Optimization of Swarm Formation in Swarm Cycling

Linglong Meng, Krutarth Parwal, Stefan Schaffer
{linglong.meng,krutarth.parwal,stefan.schaffer}@dfki.de
German Research Center for Artificial Intelligence
Berlin, Germany

ABSTRACT

Cycling in groups improves safety by adopting the "safety in numbers" approach, reducing the risk of collisions with other traffic units, and enhancing the visibility of cyclists on the road, with cyclists riding as a more prominent and visible unit. Swarm cycling, a novel urban mobility concept, involves cyclists riding together in a group in a common direction or destination. The swarms are formed automatically via peer-to-peer connection when cyclists come in proximity, and the information of the swarm and individual cyclists will be synchronized within the swarm via a Nearby Mesh Network. In order to improve the existing swarm application, a pre-test with HCI experts was conducted in a low-traffic and enclosed area. The results of the pre-test round revealed that swarm formation could be optimized by adding more real-time information about the swarm to the user. Two distinct processes based on the user state (static, and dynamic) are developed for the optimization of the swarm formation, and integrated into the swarm cycling system to provide cyclists with information such as the reachability of the swarm, estimated arrival time, distance, and recommended speed to help the cyclist to approach the swarm. Online reviews from the same HCI experts confirmed the positive effect of real-time information in bridging the user's awareness gap regarding whether the swarm is reachable and facilitating seamless swarm joining.

KEYWORDS

Swarm, Mobility, Optimization, Bicycling

1 INTRODUCTION

In recent years, the use of bicycles has seen a significant increase in popularity, driven by the increase of bike-sharing programs for urban bicycling [7] and improvement of cycling infrastructure, e.g. dedicated bike lanes [6, 9]. According to a study of the World Health Organization, it is found that the number of people cycling in cities around the world increased by as much as 70% during the pandemic as compared to pre-pandemic numbers [13]. However, road infrastructure is often designed to prioritize the efficient movement of vehicles, such as cars and trucks. The lack of presence while cycling alone put the cyclists even in more dangerous situations where traffic is intensive. In Berlin, the capital of Germany, 80% of participants in a survey on cyclist satisfaction in 2020 stated that they did not feel safe as cyclists in Berlin traffic [1]. Accident statistics from 2016 confirm this impression: 30% of those killed in traffic accidents in Berlin and about 28% of those seriously injured were cyclists, even though only 15% of all trips in Berlin were made by bicycle in 2017 [11, 16].

In previous research, the "safety in numbers" approach states that when more people are walking or biking, the likelihood of a collision with a pedestrian or bicyclist is lower [5]. Cycling in a group enables cyclists to gain better visibility on the road as they ride as one bigger visible unit. In Germany, groups of cyclists with more than 15 participants are allowed to ride together as a unit in road traffic. Cycle paths that must be used by solo cyclists are of no significance for such groups [18]. Berke et al. developed a system that inducts bicycles automatically into ad-hoc "swarms" with the synchronous pulsation of light when cyclists are in proximity to each other [3]. Recent research introduced a new form of urban mobility, namely *swarm cycling*, that creates a group of people cycling together for a while in a common direction or destination utilizing routing service with the support of trip intersection computing [8]. Swarms are formed automatically via nearby mesh networks when cyclists come in proximity.

In the current swarm cycling system, bicyclists are able to join the swarm at the so-called *checkpoint* with the support of trip intersection computing and Nearby Mesh Network. However, lack of information about the swarm, e.g. position, speed, etc., limited the efficiency of approaching the checkpoint to join a swarm. Similar optimization problems are also addressed in the research of pickup and delivery options [2]. Czioska and Sester introduce five simple optimization methods to identify reasonable checkpoint locations in ride-sharing scenarios on a real street network and found out that the intersection of space-time prisms delivers good results in terms of performance and computing capacity [4]. In order to improve the existing swarm application regarding swarm formation, we conducted a pre-test round with experts from the HCI field. The task was to walk in a low-traffic area with a predetermined start and destination point to ensure that they could safely experience the swarm functionality in the test. The results of the pre-test round showed that optimization of swarm formation is required due to the lack of user-swarm information. To resolve the optimization problem we developed two swarm formation processes based on the state of the user (static, dynamic), which processed the data of the swarm and user as input and provided the user with real-time information, such as estimated time to arrival, distance, recommended speed, and reachability of swarm to optimize the swarm formation.

