent automatically tracks viewing angles (red line). As the bicycle passes the collision marker, tracking stops.

4 Perception Model

Processed information is compared with three important aspects of visual environmental perception of a driver [7]: First, the direction or angle of an object to be detected is a key feature. Based on this, the human field of view influences the quality of perception. Further, every car decreases possible perception areas by design-related blind spots and angles. In the following, field of view and blind spots are further described. *Viewing angles* on crossroads can be categorized since the human field of view is divided into multiple segments. The average area of focus is described as an area of -30° to 30° with a vertical head axis as center. Here, three-dimensional perception is at its peak, making this area desirable for critical traffic incidents. Further, peripheral view between -60° to 60° allows us to visually capture further surroundings. However, with growing distance to the center, depth of sharpness and distance estimation is reduced. This reduction is even greater in the monocular segment from -95° to 95°. Here, vision is reduced to one eye, making three dimensional viewing impossible. Ultimately, an area of -110° to 110° can be covered with eyeball rotation (fig. 2) [7].

As every car model has unique *blind spots* in different ranges, mean approximations are used to check simulation layouts for possible weaknesses. *Capaldo et al.* [7] illustrate these ranges in an extensive collection. For our simulation, blind spots of medium and small sized hatchback cars from this collection are used. They divide into pairs for A-pillar (53°-61°, 91°-112°), B-pillar and headrest (136°-148°, 331°-339°) and C-pillar (187°-200°, 252°-273°) values (fig. 2). Simulated data is now checked against these values. Following percentages

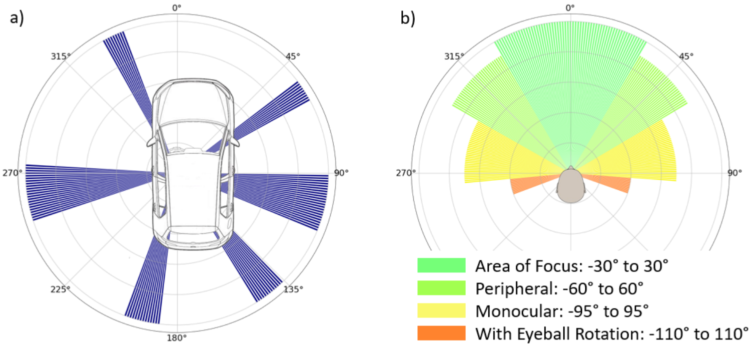

Figure 2 Blind spots of a car as tested (a) and human field of view, segmented after [7] (b)

describe the range of detected angles within a blind spot.

5 Results of the simulation

The analysis of simulation results shows that standard layouts produce best results for the area of focus. 42.6% of all collected viewing angles lie within this sector. Protected layouts follow with an amount of 30.2% and roundabouts show 25.5%. For the peripheral sector, standard layouts show 73.9%, protected layouts show 69.6% and roundabouts show 61.3%. For the monocular segment, protected layouts show best results. 95.2% of all data points are found here. Standard layouts show 88% and roundabouts show 83.9 %. All layouts show similar results for blind spots. Protected layouts lead this statistic with 13.2%, showing the smallest amount of bicycles within a blind spot over time. Standard layouts follow closely with 14.9% and roundabouts with 16.9%.

