BikeNow: A Pervasive Application for Crowdsourcing Bicycle Traffic Data

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Abstract

Pervasive urban applications are an upcoming domain in the context of open data and smart cities. They can be considered as applications with a purpose closing the loop from the provision of valuable services for citizens based on available data sets to the motivation of citizens to participate in the collection of new data. In this paper, we present BikeNow, an application that supports cyclists during their ride to minimize the stopping time at red traffic lights. BikeNow predicts the next green light phases of traffic lights along the track of cyclists and provides a suggestion to keep or change the current speed. The purpose of BikeNow is to motivate cyclists to allow the submission of ride related data like current time, position and speed that is of high value for traffic evaluation, prediction and future planing of cycle paths. The evaluation is based on a preliminary survey with 79 participants to study the target user group and a user study with 14 participants to assess the usability of the application. In addition we analyze the value of collectible data for urban traffic analysis and cycle path network planning.

Author Keywords

Bicycle; Driver Assistance System; Crowdsourcing; Traffic; Speed Suggestions; City Planning; Pervasive Application;

ACM Classification Keywords

H.5.3 [Information Systems]: Group and Organization Interfaces – *Collaborative computing*

Introduction

Smart mobility is one of the big challenges for future cities. Since solutions for traffic management and planning heavily rely on up-to-date traffic information, collecting high quality traffic data in an efficient and cheap manner is of high significance. Established traffic management and information systems mostly use stationary detectors to collect information about traffic density, vehicle location, etc. Floating car data (FCD) captured by on-board devices or smartphones is an efficient and cheap complement to an expensive detector infrastructure. Applications like Waze[1] or Google Maps[2] demonstrate the potential of data collection based on crowdsourcing. Anyway, most of the today's efforts are focused on motorized transport.

Bicycle traffic has high potential to significantly reduce issues as high traffic volume, shortage of parking space as well as high noise and air pollution caused by motorized traffic in city centers. To increase the attractiveness to use bicycles a high quality cycling infrastructure is required. To analyze existing infrastructures to detect deficits like insufficient coverage or poor cycle road surface as well as low cycling traffic quality due to long travel times or long waiting times at traffic lights a systematic capturing of data about the cycling infrastructure and the quality of cycling traffic would be required. However, in most cities bicycle traffic data is by far not as detailed and accurate as it is for motorized traffic. Equally, information and management systems for bicycle traffic are still in an experimental state.

In this paper we introduce BikeNow, a system that provides cyclists with speed adjustment information on smartphones to pass the next traffic light at a green phase. The Dresden traffic management system VAMOS [4] with more than 250 traffic lights connected provides data about location and signaling state of traffic lights. This information is used to predict a vector of future state changes of traffic lights that is provided to the BikeNow App. Knowing the route, current location and speed of the cyclist, the App determines the traffic light, the cyclist is approaching, calculates a speed window, the cyclist should move within to get the next green phase and presents the recommended speed adjustment to the user. While cyclists are using the App traffic data (time, location, speed and route information of cyclists) is recorded and fed back into the system.

The contribution of the paper is threefold. First, we describe the concepts and architecture of BikeNow including green time vector prediction, calculation of speed adjustment recommendations and user interface design to meet the requirements of cyclists. Second, we present implementation details of the BikeNow system with connection to the traffic management system VAMOS, that is in operation to control the traffic in Dresden for more than 10 years. Third, we present the results of a preliminary study with 79 participants to analyze the target user group and a user study to validate the BikeNow system in practice with 14 cyclists.

The paper is organized as follows: Next, we discuss the status quo of traffic information systems. In section we explain the objectives of the BikeNow project. In the following section the approach, the implementation and evaluation are presented. We conclude with a summary of the results achieved so far and an outlook to future work.

[1] www.waze.com
[2] www.google.com/maps

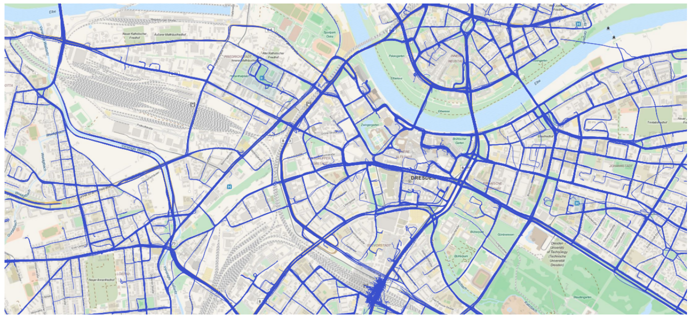

Figure 1: Floating Car Data of about 200 cars in 24 hours

Status Quo

In the following we introduce the Dresden traffic management system VAMOS [4] and discuss existing approaches to crowdsource traffic information, provide speed suggestions and Apps for cyclists.