In this paper, we present a solution for the optimization of swarm formation in swarm cycling system. Before we provide the technical description and implementation, we first introduce the concepts of swarm cycling and the use cases. We then define the problems derived from the expert pre-test round. In the technical description,

MuC'23, 03.-06. September 2023, Rapperswil (SG)

https://doi.org/10.18420/muc2023-mci-ws03-462

swarm formation processes are described based on the user states. Thereafter, we show how we evaluated the solution and discussed the results. Lastly, we conclude and highlight future works.

2 SWARM CYCLING

The idea of swarm cycling is to utilize the current mobility context of a user to create a group of people cycling together with a common direction or destination. Utilizing the routing service OSRM [14] with support of trip intersection computing, the system inducts the cyclists into a cycling swarm. When cyclists come in proximity, the swarms are formed automatically via peer-to-peer connection, and the information of the swarm and individual cyclists will be synchronized within the swarm via a Nearby Mesh Network. A smartphone application is utilized to communicate the presence and proximity of swarms to the user. Regarding the location context we utilize geofencing [17] and the peer-to-peer connection state to generate corresponding system actions and outputs for different scenarios: *Join swarm:* If a cyclist is in proximity with a swarm, the network connection will be established. Thus, a new member joins a swarm. A notification will be shown in the Android application to the new member and the swarm members. The updated swarm information is then synchronized within the swarm including the newly joined bicyclist; *Leave swarm:* If a swarm member leaves the proximity of the others, the left bicyclist will be disconnected from the nearby mesh network. And the left bicyclist will be notified with a notification. For the rest of the swarm members, the swarm information is updated and synchronized within the group.

The swarm cycling system is based on a client-server architecture. The client side of the system comprises an Android application named *Bikerider*. *Bikerider* provides the cyclists with an input interface for performing trip requests. The response of a successful trip request consists of the trip recommendations with information of trip intersections with the other bicyclists. Cyclists can select the preferred trip recommendation. A Nearby Mesh Network module integrated into the application is there for synchronization and information propagation within the swarm group. On the server side, a routing service with trip intersection computing is provided utilizing the Open-Source Routing Machine (OSRM). The bicyclist data and swarm data sent from the clients via a RESTful API are saved and processed for further use such as coordinating between swarms.

3 PROBLEM DEFINITION

We conducted a user test in a real-world setting with three experts specializing in Human-Computer Interaction (HCI). The aim of the test was to further develop the current system and improve its usability regarding swarm formation based on expert feedback. To prioritize the safety of the experts involved, the test was conducted in a low-traffic and enclosed area. Due to the limited available space, the test was conducted by walking with the smartphone holding in hand. Of course, walking differs from cycling in terms of interaction with the system. However, since the experts' task was to identify problems with the user interface that were specifically related to swarm functionality, walking should not cause any interference that could affect the results. In the test, each participant was equipped with an Android smartphone with *Bikerider* installed. Each participant was given a set of pre-defined origin-destination pairs, that were selected in such a way that trip intersections with the other participants would occur. The participants followed the trip recommendation in the *Bikerider* app to identify interaction problems during the swarm scenario.

Feedback was collected through the thinking-aloud technique as well as interviews with the experts after the experiment. Two main issues were identified. First, users were unable to make informed decisions about which swarm to join or whether to join it because they had no information about the accessibility of the swarm. For example, one participant started the trip far away from the checkpoint while the swarm was already very close to the checkpoint; in this case, the swarm is not reachable for a new participant. Second, lack of real-time information about the swarm makes it difficult for a new user to reach the checkpoint in time in order to seamlessly join the swarm. If the user is cycling too fast and reaches the checkpoint before the swarm, the user has to wait for the swarm to arrive. It is necessary to provide the user with real-time information such as the ETA(estimated time of arrival), recommended speed to arrival based on the current speed of the swarm, and the distance to the checkpoint to help the user to approach the swarm.

