Reference	*FP17*
Project Title	Rural Cycling in Focus
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Project Duration	2023-04-01 – 2024-03-31

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Contents


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Summary

Even though cycling is slowly starting to get recognised as the sustainable mode of transport it is, this is mostly limited to short trips in urban areas. However, also in rural environments the bicycle has potential to replace the car for many trips. Best practice and research findings from urban areas cannot necessarily be directly applied to the rural environment, as preconditions can differ substantially. Speeds are higher, most interactions are longitudinal, the road is often shared, and the trip purposes and road users are likely to have different characteristics. This is also reflected in the differences in crash typology for rural and urban environments.

This project aimed at further describing conflicts on rural roads between motorists and active travellers in a Swedish context by analysing crash statistics. The development of a logger that provides measurements of overtaking and oncoming passes in detail and can in the future then be used to quantify the context for situations that do not result in a (documented) collision. This way, collisions can be put into perspective for example in relation to the context (road type, speed limit, average annual daily traffic, etc.).

Objective and reliable measurements of longitudinal interactions between motorists and active road users – namely overtaking and oncoming passes – are one important ingredient to assessing the current situation and the effectiveness of potential countermeasures. The measurement devices used in research so far are usually custom-built and the data reduction process is often not fully transparent. Within this project, we built an expandable device for logging the lateral distance to overtaking and oncoming vehicles and the approach speed of overtaking vehicles. The process to extract the passing occasions and the correct overtaking distance is made available as open source.

The methodology is planned to be used in future projects aiming at improving the situation for active travel on rural roads.

Rural Cycling in Focus

1. Background

Cycling is one of the least resource-demanding ways to get around, and it is slowly being recognised as such when it comes to transportation in urban areas, not least with the recent adoption of the European Declaration on Cycling (European Commission, 2024). However, in rural areas individual transportation is still very much centred around the private car. This is manifest in the societal discourse, in rules and regulations, and also in the behaviour of individuals both when it comes to transport modality choice and to concrete behaviour in various situations in traffic.

Information about the prevalence of cycling in rural areas in Sweden is sketchy at best, even though there are several indications that it does occur more frequently than what may be generally assumed. Apart from what is described in a review on national and international research on cycling in rural areas (Kircher et al., 2022), a recent representative survey revealed that as many as 38 per cent of the adult population in Sweden use rural roads at least sometimes either as cyclists or as pedestrians (Kircher & Lindman, submitted). Of the 52 per cent of the population who currently use rural roads only with motor vehicles, a quarter indicate that they would like to cycle, too, but do not dare to, because of traffic.

The most common encounters with motorized traffic are oncoming and overtaking situations. Especially overtaking situations are experienced as uncomfortable by many cyclists and potential cyclists (Heesch et al., 2011), such that it is important to explore how these manoeuvres can be rendered reassuring for cyclists.

1.1 Crashes

Crash data are one available source to acquire knowledge of the context in encounters between motor vehicles and people using rural roads by means of active transportation. A few reports describe the circumstances in rural road crashes involving active road users.

Fatal crashes involving active road users were studied in an analysis of the Swedish Transport Administration in-depth database (Kullgren et al., 2019). The most common crash scenarios for cyclists were longitudinal (the cyclist and motor vehicle travelled in the same direction) and for pedestrians crossing paths. The majority of cyclist crashes, 71%, happened in daylight, while 62% of pedestrian crashes happened in darkness. The majority of crashes occurred on dry roads; 36% occurred on wet roads and 15% on snow or ice.

AIS2+ car-to-cyclist crashes in STRADA and fatal car-to-cyclist crashes in the Swedish Transport Administration in-depth database were analysed (Fredriksson et al.,

2014). Parameters describing separate car-to-cyclist crash scenarios were presented, among these the crash location in terms of urban/rural.

In a study using data from pedestrian and bicyclist crashes in North Carolina, active traveller crashes were compared for rural and urban crashes[1]. The rural crashes had higher percentages of fatalities, alcohol consumption, high vehicles speeds, unpaved shoulders, and midblock-related crash types.

1.2 Overtaking and measurements

In the last decade, a host of studies looking into overtaking distance have been published (Kircher & Niska, 2023; Rubie et al., 2020). A typical way to conduct research on overtaking distances is to employ a bicycle-mounted measuring device, which logs the lateral distance to the traffic and potentially additional variables like cycling speed, position, vehicle speed, etc. In some cases, the passing traffic is also filmed. The measuring devices vary not only in the data they log, but in their conspicuity and in whether their algorithms to identify vehicles are open or of black-box type. This can influence the data quality and transparency.

2 Project set up

2.1 Purpose

Overtaking manoeuvres experienced as uncomfortable are one of the main reasons for refraining from cycling in rural areas (Heesch et al., 2011; Pearson et al., 2023). While the last decade has seen an increase in research on the topic, as mentioned above, it is mainly centred around measuring absolute overtaking distances and modelling the factors that influence this distance. Some studies also look into the subjective experience of the cyclists being overtaken (Beck et al., 2021; Kircher et al., submitted; Kircher & Lindman, submitted; Llorca et al., 2017). A video-based questionnaire study showed that cyclists and drivers have different views of the risks involved with the overtaking manoeuvre (Rubie et al., 2023), which was also found in a survey from Finland (Trafikskyddet, 2022). However, there are still research gaps, and given the different driving regulations and also cultures between countries, it is doubtful that the results from one country can be fully carried over to another.

The purpose of this project was to create an overall description of rural road encounters between motor vehicles and people using active transportation and to build a data collection tool – a lateral distance measuring device (LDMD) to be used in future research on details in overtaking situations. The LDMD should be inconspicuous, easy to transfer between bikes, easy to operate and with a transparent and reliable data logging mechanism. A prototype version of such an LDMD was available via a previous project, which helped identify issues and additional needs. These were meant to be addressed in the current project.

[1] https://www.fhwa.dot.gov/publications/research/safety/10052/10052.pdf

2.2 Objectives

The goal was two-fold. First, we want to provide an overview of the Swedish rural road crash situation for car-to-pedestrian/cyclist situations, to complement the analysis in MICA2 that focused generally on car-to-cyclist overtaking situations (Rasch, 2023). To provide a base for future data collection projects, information about the people and situational factors connected to collisions were investigated using crash data.

The second goal was to improve an existing prototype LDMD that is **unobtrusive, easily portable between different bike types**, and can be used to collect a host of data from a bicycle point of view. The improved version should be able to log speed of overtaking **and oncoming** vehicles, should log the lateral overtaking distance **reliably**, should log all relevant information in **as few different data files as possible**, should log at a **higher frequency** than what is currently the case, should have a battery time of at least **eight hours**. It should be possible to extend the logger with add-ons. (The text in **bold** indicates improvements or additions to the existing logger.)

The ability to register not only overtake passes but also oncoming passes was important to us, as we want to have the possibility to relate overtaking behaviour to the presence of oncoming vehicles. This implies that the sensor range must be large enough, and that there must be a reliable identification of, and distinction between those two types of passes.

