Bikeability and Beyond: Approaches for Measuring the Quality of Cycling

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Abstract. In this paper, we explore how the quality of urban cycling can be measured and analyzed with GIS and location-based data. We discuss different approaches and focus on measurements with ultrasound sensors.

Keywords. Cycling, sensors, GIS analyses, Bikeability

1. Introduction

Many cities want to become more bicycle-friendly for different ecological, economical and other reasons. However, the actual urban cycling experience is impaired by several factors, such as the lack of cycling infrastructure, the low quality of cycling paths, or cars that overtake to closely.

One approach to measure the quality of urban cycling is the “cycling climate” by the Allgemeiner Deutscher Fahrrad-Club (ADFC) Fahrradklimatest[1]. The test, which is actually a survey among citizens, assesses 27 criteria, which are aggregated into five major factors.

While the ADFC Fahrradklimatest gives a good first overview about which cities can be regarded as cycling-friendly and which aspects are regarded as good and bad in certain cities, there are two shortcomings of this ranking: Firstly, it is more based on subjective factors (citizens’ assessments) than on actual objective measurements. Secondly, it only gives an overall score for the city and thus does not differentiate between different areas within cities. Hence, it does not show *where* exactly action should be taken.

Here is where geospatial thinking and location-based approaches come into play. In this paper, we discuss several approaches how quality of cycling can be measured with location-based data and then focus on the measurement of overtaking cars.

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[1] https://fahrradklima-test.adfc.de/

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2. Related Work

The concept of bikeability as an indicator for cycling friendliness has been developed, discussed, and applied by several authors (e.g., Gehring 2017, Nielsen et al. 2018, Schmid-Querg et al. 2021, Hardinghaus et al. 2021) in different cities with different administrative areas (polygons), path segments or raster cells of equal size. Different approaches have also considered different factors that might positively or negatively influence the attractiveness of neighbourhoods for cycling activities. Factors include topography, cycling infrastructure, or landscape aspects. The importance of perceived safety and physical road properties for individual and group differences in cycling route choices have been evaluated by Hardinghaus & Cyganski (2019).

Werner et al. (2023) argue that mixed methods (that is, a mix of qualitative and quantitative approaches) studies are particularly useful to further answer cycling-specific domain questions. They identified and defined three main aspects of interests: safety (objective/perceived), stress (individual) and smoothness (simplicity, speed). The effect of passing distances in urban areas as indicators for stress and safety have recently been investigated by Beck et al. (2021) and Stülpnagel et al. (2022).

3. Measuring the Quality of Cycling: Broader Research Context

The broader context of our research is to investigate the quality of urban cycling and how it can be measured. The focus is on location-based data within the research area of the city of Würzburg.

At the time of writing, our work packages include:

1. Calculating bikeability to identify intra-urban differences in different neighborhoods of the city, based on a 100x100m raster
2. Building a cycling path cadaster with meaningful categories as a foundation for further analyses
3. Validating theoretical accessibility analyses with systematic test rides to identify the influence of topography and building structures
4. Developing methods for quantifying landscape aspects such as scenery
5. Measuring roughness of cycling paths with shock sensors
6. Analyzing smoothness by systematic speed measurements and identifying waiting times

7. Analyzing safety based on user surveys, historical accident statistics and ultrasound sensors for identifying places where cars overtake too closely

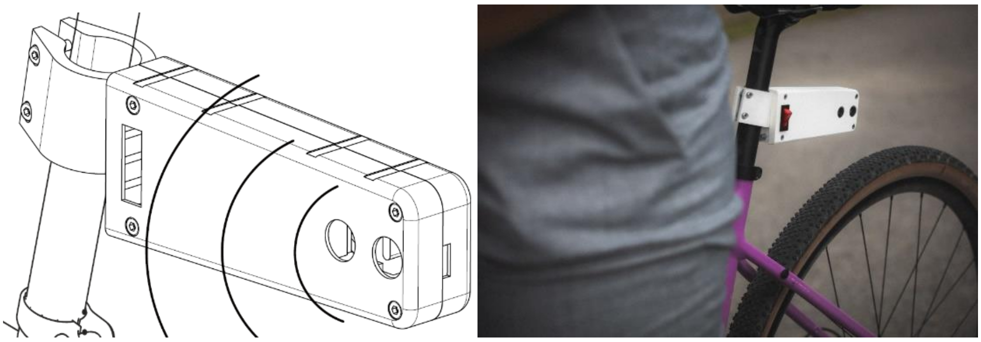
In the remainder of this paper, we are going to focus on 7), i.e., how overtaking lateral distances can be measured on-bike, that is, while cycling.