4 IMPLEMENTATION

4.1 Swarm formation process

To address the issues identified in Section 3, we formulated them into a mathematical problem. The problem entails determining the possibility for a bicyclist to reach a checkpoint and approach a swarm, considering their position, speed, and trip geometry, as well as those of the swarm, all within the constraints of speed limitations in the urban area. If reaching the checkpoint is possible, what are the distance, ETA, and recommended speed to achieve this. We developed two distinct mathematical processes based on the state of the user: the static process is employed when the user is stationary at the start of the journey, while the dynamic process is utilized once the user begins the trip, generating real-time information, including the swarm's reachability, distance, ETA, and recommended speed. First, we defined the following terminology:

(1) $Checkpoint_x$: Geo coordinate of the checkpoint
(2) $Polyline_x$: A path represented in form of polyline [10]
(3) $Speed_x$: The current speed of x, in meters per second
(4) ETA_x: Estimated time of arrival to the checkpoint for x, in seconds
(5) $Geolocation_x$: Geo coordinate of the x
(6) $Polyline\_current\_geocoordinates_x$: The nearest geo coordinate to $Geolocation_x$ in the decoded array of $Polyline_x$
(7) $Polyline\_checkpoint\_geocoordinates_x$: The nearest geo coordinate to $Checkpoint_x$ in the decoded array of $Polyline_x$
(8) $Distance_x$: Distance of x from current geo coordinate to the $checkpoint_x$ along the $Polyline_x$, in meters
(9) $Recommended\_Speed_x$: Recommended speed for the user to reach the checkpoint

4.1.1 Static Process: The static process aims to inform the user about the accessibility of the checkpoint before the user has started the trip by comparing ETA_{user} with ETA_{swarm}. To calculate ETA_x

and $Distance_x$, first, $Polyline_x$ is decoded into an array of geo coordinates that represent the path. Second, the nearest geo coordinates to $Geolocation_x$ and $Checkpoint_x$ in the decoded path array are found, denoted as $Polyline\_current\_geocoordinates_x$ and $Polyline\_checkpoint\_geocoordinates_x$. With these as input, the distance along the path between the two geo coordinates $Distance_x$ can be calculated by utilizing Geolib [12] library. With $Distance_x$, ETA_x can be simply calculated by:

$$ETA_x = \frac{Distance_x}{Speed_x}; x \epsilon \{user, swarm\}$$

To calculate ETA_{user}, since no actual speed of the user is available when the user just started the trip and has not moved yet, we take 22 km/h (6.11 m/sec) as a hypothetical value for user speed, which is the maximum mean speed for bicyclists of all age groups with a conventional bicycle [15]. Afterwards, ETA_{user} is compared with ETA_{swarm} to determine the reachability of the swarm:

$$isSwarmReachable = \begin{cases} 1 & ETA_{swarm} - ETA_{user} \geq 0 \\ 0 & ETA_{swarm} - ETA_{user} < 0 \end{cases}$$

If *isSwarmReachable* is 1 means that the swarm is reachable, otherwise, the swarm is not reachable. Furthermore, in order to calculate the recommended speed $Recommended\_Speed_{user}$ for the user to reach the checkpoint, the distance to the checkpoint for user $Distance_{user}$ and the ETA of the swarm to the checkpoint ETA_{swarm} are needed:

$$Recommended\_Speed_{user} = \frac{Distance_{user}}{ETA_{swarm}}$$

This process provides the user with important details, such as the recommended speed, estimated time, distance, and the possibility of reaching the checkpoint from their current geolocation. This information assists the user in making decisions not only regarding the accessibility of the checkpoint, but also whether the required speed is within the comfort zone for bicyclists. Additionally, if multiple checkpoints are available, the user has the option to select any of them according to preferences.