The Dresden traffic management system VAMOS
VAMOS [4] is using about one thousand stationary sensors to detect the road traffic condition in Dresden. This data is complemented by floating car data (FCD) of about 500 taxis. Also, more than 250 traffic lights are connected to the system, providing data about the state of signaling. Using this and other sources of data, innovative and complex algorithms for data filtering, data processing and data fusion are applied to gain valuable information about current and future traffic conditions for motorized individual traffic. The obtained information is used for traffic optimization, traffic prediction and traffic information. In the following we discuss the aspects of VAMOS relevant for the BikeNow system, namely the use of floating car data, the usage of signaling state information of traffic lights for green phase prediction and the integration of crowdsourced data.

Floating Car Data (FCD) are tracks of data sets including location, speed, travel direction and time information of moving vehicles. Figure 1 shows FCD tracks (blue colored), recorded by approximately 200 cars within 24 hours in the center of Dresden. Using this data important parameters of road traffic like travel times and congestion can be determined. It is also possible to map used roads and derive information about the road network. As Figure 1 demonstrates an almost complete coverage of the road network in the center of Dresden is achieved. Since their is a high similarity between Floating Car Data and Floating Bicycle Data the latter can be integrated and processed in VAMOS in a comparable way.

The *VAMOS green time prediction algorithm* is using data of about 250 out connected traffic lights which send the current state of signaling to the system. Analyzing this data, a prediction algorithm is calculating the probability for future signaling. Prediction is required since signaling not always follows a fixed schedule but is influenced by factors like traffic density, bus or tram priority, etc. Predicted green light vectors are the basis for BikeNow to calculate the speed adjustment suggestions.

The *ExCELL - crowdsourcing and service plattform* [3] is being developed in the the ExCELL research project and already offers services to upload live tracking data collected by mobile devices like smart phones, tablets or on board units in cars. The uploaded data is anonymized, filtered and stored for further processing. The calculation of Level of Service on the basis of FCD is already in use. Floating Bicycle Data can be handled similarly.

Driver assistance for green light passing
Minimizing the number of stops and starts in urban traffic supports economic driving with respect to energy or fuel consumption. It also contributes to an increased traffic qual-

ity with reduced time loss at traffic lights resulting in an optimized travel time.

This can be achieved with different approaches. The most simple one is to define a fixed recommended speed and a synchronization of traffic lights according to that speed. When adjusting the driving speed to the recommendation, drivers can expect to pass a sequence of traffic lights without stops. Such solutions are used for instance for cyclists in Copenhagen [5]. A more flexible approach could use adjustable traffic signs to support variable speed recommendations to incorporate traffic density and further influences on traffic light schedules like bus or tram prioritization.

Another system using speed recommendations is COSEL [9] that provides speed recommendations for tram drivers on certain lines in Dresden based on an Android App. On a path from the north to the south of Dresden trams operate in a high frequency of up to 62 per hour. The path includes 19 traffic lights. To optimize the traffic on this path dynamic scheduling of traffic lights is used. The schedule integrates information about tram schedules, potential connections as well as traffic density on roads. To optimize energy consumption and customer satisfaction COSEL provides recommendations when to leave a stop, maximum/recommended acceleration and to drive with constant speed. COSEL as well as BikeNow are based on the Dresden traffic management system VAMOS, i.e. using the same prediction data for traffic lights.

SiBike [1] is a system for cyclists that relies on actively controllable traffic lights. Using GPS positions, the system detects if cyclists are approaching traffic lights and sends a signal to the according traffic light to switch to green or to extend the green phase. Especially, consecutive traffic lights can be synchronized. In difference to SiBike BikeNow does not actively influence the scheduling of traffic lights but relies on information about predicted schedules. From the cyclists point of view SiBike would be more convenient since no interaction with an App is required except the starting of the App.

Crowdsourcing of traffic information
The goal of BikeNow is to motivate cyclists to use the App and to enable the recording of bicycle traffic information.

For motorized traffic Apps like Waze or Google Maps can be used to get information about the current traffic conditions. Most of these systems collect traffic information based on crowdsourcing, i.e. floating car data is collected and analyzed.