In German law, a lateral overtaking distance of 1.5m is required in built-up areas when a cyclist is overtaken. However, in reality, cars frequently overtake within a smaller lateral distance - due to impatience, ignorance, or the assessment that a smaller distance is also sufficient and harmless. This often leads to conflicts between car drivers and cyclists, which might regard this as a reduction of their personal safety.

4. On-Bike Measurements with Ultrasound Data

One popular framework for analyzing overtaking distances is OpenBikeSensor[2]. However, for our research we chose a slightly different setup for several reasons. Firstly, the production of our sensors uses the university's current resources, resulting in a 70 percent cost-reduction in comparison to the OpenBikeSensor project. Secondly, the self-developed code allows for complete customization and flexibility in terms of the functions and behaviour of the system. Finally, our setup also provides full control over the data collected, which can be beneficial where privacy is concerned.

For measuring the overtaking distances, we 3D-printed and assembled a box, and equipped it with a standard on-off switch. Inside this box, there are an Arduino board with an HC-SR04 ultrasound sensor, a GPS receiver and a SD card. This box can be mounted below the saddle of any bicycle with standard bicycle tools (Allen keys), see Figure 1.



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[2] Openbikesensor.org

Figure 1. Sketch (left) and photograph (right) of our bike sensor.

The functionality of the Arduino board can be programmed with C++ code. We wrote specific code to ensure the ultrasound sensor records every object that is within a distance of 2.5 meters to the left at the height of the sensor.

Before measuring, the rider has to switch on the box and wait for a GPS fix. Then, the sensor starts recording objects which are within 2.5m lateral distance. These objects become new datasets in a CSV file, which is stored on the SD card and edited as long as the button is switched on and the location data are valid. The datasets contain several fields such as X/Y/Z coordinates, timestamp, speed, the distance of the object and a binary/Boolean "tooclose" field, which classifies whether the object was within a 150 cm distance or not (see Table 1 for an excerpt of the recorded data).

Bikenumber	Latitude	Longitude	Distance	tooclose	Time	Date	Speed
5	49.794048	9.91797	137	1	09:30:28	06.07.2023	15.73
5	49.794273	9.917084	76	1	09:30:50	06.07.2023	9.35
5	49.794277	9.917039	172	0	09:30:51	06.07.2023	12.15

Table 1. Excerpt of the CSV file that is written while recording

When switching off the box and thus its sensors, the CSV file is no longer edited. After data has been recorded, the CSV file can easily be integrated in any GIS system. Areas where objects were "too close" to the ultrasound sensor can thus quickly be identified. First successful test rides with students were performed at the Frankfurter Straße in Würzburg-Zellerau in July 2023 (see Figure 2 for a map of objects that were recorded).

Figure 2. Red dots indicate object within a range of <1.5 m, blue dots indicate objects within a range of 1.5-2.5 m.

After recording, cleaning and filtering the dataset, 908 objects remained as candidates of overtaking cars. The mean of these objects was 1.46m, the median 1.34m (standard deviation: 0.58m). These results suggests that many cars overtake at a dangerous distance, which is legally too close. It is particularly interesting that within bicycle protection lanes, the mean distance even decreased to 1.15m, and 43% of the values were less than one meter.

However, it has to be noted that not every object which is recorded as "too close" is necessarily a "dangerous" overtaking car. Firstly, these objects can also be other objects than cars (i.e., traffic lights or tram stops). Secondly, cyclists often overtake waiting cars to their right side on traffic lights. We thus already omitted measurements where the bike rider was slower than 8 km/h. A detailed speed analysis of the bike can lead to further insights here.

5. Conclusion

There are several ways in which the quality of cycling can be "quantified" by using geospatial analyses and location-based technologies such as sensors. Since more and more sensors and geospatial data are publicly available, the major challenge rather consists of combining and weighing the data, in order to create valid, reliable and objective indicators for the quality of cycling, such as bikeability indices.

Measuring overtaking distances is an important piece in the broader analysis framework for assessing the quality of cycling. While measuring objects at a certain lateral distance already works quite well, it remains a challenge to identify the subset of overtaking cars from all sorts of objects appearing within a certain distance.

It also has to be noted that it is not our aim to denounce individual car drivers. As geographers and geovisualizers, we are interested in identifying locations *where* these risky overtaking maneuvers are a problem, perhaps due to poor cycling infrastructure.

Further research should also focus on the analysis of the perceived danger of an overtaking maneuver. This issue could be tackled by giving participants the opportunity to record whether the overtaking object was regarded as dangerous or not. We hypothesize that the perceived danger depends on several factors – not only on the lateral distance, but also on the speed of the overtaking car.

We plan to enhance our measurements with mixed-methods approaches as suggested by Werner et al. (2023). Specifically, that means more user surveys and post-ride interviews are needed to identify the factors that actually are most important for cyclists regarding the quality of their cycling experience.

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