4.1.2 Dynamic Process: Once the user starts the trip and the actual speed is available, the dynamic process is utilized to compute the real-time information. The computing of ETA_x, $Distance_x$, $Recommended\_Speed_x$ and *isSwarmReachable* utilize the same method with static process. However, the actual speed of user $Speed_{user}$ is used for the calculation of ETA_{user} instead of a hypothetical value used in the static process because the actual speed of the user is available after the user moved on along the trip. In the dynamic process, an ERTSO(real-time speed optimization) is also computed to provide the user with speed advisory such as accelerating, decelerating or maintaining speed:

$$ERTSO = Recommended\_Speed_{user} - Speed_{user}$$

Here, a positive *ERTSO* indicates the need to accelerate, and a negative value indicates the need to decelerate. If the value is 0, the user must maintain the current speed. In the *Bikerider*, user's geolocation is updated with a frequency of 1 Hz. The dynamic process is set to the same frequency to provide the user with real-time information.

4.2 Technical Integration

The swarm formation processes are integrated into the *Bikerider* application. The back-end server provides the required data of swarm/user to *Bikerider*, including the trip geometry, the current location, and the current speed of the swarm/user. Upon receiving the input data, the swarm formation processes utilized it to compute the required information such as estimated time of arrival, recommended speed to arrival, the distance to the checkpoint, and whether the swarm is reachable, as output. The computed output is then utilized to notify the user with a popup information window, as depicted in Figure 1 (Middle).

5 EVALUATION

To access the functionality and the usability of the implementation which address the issues that are identified in Section 3, we conducted an online review with the same experts who were involved in the pre-test round. As the experts have already experienced the swarm cycling system in the pre-test round, it is sufficient to provide them with screen-recorded videos to access the implementation in terms of functionality and usability. The videos were recorded with a screen recorder on the smartphone while three participants followed the same test routes and experiment settings as the pre-test by HCI experts in the same area. For each participant, two videos are captured based on the test scenarios. Overall six videos from three participants are collected. The experts were briefed with the problem definitions and the implementation including swarm formation processes prior to evaluation. Following the video evaluations, feedback from the participants was obtained in a semi-structured interview.

5.1 Example Scenario: Join Swarm

To demonstrate the implementation we describe the integration into the user interface, with an example of *Join swarm* scenario. First, to determine whether the user can successfully join a swarm, we showcase the system's capability to facilitate swarm formation, which was evident in both cases, as they provided users with prior information on whether they would be able to reach the swarm. Second, to showcase how a user can approach a swarm, illustrating the effectiveness in guiding users towards the checkpoint. In the scenario, three participants are involved, two of them are already in a swarm, and another is attending to join the swarm.

5.1.1 Swarm successfully joined. Before starting the trip, the user sent a trip request by selecting the destination. As shown in figure 1 (Left) the blue marker represents the user's start position, and the black bicycle icons represent the geolocation of users in the swarm. In addition to the user's trip information, the app also provided user with information of the reachability of the swarm, ETA to the checkpoint, distance, and the recommended speed which are computed with the static process. In this case, the swarm is reachable and the user started the trip. During the trip, the dynamic process provided the user with real-time information including ETA, distance, and recommended speed to reach the checkpoint in time, as shown in Figure 1 (Middle). As soon as the user started to move, the user's current location is represented by a bicycle icon with a yellow background. With the help of the real-time information, the