Unobtrusiveness was important to ensure that motorists would not be influenced by the appearance of the bicycle, and that logging could be done easily in naturalistic riding. Portability and flexibility in mounting are important to ensure that the LDMD can be used in studies where participants use their own bicycles.

2.3 Project period

The project period was from 1st of April 2023 to 28th of February 2024, with an extension to 31st of March 2024.

2.4 Partners

VTI was project leader, collaborating with If. VTI had the task of working on the improved LDMD and the overtaking log data, whereas If analysed and evaluated crash data.

3 Method and activities

As schematically illustrated in Figure 1, the current project builds on previous research that identifies overtaking passes as a main contributor to perceived and actual risk for active travellers on rural roads. This project aimed at further describing conflicts on rural roads between motorists and active travellers in a Swedish context by analysing

crash statistics. The development of an LDMD that describes overtaking and oncoming passes in detail and a good level of accuracy can then be used to quantify the context for situations that do not result in a (documented) collision. This way, collisions can be put into perspective for example in relation to the context (road type, speed limit, average annual daily traffic, etc.). This, in turn, can provide information for which system changes are necessary to enable an increase in the active travel share on rural roads, which is desirable for sustainability of the transport system. Today, the magnitude of any of the variables in the box on the right-hand side of Figure 1 are not quantified.

It is possible and highly desirable that the share of crashes will decrease with an increased share of active transport on rural roads (Elvik & Goel, 2019). An improvement of how motorists interact with active road users could make a significant change. Also, enhancing the general attractiveness of the rural road environment for active travel with respect to noise and pollution will contribute to the overall goal of increased active travel and a higher share of active mobility (Eriksson et al., 2022).

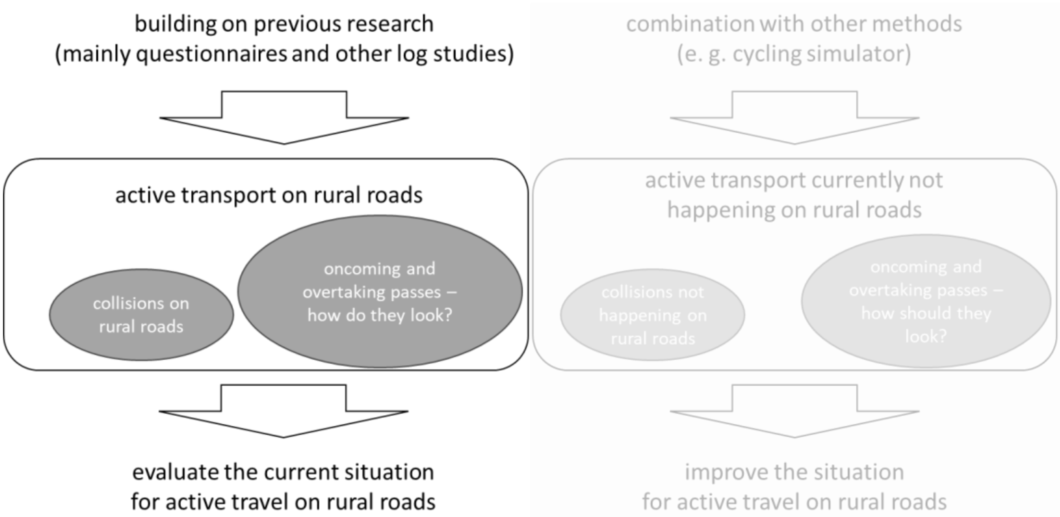


Figure 1. A schematic illustration of the contribution of the present project (left-hand side) and its expected impact on future research (right-hand side).

3.1 Crash data

The People Around the Vehicle (PAV) crash database was used for describing rural road car-to-cyclist and car-to-pedestrian crash situations.

Information in PAV was collected from insurance information at If P&C Insurance (If). Passenger car to active traveler crashes were identified using claims reported by the third-party liability motor insurance, which covers damage to property and personal injuries. The data cover crashes all over Sweden and include a wide range of car makes and models. Insurance claims data include crashes of all injury levels, from no injury at all to fatal outcomes, and so the dataset represents a broad spectrum of crash situations.

For each crash, information was annotated using crash descriptions from the driver and the cyclist or pedestrian. When police reports were available, they were also used, as well as complementary witness information when at hand. All crash cases were anonymised so that persons cannot be identified. If cyclists or pedestrians were injured, hospital reports and medical information were available for coding according to the Abbreviated Injury Scale.

Rural road crashes are not readily identifiable as such in crash databases. In Fredriksson et al. (2012) urban areas were defined as roads with posted speed limits of 50 km/h or lower, hence roads with higher posted speed limits than 50 km/h were suggested to belong to rural areas. Crashes on the national road network were interpreted as having occurred mainly on rural roads in Kullgren et al. (2019). The recent report on road deaths on rural roads from the European Transport Safety Council states that "the definition of road types varies from country to country, thus the data are not comparable" (European Transport Safety Council, 2024).

Limiting the selection of rural road crashes to roads with posted speed limits of 50 km/h or higher will exclude roads similar to the example presented in Figure 2 that shows a section of a rural road that has posted speed limit 50km/h when passing a sparsely populated village. For many households, the only way to reach the school building and the grocery store is by travelling along this road. On the other hand, including roads with a posted speed limit of 50km/h may introduce many non-rural road crashes.

Figure 2. A rural road leading through the sparsely populated village Västra Örträsk (Northern Sweden). (Google, "StreetView", digital images photographed October 2022, https://www.google.com/maps/@64.1332154,18.9380864,3a,75y,146.03h,86.94t/data=!3m6!1e1!3m4!1s_Kw79OJM4WhlIrFSfRWKVA!2e0!7i16384!8i8192?authuser=0&entry=ttu,, accessed 2024-04-26 accessed 2024-04-26).

For this study, a conservative selection identifying crashes in rural roads was applied using following filters:

- posted speed limits of 50 km/h and higher
- crashes not taking place on city streets, open areas as squares, parking areas, motorways
- crashes in "sparsely populated" areas

In total, 111 car-to-cyclist rural crashes and 72 car-to-pedestrian rural crashes between 2000 and 2022 were included in the analysis, whereof 90% happened between 2010 and 2022, and 50% between 2017 and 2022. As reference, a sample of car-to-cyclist/pedestrian crashes in densely populated city streets with a posted speed limit of 30 km/h was used, including 417 car-to-cyclist and 130 car-to-pedestrian crashes. Overall MAIS, representing the highest injury severity to the pedestrian or cyclist in the crash, in a subsample representing crashes up to and including year 2018 are presented in Figure 3. The contrast in overall MAIS2+ injury outcome (52% in rural road crashes versus 22% in city crashes) reflects the distinct circumstances experienced by each group.