Strava [8] is a system for crowdsourcing information from cyclists. It is a social network for cyclists and other athletes. It allows them to record, upload and share their activities by using a GPS enabled device (e.g. smartphones or fitness wristbands). While it's not dedicated to cyclists it supports the crowdsourcing of cyclist's GPS tracks.

Apps for cyclists
A large variety of Apps for supporting cyclists are available in the app stores for Android and iOS. Main categories are fitness and routing apps. The latter apps usually provide a bicycle mode for calculating routes and rely on data provided by OpenStreetMap, Google or similar providers. Bike Citizens [2] is an iOS and Android App that is tailored to the needs of cyclists. It provides navigation for cyclists by taking information like type of bicycle and cycling style into account. In addition to the navigation the App provides cyclometer functions and route tracking but no support for speed recommendations like BikeNow.

In summary, a set of Apps and systems already provides support for speed recommendations to pass traffic lights at green phases and crowdsourcing of traffic information, in few cases also to crowdsource traffic light schedules. Most of them are targeted to motorized traffic. From the group of bicycle focused solutions BikeNow is the only system that relies on a traffic management system in operation.

Objective

In our approach we intent to use the speed adjustment recommendation as an incentive for cyclists to share their position data with the traffic management system. Analogous to floating car data we want to collect 'Floating Bicycle Data'.

From the collected data we want to derive quality parameters of bicycle traffic like loss times and travel times. Further, we want to extend knowledge about bicycle traffic in urban areas to answer questions like: Which routes are chosen?, What is the average driven speed on which section of the network? and What are the peak times in bicycle traffic? We also aim to collect data to enable an optimization of the bicycle infrastructure and to support planning processes. In the following our main objectives are listed:

Measurement of quality of bicycle traffic: FCD are used to measure the quality of traffic flow for motorized individual traffic. We want to adapt and apply these algorithms to 'Floating Bicycle Data' to measure the quality of bicycle traffic and focus on some characteristic variables like travel time and loss times on traffic lights at intersections.

Measurement of quality of bicycle infrastructure: Nowadays the planning for bicycle infrastructure like bicycle lanes is based on few data like traffic counting and assumptions. This will be still important in the future but could be complemented by crowdsourced data. Using crowdsourcing data it will be known, which paths cyclists really take. It will also help to identify and focus on parts of the network with problems like insufficient capacity or reconstruction needs.

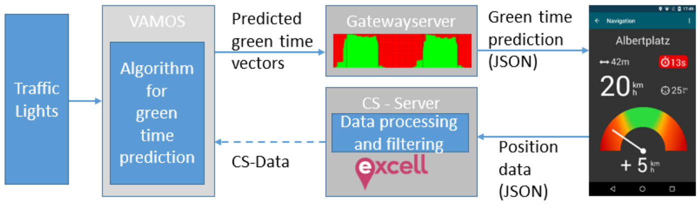

Figure 2: Architecture of BikeNow

Identification of dangerous intersections: Currently traffic signaling is not optimized for bicycles in Dresden. As a consequence, some traffic lights are ignored by cyclists regularly. A comparison of anonymized tracks of cyclists with records of the signaling of traffic lights could reveal hot spots of infringements against red light. This can be an input for traffic planners to change or optimize signaling for cyclists on the identified intersections.

Value added services and user motivation: Collecting crowdsourcing data is difficult since the crowdsourcing approach often lacks a critical mass of participants. We want to motivate cyclists to participate continuously in our crowdsourcing by providing value added services like reduction of waiting times at red traffic lights and increasing comfort of cycling to the cyclist community.

Approach

In the following we introduce the architecture and key concepts of the BikeNow system, namely the prediction of green time vectors, the calculation of speed adjustment recommendations and the design of the user interface for the smartphone App.

Architecture

The architecture of the BikeNow system is depicted in Figure 2. It comprises of the traffic management system VA-

MOS, a gateway server, the BikeNow App and a Crowdsourcing Server. The VAMOS system was already introduced in Section 2. Its role in BikeNow is to provide green time vectors for the traffic lights in Dresden.

Since VAMOS is a productive system, Apps are not allowed to directly access it. Instead, the prediction vectors are transmitted to a gateway server based on a secure connection. The server stores the predictions for all available traffic lights and handles the requests from the clients. Similarly, the crowdsourced data collected by the App is not directly transmitted to the VAMOS system. Instead a Crowdsourcing Server is in charge of receiving and storing the data. In this way the App and the functionality that belongs to the research system is completely decoupled from the productive system.