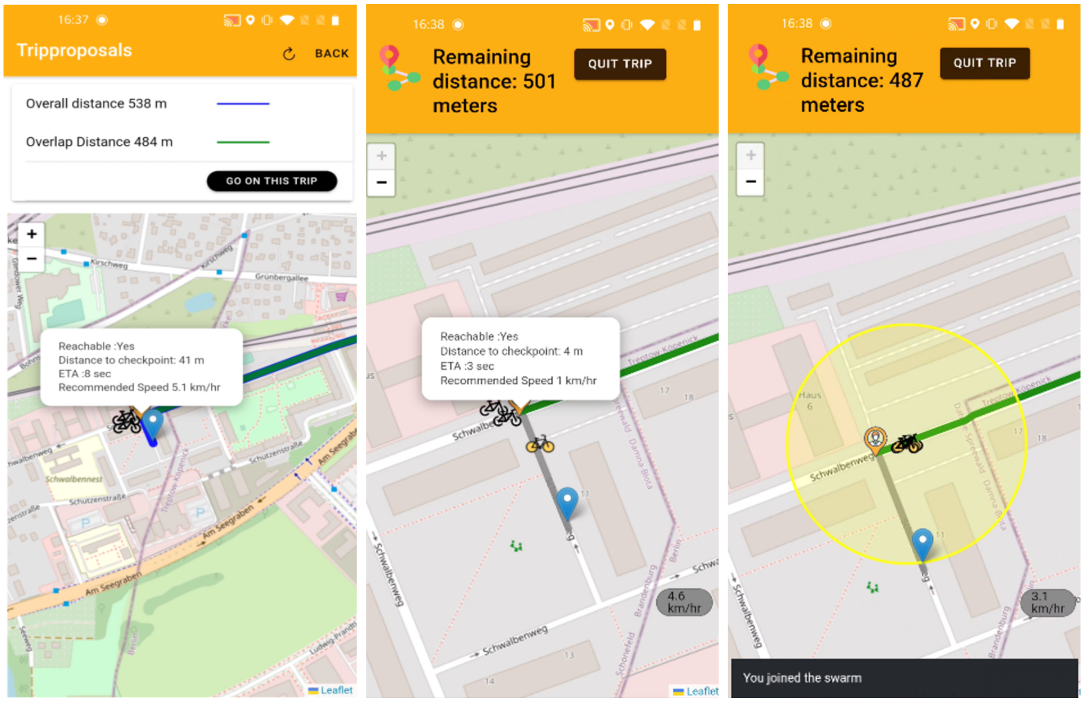

Figure 1: Swarm successfully joined. Left: when the user received the trip recommendation, it shows a pop-up information window with reachability of swarm, etc; (Reachable: yes, Distance to checkpoint: 41m, ETA: 8 sec, Recommended Speed: 5.1 km/h); Middle: shows a pop-up window with real-time information to help the user to approach the swarm; (Reachable: yes, Distance to checkpoint: 4m, ETA: 3 sec, Recommended Speed: 1 km/h); Right: a notification at the bottom of the screen "You joined the swarm" confirms the successful joining of the swarm for the individual user.

user managed to approach the swarm in time and joined the swarm as a group, as shown in figure 1 (Right). The app generated a toast notification of joining a swarm and show a yellow circle around the bicycle icon to indicate that the user is in a swarm.

5.1.2 Swarm join unsuccessful. In this scenario, the user requested a trip recommendation, as shown in figure 2 (Left). The static process predicted that the user was not able to reach the swarm in time. However, the user continued with the trip to test how the dynamic process adapts when the swarm is not reachable. After the user started the trip and moved forward, the dynamic process predicted that the user is still not able to reach the swarm based on the current speed of the user, as shown in figure 2 (Middle). Figure 2 (Right) shows that the user reached the checkpoint, but the swarm already passed the checkpoint.

5.2 Results

Compared to the pre-test round, the experts found that the system provides users with sufficient information to help them approach the checkpoint to join a swarm. The real-time information proved beneficial as it allowed users to make informed decisions regarding whether to join the swarm or which swarm to join. The swarm formation processes provided the user with the necessary speed information required to reach the designated checkpoint before or at the same time as the swarm. Nevertheless, the experts also suggested that the initial and final members' coordinates of a swarm could be considered in the process, as a large swarm may take some time to cross the checkpoint, and the user may be able to get there before the last member of the swarm does. Additionally, calculating the cruising speed for the entire swarm might help the user to better understand the nature of the swarm. In summary, the experts concluded that the implementation of swarm formation optimization significantly advanced the objective of the app to form or join swarms and effectively offered valuable insights to users, increasing the likelihood of successful swarm formation.