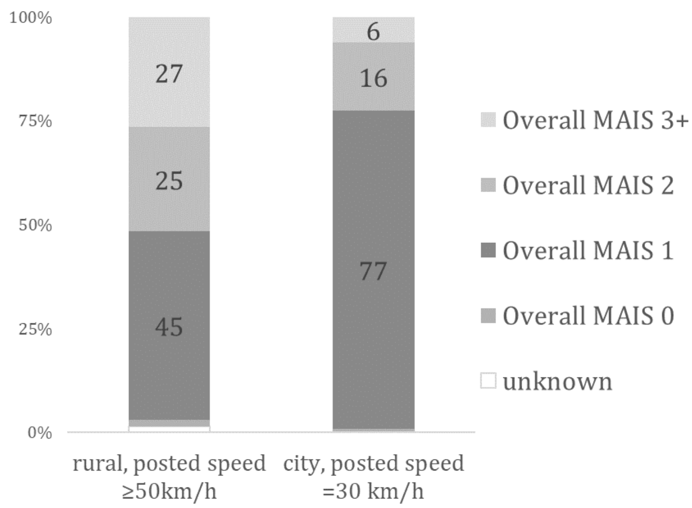


Figure 3. Comparison of MAIS scores depending on whether the crash occurred in a rural or city area.

3.2 Data collection with the prototype LDMD

The initial data collection was conducted by one member of the project team over the course of approximately 1.5 years, during 34 private rides undertaken in the wider area around Linköping, Östergötland. Most of the rides were done alone, with some rides done in company of at least one additional cyclist. The data were collected with a gravel bike and with a road bike and the cyclist wore cycling clothes and a helmet. The

cycling behaviour corresponded to "naturalistic cycling" (Johnson et al., 2010; Schleinitz et al., 2017), meaning that speed choice and lateral positioning corresponded to what felt natural in the situation at hand. This can include moving more towards the middle of the lane to prevent inappropriate overtakes, such that the cyclist may have influenced motorist behaviour on some occasions. The routes were chosen to be comfortable for cycling, including a mix of roads with low to medium traffic (mostly categorised as yellow ("okay, but not great" and better on the website www.roadfinder.se, which grades tarmac roads based on a combination of the variables posted speed limit, average annual daily traffic and road width). Most of the riding occurred on rural roads, with some shorter sections in built-up areas.

The cyclist pressed a microswitch button attached to the aerobars of the bicycle to mark overtakes and oncoming passes in the log data. This was done to ascertain a reliable event detection in the data stream (more on this in 4). The button was only pressed when the cyclist was in mixed traffic, that is, when the road was shared. This includes cases where a cycle path was present, but the cyclist chose to use the road or street, when a cycle lane or road shoulder was indicated with paint, but with no physical separation from the lane used by motorists, and, most commonly, when the road was shared between transport modes. When the cyclist used physically separated cycling infrastructure, no overtakes or oncoming passes were marked. Oncoming passes were not marked when there was a physical separation between the lanes, when there was more than one lane in the direction of where the cyclist was travelling, and when the shoulder was approximately as wide as a lane, such that oncoming traffic essentially was two lanes away.

Other projects use either video confirmation (Nolan et al., 2021), confirmation via a button press (von Stülpnagel et al., 2022), or no external confirmation for the identification of overtakes, as for example in commercial devices[2]. We opted for the button press as a method that has potential to deliver relatively accurate results without much overhead for each logged ride, once the post-processing is automated and quality-assured. Also, it can be used to distinguish between overtakes and oncoming passes. Here, this was done such that the cyclist used a short button press to mark an oncoming pass and a longer press to mark an overtake. In both cases, the button was pressed when the vehicle was physically in front of the cyclist, that is, after the overtake had occurred, but before the oncoming pass was registered by the ultrasonic sensor. Thus, this provides redundancy in the signal. Figure 4 and Figure 5 illustrate the button presses in relation to an idealised change in the signal.

[2] https://www.dashbike.de/en/; https://www.tether.bike/

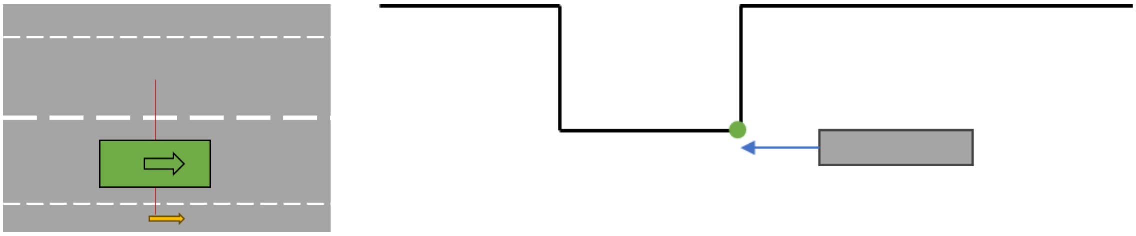


Figure 4. Illustration of an overtaking situation and the resulting signal in the lateral distance data stream. The "dip" in the lateral distance measurement signal stems from the overtake. The button is pressed for around a second (grey box) when the car has passed the cyclist.

Figure 5. Illustration of an oncoming situation and the resulting signal in the lateral distance data stream. The "dip" in the lateral distance measurement signal stems from the oncoming pass. The button is pressed briefly (grey circle) before the car has passed the cyclist.

Currently there is no feasible way of logging the cyclist's lateral position on the road providing an absolute distance value from the side of the road or from any road markings. The cyclist's lateral position could in theory be estimated from video, at least relative to road markings, but this is a time-consuming process which does not scale well.

Under certain conditions the signal of the prototype LDMD is rather noisy. This appears to be the case especially when humidity is high, or in the presence of particles like sand, snow or water sprayed from tyres. In those cases, it becomes complicated to detect the correct lateral distance from the sampled values. The process employed is described in 4.1.

3.3 Construction of RADARIDE

The upgraded LDMD built within the project was called RADARIDE. Its construction is described here.

For improved and flexible battery time, a battery for electric screwdrivers was chosen as base. Around this, a customised box was 3D-printed to accommodate the raspberry pi operating as heart of the RADARIDE.