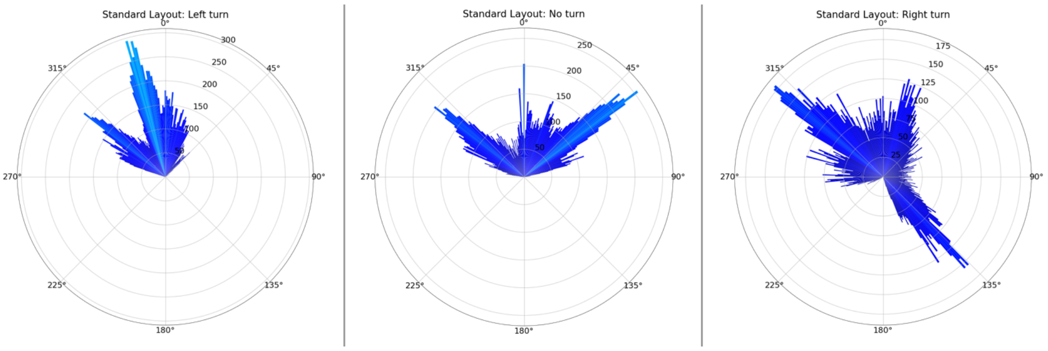

Figure 3 Viewing angles for standard layout by turning direction

Finally, overall viewing angles can be analysed by visualizing most frequent values for every layout and every destination. Starting with the standard layout, it is noticeable that for this design the highest variability in the range of values occurs. Drivers have to observe a total range of 285° in order to spot every bicycle. Especially right turns demand frequent observation of angles at around 135°. This wide angle demands careful shoulder views and turnings of the head by approximately 100° in order to focus on potential dangers. All three plots in fig. 3 show a distinct peak at around 300°. This can be explained by agents entering the crossroad in a similar way, paying attention to crossing traffic from the left. Vehicles crossing straight ahead show another peak at 50° for the second crossing of the right-hand side traffic. Finally, left turning vehicles have a second peak at around 20° for oncoming traffic in the focus area (fig. 3). Protected crossroads show a range of 209°, significantly less than the standard layout. Again for entering the crossing, every layout shows a peak at around 300° as the destination does not influence the entering process. Left turning vehicles have to observe the smallest range with potential collision spots within the focused or peripheral segment. Angles for straight driving vehicles are distributed between 0° and 90°. Right turning vehicles show a similar pattern. However, a smaller peak at around 120° also shows the necessity to look over the shoulder in an angle of approximately 90°. In comparison to the standard layout, these values occur less often (fig. 4).

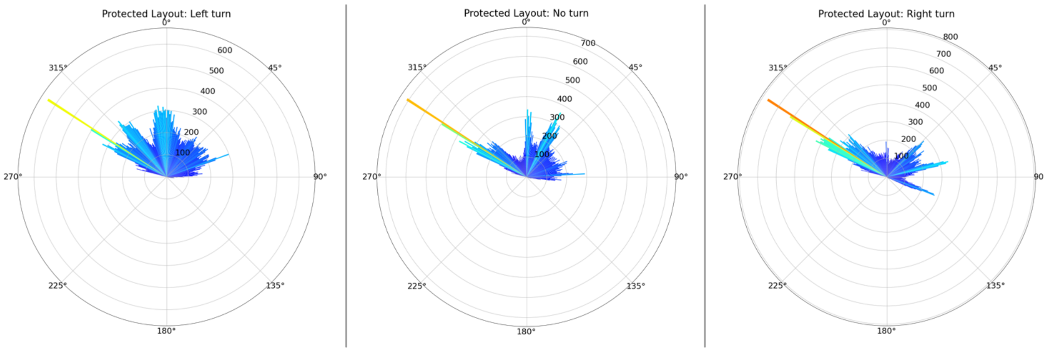

Figure 4 Viewing angles for protected layout by turning direction

The roundabout shows very similar patterns for every plot. Again, the entering peak can be observed at 300°. Further, viewing angles are almost evenly distributed over a range of 214° in total. Here, all plots show a minor peak at around 120° since every car has to perform a similar right turn in order to leave the roundabout. Another anomaly can be observed for right turning vehicles. Here, several values gather around 45°. This can be explained as these cars do not follow the circular structure and leave shortly after entering. This causes a different pattern than the other destinations (fig. 5).

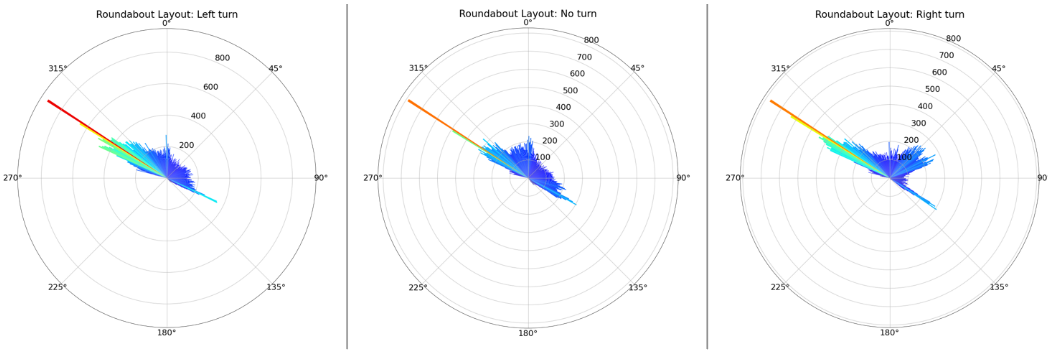

Figure 5 Viewing angles for roundabout layout by turning direction

6 Conclusion

In summary, roundabouts show the least satisfying results. Bicycles frequently appear to be outside of the optimal field of view. Additionally, blind spots show the highest values although they are in a close range for every layout. Further, the range of viewing angles is higher than for the protected solution. Standard layouts show good results especially for the field of view and blind spots. Collision points appear within a good angle. Yet, especially the broad range of viewing angles and potentially dangerous right turns with the necessity to turn the head very far are the layouts weak spots. Protected layouts show best overall results concerning bicycle safety. Field of view and blind spots can be evaluated as positive in comparison to the others. Further, the smallest range of viewing angles supports drivers with a predictable traffic situation. Bicycle safety in dynamic traffic conditions is a complex topic. Viewing angle is one of several parameters whose analysis may improve existing designs. However, several aspects such as space requirements, traffic flow, layout variation and many more influence these outcomes. To gain a holistic overview, all these aspects should be taken into consideration. The introduced simulation is well suitable for identifying viewing angles and showed special characteristics of every tested layout. For future work, this simulation can be extended with adjustable agents and additional layouts.

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