6 CONCLUSION AND FUTURE WORK

In order to further develop the current swarm cycling system to improve the swarm system regarding swarm formation, we conducted a pre-test round with three experts from the HCI field in an enclosed area. To address the issues identified during the pre-test round, we introduced an optimization for swarm formation comprising of two distinct processes, which are tailored based on the user state. These processes utilize swarm and user data as inputs to calculate real-time information, including estimated time of arrival, recommended speed for arrival, distance to the checkpoint, and swarm reachability to assist the cyclist in effectively approaching the swarm. From the results of an online review of HCI experts based on videos, the implementation has been shown to provide sufficient information for optimizing the formation of a swarm and

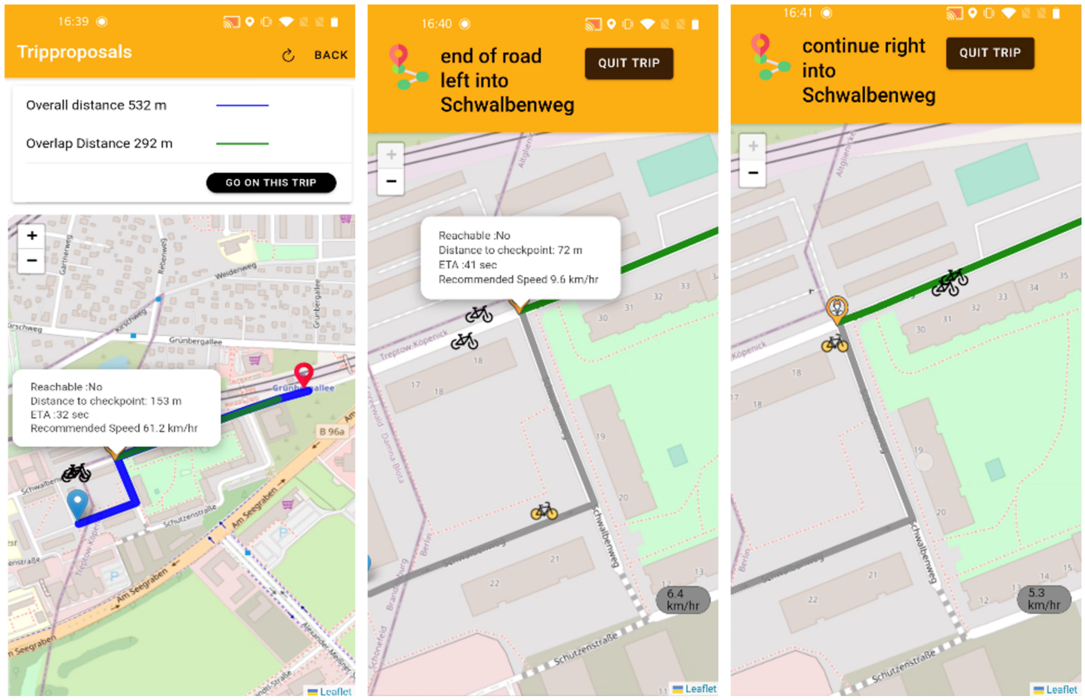

Figure 2: Swarm join unsuccessful. Left: when the user received the trip recommendation, it shows a pop-up information window with reachability of swarm, etc (Reachable: no, Distance to checkpoint: 153m, ETA: 32 sec, Recommended Speed: 61.2 km/h); Middle: shows a pop-up window with real-time information after the user started the trip and moved forward (Reachable: no, Distance to checkpoint: 72m, ETA: 41 sec, Recommended Speed: 9.6 km/h); Right: The user arrived at the checkpoint, but unable to join the swarm as the swarm already passed the checkpoint.

improving the user experience when approaching the swarm. However, there is a limitation in the current approach. The optimization of swarm formation was developed and experimented with only three participants in the swarm, which represents the minimum number required for swarm scenarios like *Join swarm*, *Leave swarm*, etc. As the swarm size increases significantly, the swarm length should also be considered. In our future work, we will continue to develop and experiment with the swarm cycling system with more participants in the swarm to extend the scalability of the system.

7 ACKNOWLEDGMENT

This research is funded by the German Federal Ministry of Education and Research (BMBF) project SocialWear (01IW20002).