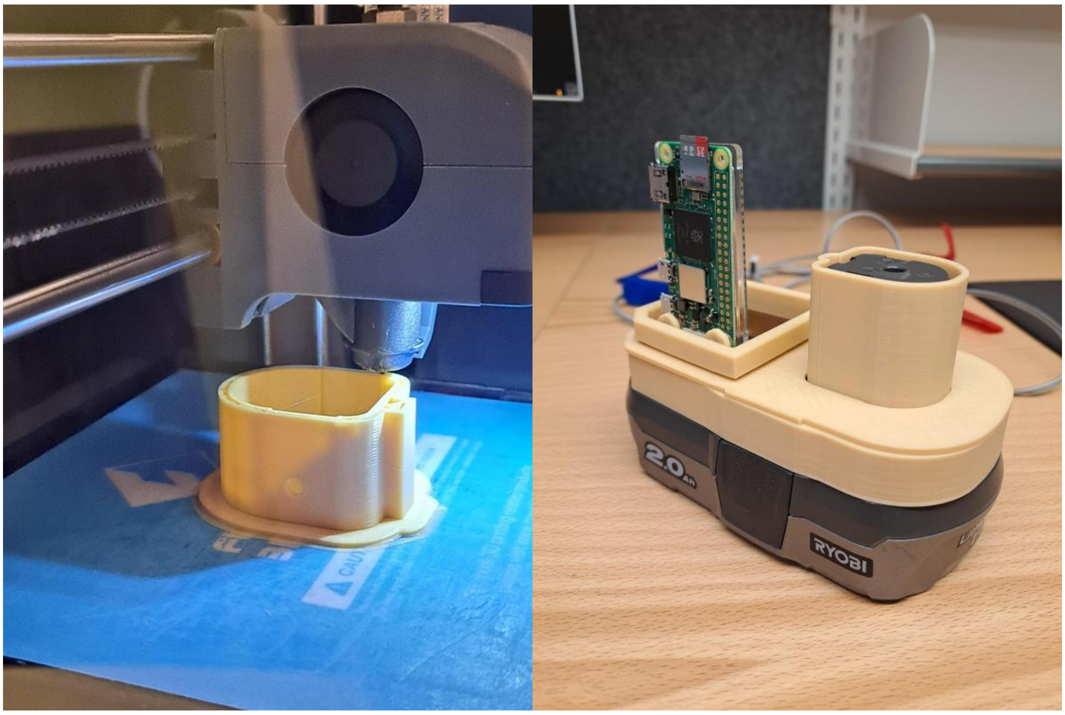


Figure 6. 3D-printing and the first stages of the construction of RADARIDE.

A lidar sensor was chosen for lateral distance measurement. It has a range of up to 10 m, which is sufficient to detect both overtaking and oncoming vehicles also on wider roads.

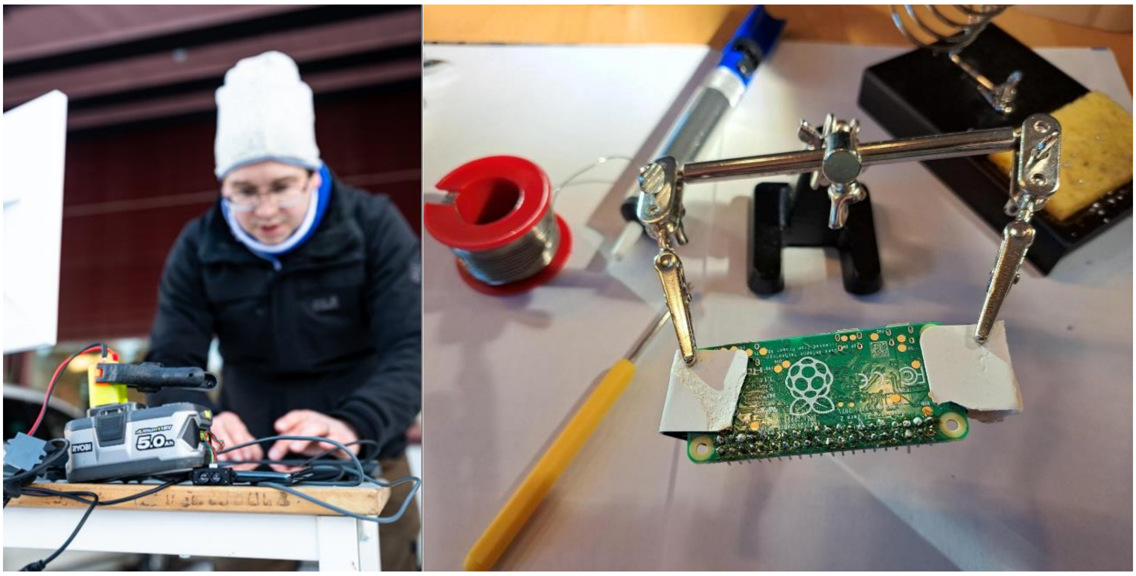


Figure 7. Testing of the distance measurement on the VTI courtyard (left) and building of the RADARIDE components.

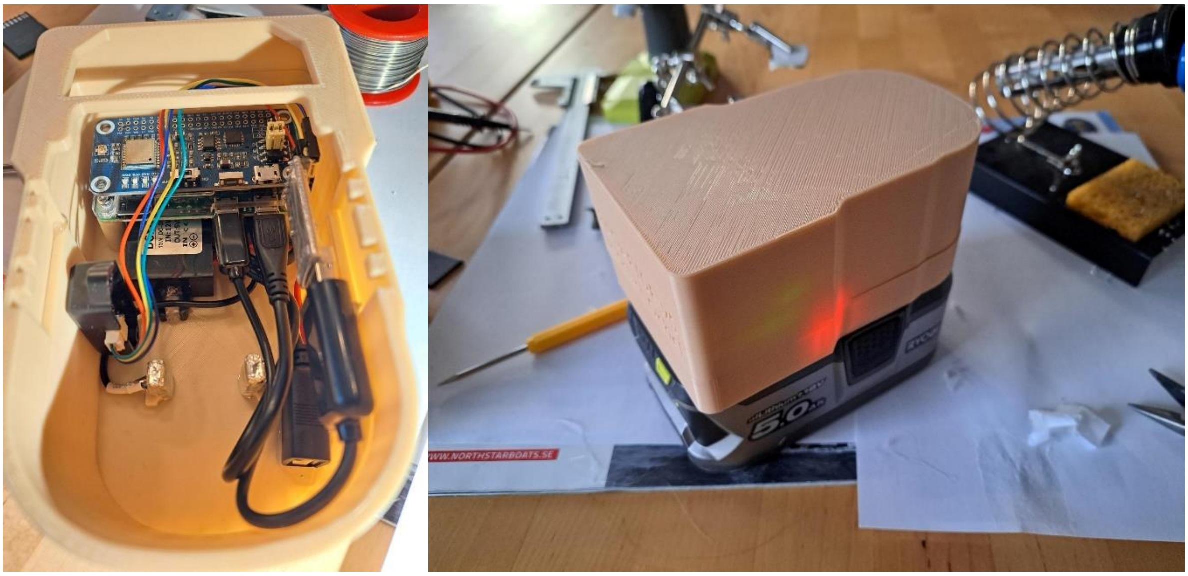


Figure 8. The inside of the RADARIDE box (left) and the unit with the lid on (right).

In addition to RADARIDE, we continue using a commercially available radar (Garmin Varia 760) with built-in camera set to continuous recording. The radar was already deployed in conjunction with the prototype LDMD.