The BikeNow App is running on the cyclists smart phone and requests the green time prediction vector for the next intersection, using the current location. It is responsible for the calculation and visualization of speed adjustment recommendations as well as for handling user interactions. In background GPS location information is recorded and periodically sent to the CS Server.

Predicting green time vectors
A prediction vector has a temporal resolution of 1 second and a prediction horizon of a few minutes. It contains information about the location of the traffic light and the probability of green light for a requested signal head for each second within the prediction horizon. If the probability for green is higher than 85 percent we assume the signal head to show green in the chosen second.

Calculating speed adjustment recommendations
Combining the information from the prediction vector with the cyclists location, speed and direction of travel, BikeNow is calculating a minimum and a maximum speed. With the minimum speed the cyclist will arrive at the end of the green phase, just passing the traffic light before it switches to red. The same happens vice versa for the maximum speed and the beginning of the green phase.

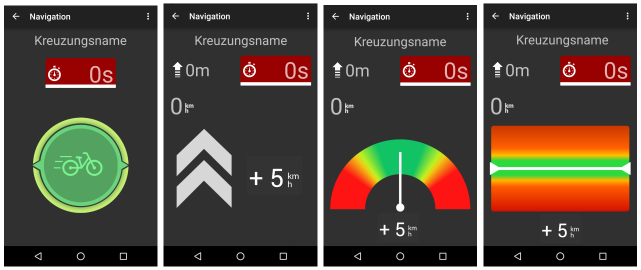

Figure 3: Four variants of the user interface a) minimal b) arrow c) pointer d) rectangle

Crowdsourcing bicycle traffic data
BikeNow is a part of a crowdsourcing infrastructure. Not only it provides value added services to users, it also collects important data about cycling: the cyclists location, altitude, speed, direction of travel and GPS-accuracy are recorded and uploaded to our ExCELL - Crowdsourcing Server using a RESTful web service. On the server the data are anonymized, filtered and stored for further processing.

In further steps the processed data will be uploaded to the VAMOS traffic management system and be used for bicycle traffic management and information systems. Providing this data to cyclists, the loop between the provision of valuable services for citizens based on available data sets and the motivation of citizens to participate in the collection of new data can be closed.

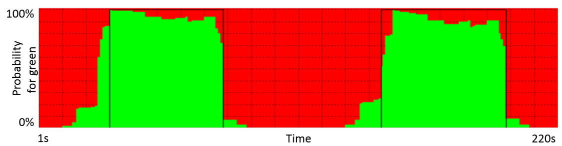

Figure 4: Example of a green time prediction vector, Nürnberger Platz, signal heads K1/K2

UI design
A critical point for driver assistant systems is the design of an user interface that supports minimal driver distraction. We used the approach of User-Centered Design to develop the user interface for the App. First designs were shown to users in a preliminary survey. It was also asked which information would be essential in a driving situation. In addition, the UI needs to have a clear, contrasty appearance since it is used outdoors. Finally, four variants were designed and implemented prior the evaluation (see Figure 3). In these variants different representations of traffic light information were examined.

On the upper side of the screen information like distance to next traffic light, name of crossing ahead and countdown till phase change is displayed. Several different indicators were developed, to show cyclists how to adjust their speed.

Prototype
We have implemented the BikeNow system as an Android App and a set of RESTful services.

For the prototype a fixed route between *Albertplatz* and *Nürnberger Platz* in Dresden was defined and a gateway server was set up to handle the green light prediction vectors, pushed from the management system. A prediction vector with a prediction horizon of a few minutes contains several green phases. Figure 4 shows a visualization of a prediction vector, were the green area indicates the prediction of green and the black line denotes the real signaling for the shown signal head. [6]

The calculation of speed adaptation is carried out on the client. Using the GPS time stamp, the client is synchronized with the prediction vector. Since the current position and speed of the cyclist is known to the App as well as the location of the traffic light, an arrival time at the intersection is calculated. Based on a comparison of the calculated arrival time and the predicted green phases, one of the green phases is chosen, taking the current speed and position of the cyclist into account. For the chosen green phase a speed window is calculated and displayed using the UI. [7]

Figure 5 shows the data collected during a particular test ride along the predefined route. Besides the cyclists location, the altitude, speed, direction of travel and GPS-accuracy are recorded by the prototype.

A short demonstration on how the application is used can be seen in this video: https://vimeo.com/170281365.

Evaluation
In order to get a better overview about the target group and the resulting requirements, a survey was conducted. The results were then used to consolidate the requirements and the UI concept.