REFERENCES

[1] ADFC-Bundesverband. 2021. MADFC-Fahrradklima-Test: Unzufriedenheit in Berlin ist hoch – Aus Trippelschritten muss mutiges Voranschreiten werden. (WWW). https://adfc-berlin.de/radverkehr/infrastruktur-und-politik/969-adfc-fahrradklima-test-unzufriedenheit-in-berlin-ist-hoch-aus-trippelschritten-muss-mutiges-voranschreiten-werden.html

[2] Gerardo Berbeglia, Jean-Franßois Cordeau, and Gilbert Laporte. 2010. Dynamic pickup and delivery problems. *European Journal of Operational Research* 202, 1 (2010), 8–15. https://doi.org/10.1016/j.ejor.2009.04.024

[3] Alex Berke, Thomas Sanchez Lengeling, Jason Nawyn, and Kent Larson. 2019. Bike swarm. In *Conference Companion Publication of the 2019 on Computer Supported Cooperative Work and Social Computing*. 1–4.

[4] Paul Czioska and Monika Sester. 2015. Determination of efficient meeting points in ride-sharing scenarios. In *18th AGILE Conference on Geographic Information Science*.

[5] Peter Lyndon Jacobsen. 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention* 9 (2003), 205–209. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1731007/pdf/v009p00205.pdf

[6] J. Kim, A. Park, K. Kim, S. Park, and D. Kim. 2019. The Impact of Dedicated Bike Lanes on Cycling and Driving in Seoul, South Korea. *Transport Policy* 17, 2 (May 2019), 143–152. https://doi.org/10.1016/j.tranpol.2019.01.002

[7] Joseph P. Kuzmyak, Eric Martin, and David Vaughan. 2019. Bike-Sharing in Columbus, Ohio: The Impact on Car and Bike Trips. *International Journal of Environmental Research and Public Health* 4, 20 (2019), 3865–3880. https://doi.org/10.3390/ijerph16203865

[8] Linglong Meng, Stefan Schaffer, and Vincent Wappenschmitt. 2022. A Connected Swarm Cycling System. In *2022 IEEE International Smart Cities Conference (ISC2)*. 1–5. https://doi.org/10.1109/ISC255366.2022.9922268

[9] National Association of City Transportation Officials. 2017. *Benchmarking Report 2017*. Technical Report. National Association of City Transportation Officials. https://nacto.org/wp-content/uploads/2017/10/NACTO_Benchmarking_Report_2017.pdf

[10] A. V. Nilesh and B. S. Suresh. 2011. Polyline: Representing a Path or Line using Connected Points or Vertices in 2D or 3D Space. *International Journal of Computer Applications* 18, 8 (2011), 43–48. https://doi.org/10.5120/2660-4525

[11] Dr. Claudia Noibs, Denise Obersteller, Anne Klein-Hitpaß, and Fritz R. Viertel. 2020. Agora Verkehrswende (2020): Städte in Bewegung. Zahlen, Daten, Fakten zur Mobilität in 35 deutschen Städten. (WWW), Germany, Berlin. https://www.agora-verkehrswende.de/veroeffentlichungen/staedte-in-bewegung/

[12] npm. 2021. Geolib. (WWW). https://www.npmjs.com/package/geolib

[13] World Health Organization. 2020. More People Are Cycling in Cities Around the World During the COVID-19 Pandemic. https://www.who.int/news-room/detail/11-09-2020-more-people-are-cycling-in-cities-around-the-world-during-the-covid-19-pandemic

[14] OSRM. 2021. Open Source Routing Machine. (WWW). http://project-osrm.org/

[15] Katja Schleinitz, Tibor Petzoldt, Luise Franke-Bartholdt, Josef Krems, and Tina Gehlert. 2017. The German Naturalistic Cycling Study–Comparing cycling speed of riders of different e-bikes and conventional bicycles. *Safety science* 92 (2017), 290–297.

[16] Verkehr und Klimaschutz Senatsverwaltung für Umwelt. 2017. Mobilität der Stadt, Berliner Verkehr in Zahlen 2017. (WWW), Germany, Berlin. https://www.berlin.de/sen/uvk/verkehr/verkehrsdaten/zahlen-und-fakten/mobilitaet-der-stadt-berliner-verkehr-in-zahlen-2017/
[17] Wikipedia. 2021. Geo-fence. (WWW). https://en.wikipedia.org/wiki/Geo-fence
[18] Wikipedia. 2021. Verbandregel. (WWW). https://de.wikipedia.org/wiki/Verbandregel