4 Data processing

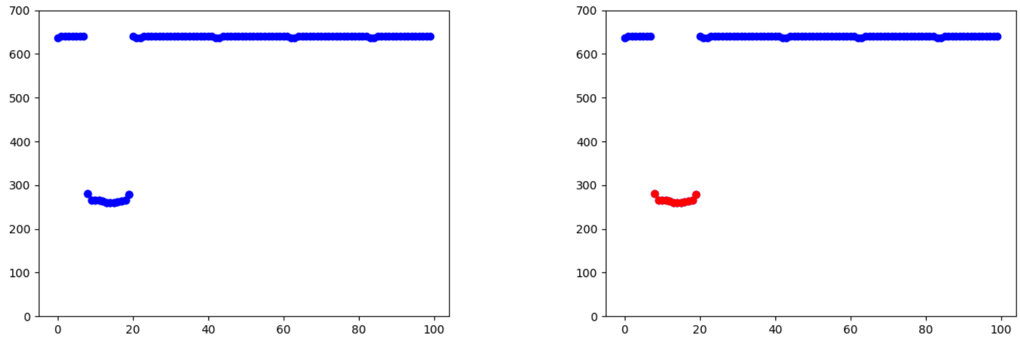
The description of the data post-processing pertains to the prototype LDMD. The assumption is that the method can be transferred to RADARIDE, with the hope that the data quality will be better.

There are three devices that we used which can potentially contribute to better identification and measurement of overtaking events and lateral distances during these:

- The custom-built LDMD RADARIDE (based on ultrasound)
- Rear-view camera (integrated in Garmin Varia radar)
- Rear-facing radar (Garmin Varia 760 in our case)

4.1 The LDMD RADARIDE

The data about overtaking (OT) distances (lateral distances between the bike/rider and the vehicle involved in the overtaking situation) come in the form of chronological text records, one per each 1/22s. The rider marks the approximate location of an OT event by a button press while cycling, right after the event (see 3.2). This restricts the search for the lateral distances corresponding to this overtake to only a few tens of lines in the reverse time direction from the button press. See Figure 9 for an illustration of how we visualise this – button press is on the very left of each figure, lateral distance records plotted one each 1/22s going back in time towards the right of each figure.

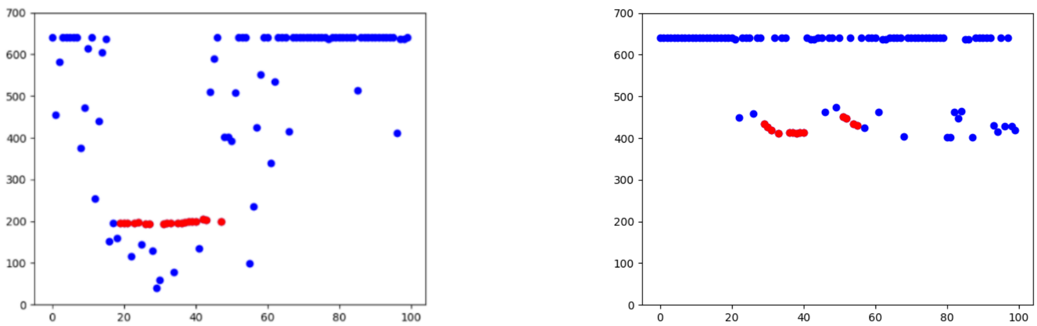


(a) (b)

Figure 9. Unprocessed neighbourhood of lateral distance records containing an overtaking event in (a) and OT event detected and highlighted red in (b).

Unfortunately, noise in the data leads to various detection issues, mainly for automated event identification (Figure 10a), but sometimes also for a human (Figure 10b). To identify the lateral distances that correspond to the overtaking events, we utilise community detection methods on a reduced problem – we convert our data problem to a graph problem and then detect communities in the graph/network. Next, we pick one of the detected communities to be our overtaking event (this selection process is non-trivial in itself) and lastly, we clean up the values in this "community" to contain no outliers coming from the noise in the sensor readings. The resulting "community" is taken to be the sought sequence of lateral distances during the overtaking event.

We aim to automate the OT event detection from the raw data in anticipation of data volumes that do not make it feasible to do manual checking. Consequently, there are going to be mistakes in the results. While those seem to be rare in the scheme of things, we need to ensure that errors introduced this way are not systematic and if so, that they do not have a significant impact on the results we plan to obtain in this way. This part of the project is an ongoing effort.



(a) (b)

Figure 10. Automatically detected "overtaking events" in red. The right-hand side makes it difficult even for a human to tell which distances are part of an overtaking event.

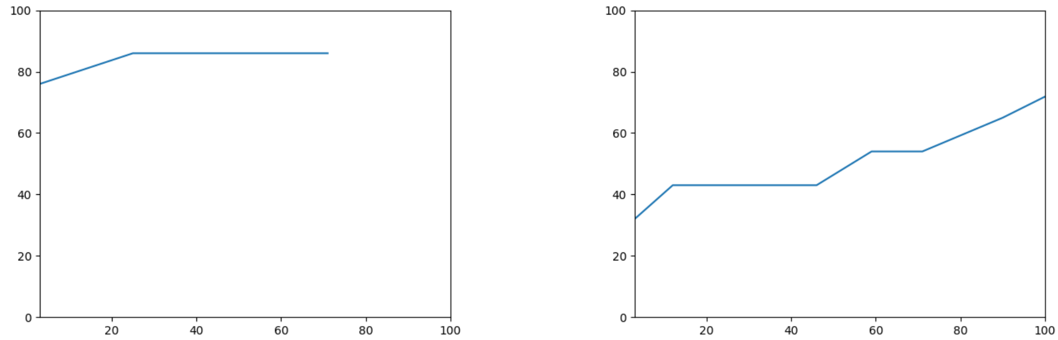
4.2 Radar

The Garmin Varia 760, when connected to a head unit, provides real-time information about vehicles approaching from behind. On the head unit, the number of approaching vehicles and their current distance to the cyclist is illustrated visually. Normally, this information is not saved, but a widget is available for Garmin head units, with which a number of variables delivered from the radar can be saved to the FIT-file recorded by the head unit[3]. Recording happens at 1Hz frequency.

So far, we have only made a cursory evaluation of the available data. Systematic tests in a controlled setting suggest that there is a systematic drop of 10 km/h at a certain distance from the cyclist in the recorded absolute speed of the overtaking car that does not correspond to a real speed drop. We have not established yet whether the relative location of the speed drop is related to more variables than the distance to the cyclist (e. g. the initial speed of the vehicle, the speed of or the lateral distance to the cyclist). Under ideal conditions, the radar starts reading the approaching vehicle from approximately 140 m. The logging frequency is comparatively low and the vehicle speed is given in steps of 5 km/h, but it might still be possible to discern flying overtakes (Figure 11a) from accelerating overtakes (Figure 11b).

However, to fully understand the quality and usability of the radar data, the available material would need to be evaluated in greater detail and formal tests with known parameters would need to be made to assess the reliability and validity of the signal.

[3] www.mybiketraffic.com



(a) (b)

Figure 11. The absolute approach speed (in km/h) of the overtaking vehicle per distance (in m) from the cyclist (the overtake occurs at x = 0 m). No correction is made for the described speed drop error. Clear examples of a flying overtake (a) and accelerating overtake (b) are provided.