Preliminary Survey
In a survey, which was active for about 2 weeks, 109 participants took part of which 79 people completed all questions. The survey was was divided into three sections, namely information needed in a driving situation, understanding of already developed UI elements and questions about the user and behavior. Based on the collected data it was pos-

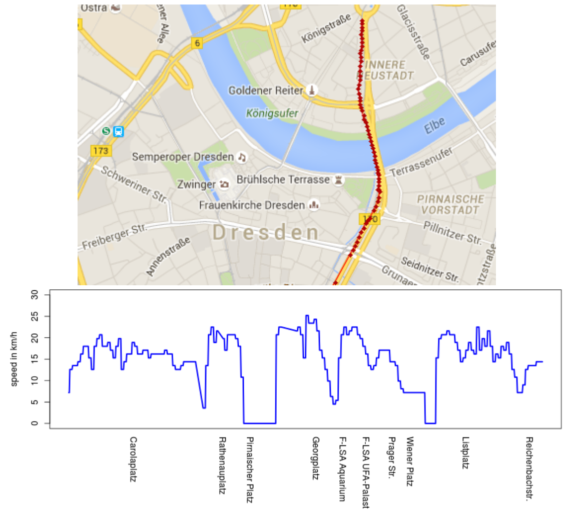

Figure 5: Speed data from a test user on the test route

sible to gain a coarse insight into the needs of the target group. The age of the respondents ranged from 14 to 59 years with an average of 29.4 years. 69.6% of the users were male and 24% female. 40.5% were primarily using a city bike, followed by 36.7% which were using racing bikes and 15.2% which were using mountain bikes and it appears that 54.4% want to drive quickly and 41.7% even want to drive as fast as possible. The majority of 62% uses their bike everyday or two to three times a week (30.4%). Only 7.6% of the respondents were content with the signaling of traffic lights. 70% stated that they would use an application that would show them exactly when the phase change of the traffic light happens. This, the dissatisfaction with traffic light coordination and the fact that driving assistance tools are already used by cyclists indicates that BikeNow could provide added value for cyclists in Dresden.

Evaluation of the UI with a user study

To evaluate the prototype 14 bicyclists tested the application in a practice. The testers had to drive the test route between *Albertplatz* and *Nürnberger Platz* in Dresden. The smartphone was mounted on the handlebar of the bike. The goal of this evaluation was to see which UI variant is the most comprehensible and what could be changed to improve the overall usability. Therefore testers had to select one of the four UI variants for each ride. An interview was conducted after the ride, applying the method of „thinking aloud".

A short survey about usability had to be completed afterwards, applying the system-usability scale and personal information (gender, age, the used bike and the type of cyclist) were asked. The user group showed a similar composition like the one in the preliminary survey. The measured system-usability scale resulted in a score of 83,9 in average indicating a high usability of the BikeNow App. Ten of the 14 participants were male and four female. The majority of 57% stated that the pointer view (see Figure 3c) is the most comprehensible, followed by 29% who chose the arrow view (see Figure 3b). Seven of 14 users felt that they were distracted by the application. This issue has to be resolved in further iterations with the exploration of sounds and/or vibration signals. The UI was well understood by the testers.

Conclusion and Future Work

In this paper we presented the BikeNow system that provides the added-value service of speed recommendations for passing crossings at green light to cyclists as a incentive to participate in the crowdsourcing of bicycle traffic information. BikeNow does not actively influence traffic light schedules but relies on predicted green time vectors from the VAMOS system, that is in operation for traffic management and information in Dresden. The system was fully implemented to demonstrate the feasibility of our approach. The field test conducted with 14 cyclists allowed us to identify the pointer as the best visualization approach out of four different designs. The system-usability scale was used to measure the App's usability. A score of 83,9 in average underpins the high usability of the BikeNow App.

As a next step the implementation of BikeNow should be advanced to a productive system. As user tests revealed improvements are required for the calculation of speed recommendations, location accuracy and energy consumption. To cover the whole city of Dresden with our app it might be useful to integrate a routing and navigation system.

With an improved and stable implementation, we intent to conduct a larger field test to collect an appropriate set of crowdsourced data. Analysis of collected data has to prove its expected value. Once we have the critical mass on users and collected enough data we'll start adopting FCD algorithms on bicycle data to measure quality of bicycle traffic and analyze bicycle paths to support the planing processes of bicycle network. Feeding back the information extracted from the raw crowdsourcing data, we will close the loop between data provision and consumption. Cycling will be smooth and comfortable in Dresden.

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