4.3 Video

To aid our event detection techniques based on lateral distance data, we can utilise rear-view camera recordings and attempt to recognise vehicle objects in them. Provided these are timestamped correctly, or at least consistently, we can then verify or even predict when and what kind of change in lateral distance data there is going to be for this event. As proof of concept, we extracted a few frames from the videos and used the YOLOv8 model (Jocher et al., 2023) to detect objects: car, motorcycle, bus, train, truck. See Figure 12 for a detection on a frame from our video material.

(a) (b)

Figure 12. An overtaking car object (a) and an oncoming car object (b) was detected with the given confidence.

As mentioned above, currently we record video continuously, which could be problematic at scale, as it generates large amounts of data. With the setting to only record when an OT-event is detected by the radar, the information on OT vehicles should still be basically complete, as the radar seems to miss very few to no vehicles approaching from behind (with a few false positives). However, OC traffic would generally not be on film. A potential way around that would be an automated extraction

of relevant video snippets based on radar information, button presses or other indicators in the data, where the remainder of the recordings would be discarded after this post-processing.

5 Results and Deliverables

5.1 Crash data: description of rural road conflicts

The People Around the Vehicle (PAV) crash database was used for describing rural road car-to-cyclist and car-to-pedestrian crash situations. In total, 183 crashes on roads in sparsely populated areas with posted speed limits of 50 km/h and higher (rural), and 547 crashes on city streets with posted speed limit=30 km/h in densely populated areas (city) were included in the analysis.

5.1.1 Conflict situations

The conflict situation describes the pre-crash manoeuvres of involved participants in a crash (Lindman et al., 2015). Figure 12 compares the distribution of aggregated conflict situations in car-to-cyclist and car-to-pedestrian crashes. In comparison to urban crashes, a greater proportion of rural crashes occurred longitudinally. That is, there were more Same Direction and Oncoming conflict situations on rural roads.

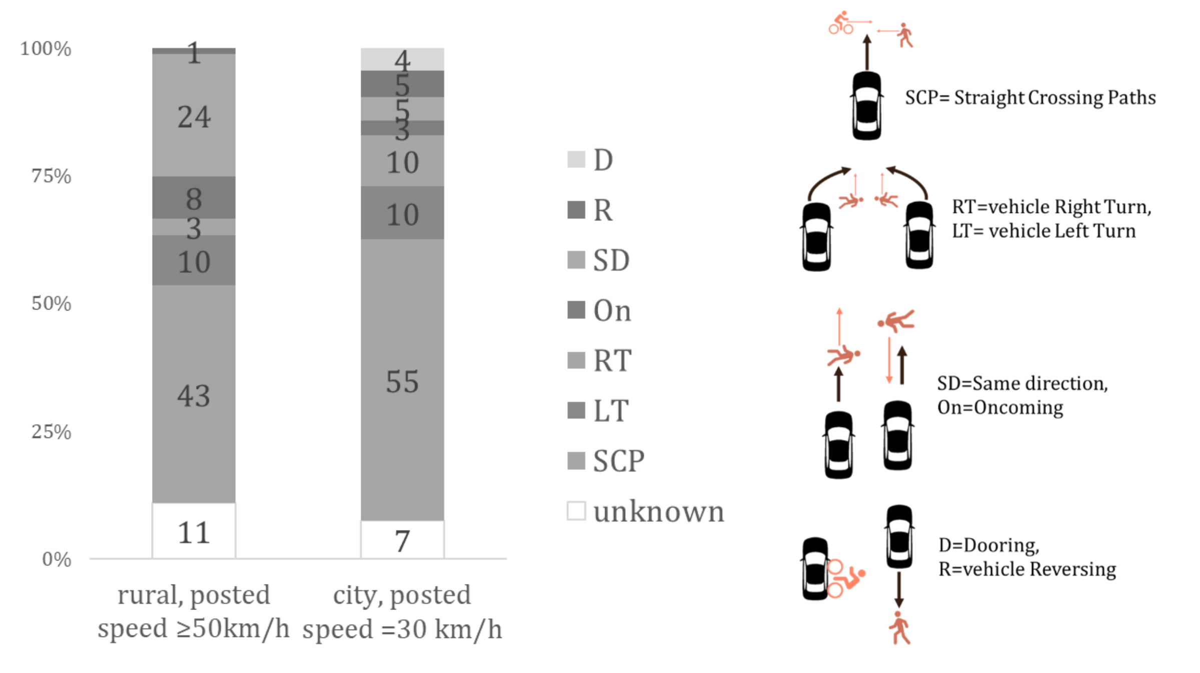


Figure 13. Distribution of conflict situations in pedestrian- and cyclist crashes on rural and city roads.

5.1.2 The car driver

The share of male (Figure 14) and older (Figure 15) drivers in rural crashes was higher than for inner city crashes. It was also more common that the cars driven were of older model years (Figure 16).

Though there is a high share of unknowns in the data, more drivers on rural roads reported that they did see the cyclist/pedestrian before the crash than for city crashes (Figure 17).

In about 50% of the cases, an estimation of the drivers' speed at crash was available (Figure 18). On city roads, reported speed at crashes were almost always in line with the speed limit, while on rural roads a variety of speeds were noted.

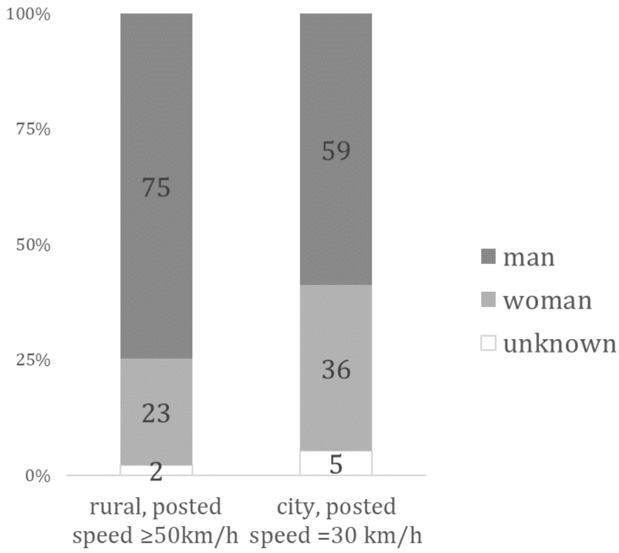


Figure 14. Distribution of the car drivers' gender in pedestrian- and cyclist crashes on rural and city roads.

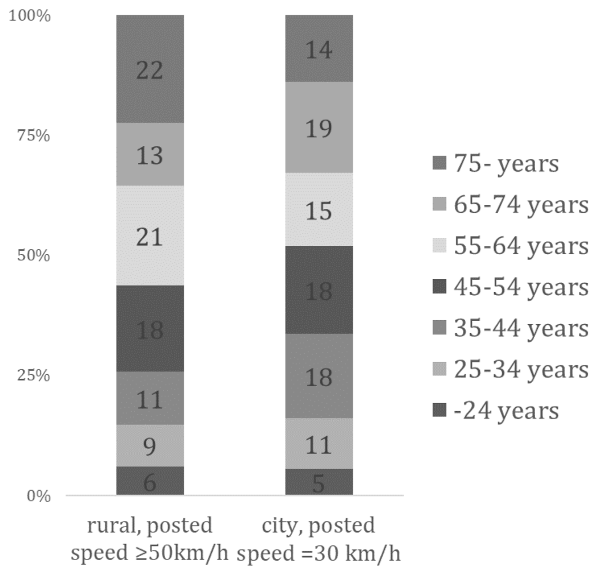


Figure 15. Distribution of the car drivers' age in pedestrian- and cyclist crashes on rural and city roads.

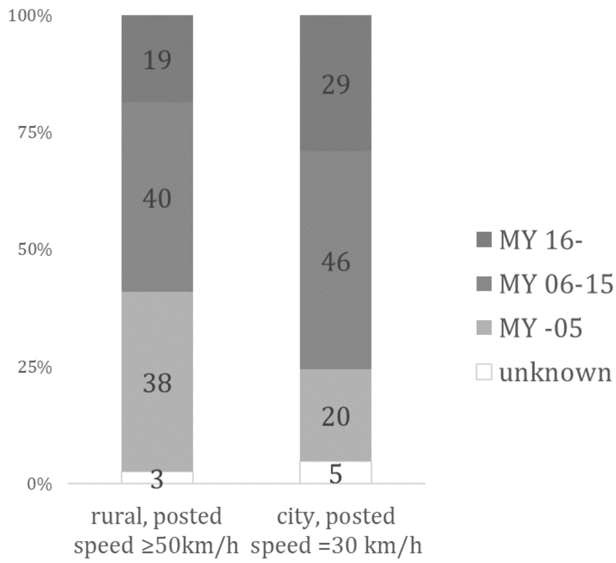


Figure 16. Distribution of car model year in pedestrian- and cyclist crashes on rural and city roads.

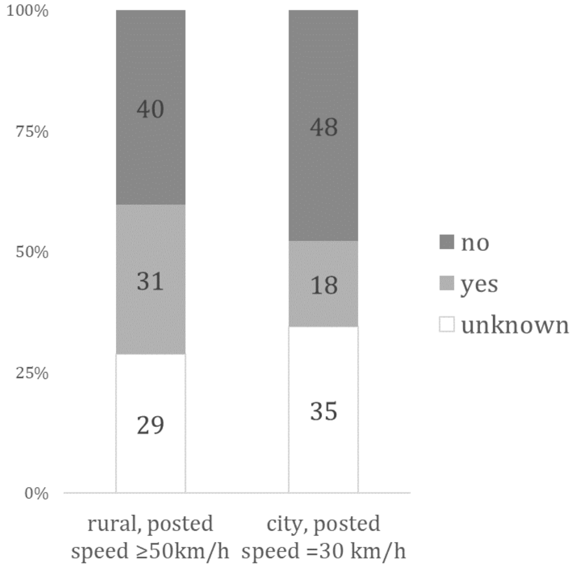


Figure 17. Car driver awareness of the pedestrian/cyclist before the crash on rural and city roads.

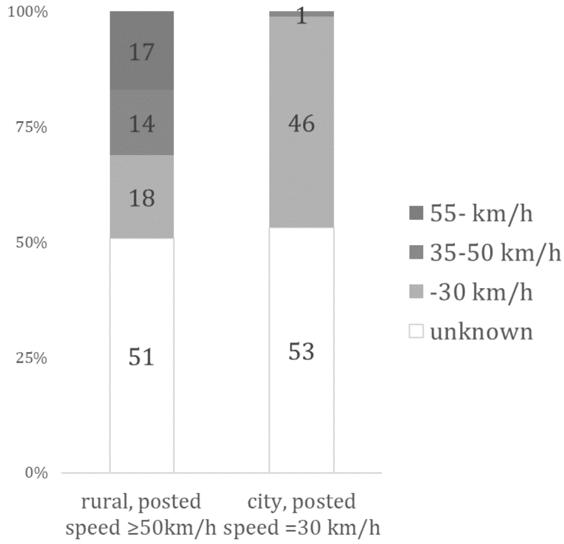


Figure 18. Distribution of subjectively estimated car speed at crash in pedestrian- and cyclist crashes on rural and city roads.

5.1.3 Environmental circumstances

A higher percentage of rural crashes happened in darkness (Figure 19) compared to those on city roads. A majority of the rural crashes occurred during dry weather (Figure 20) and on dry road surface conditions (Figure 21).

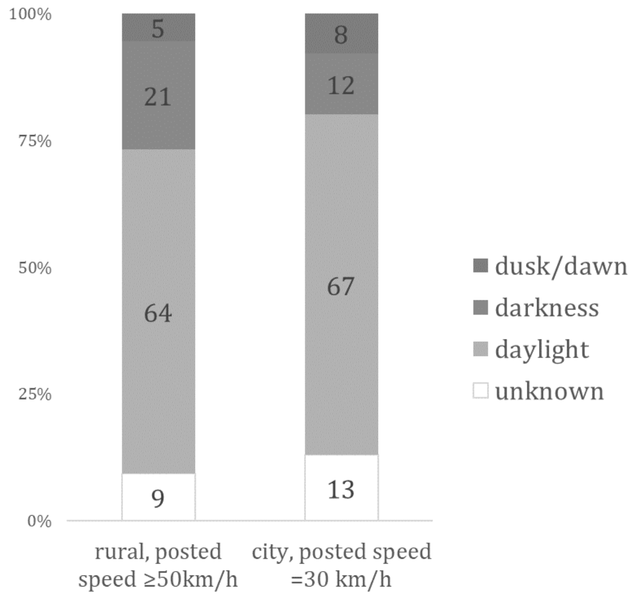


Figure 19. Distribution of daylight conditions in pedestrian- and cyclist crashes on rural and city roads.

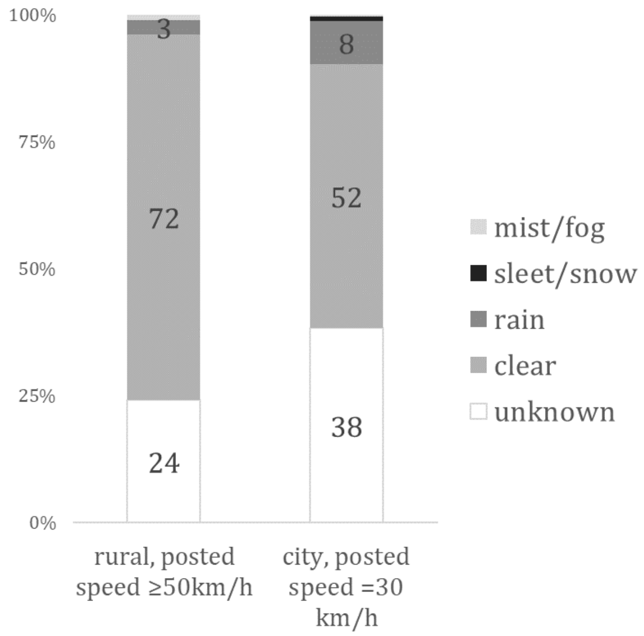


Figure 20. Distribution of precipitation in pedestrian- and cyclist crashes on rural and city roads.

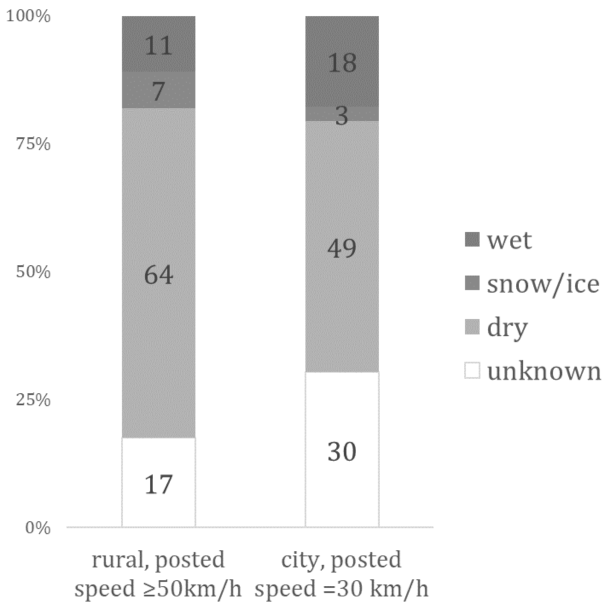


Figure 21. Distribution of road surface condition in pedestrian- and cyclist crashes on rural and city roads.

5.2 LDMD data - overtakes on rural roads – data reduction

Given the delay in the development of RADARIDE, the data from the prototype LDMD were used to produce the distribution of overtaking clearances (empty space between cyclist and vehicle) based on the procedure described above (Figure 22). Oncoming passes will be analysed at a later stage, as the detection method is not finalised yet. Altogether, 704 valid overtakes were logged with the prototype LDMD. The lateral distance that we choose to represent an overtake is the minimum over 90% of the largest lateral distance readings in the overtaking event.

The clearance values are corrected for the width of the cyclist's body protruding over the sensor (estimated at 20 cm). Any parts on the vehicle that might protrude over the vehicle part detected by the ultrasonic sensor are not accounted for. This means that the clearance values in the distribution are approximate, but it is highly unlikely that they are much smaller than what is shown here.

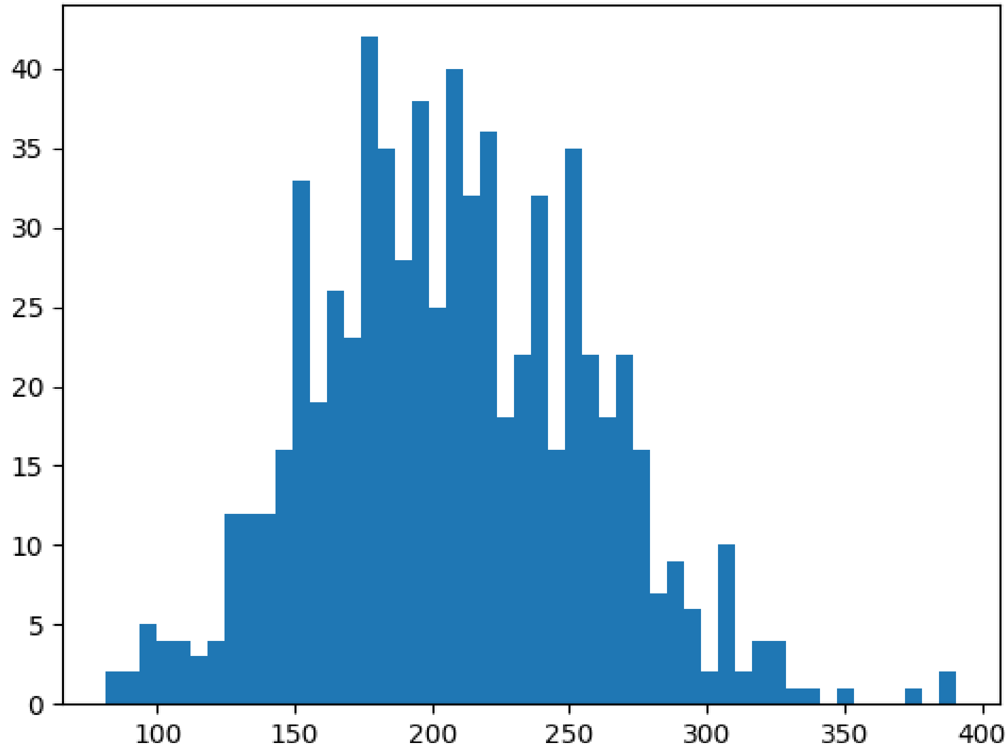


Figure 22. Distribution of lateral distances of 704 overtakes. Each value represents the minimum over 90 % of the largest lateral distance readings in the overtaking event.

In the sample recorded here, 1.3 per cent of the overtakes had a clearance of below one metre and 10.8 per cent had a clearance of below 1.5 metres, with a median value of 2.06 metres. This can be compared to data from Nolan et al. (2021), whose dataset consists of 46769 overtakes in and around four towns in Australia, and who found 5.9 per cent to be below one metre and 38.4 per cent below 1.5 metres. Also in Australia, Beck et al. (2019) registered 18527 overtakes with a median of 1.73 metres, 5.9 per cent of the overtakes were below 1.0 m. In areas with speed zones above 60 km/h the share of overtakes below 1.5 metres was 32 per cent.

The difference between the two Australian studies and our dataset could stem from several sources, or a combination of these. Australian motorists could respect cyclists less on average, the sites selected for measurement could have differed in systematic ways to not allow a fair comparison between countries, road and lane widths could be systematically different, or the data reduction method may differ such that the resulting values are systematically lower in the Australian dataset. Unfortunately, the exact method for how the lateral passing distances were established from the sensor readings is provided by neither Nolan et al. (2021) nor Beck et al. (2019), such that we cannot be sure how noise in the signal was treated. Both authors state that the devices were calibrated against a static wall and in the case of Nolan, also on a test track with an actual passing vehicle. In our experience, noisy signals are more likely to occur when on

the road where particles and debris are sent flying by passing vehicles. Additionally, noise and imprecise readings are two distinct problems we encountered. It is one thing to establish the accuracy of a valid reading, and it is another thing to then be able to pick such readings apart from the noisy readings. In particular, the key issue is to automate the following decision problem: is this lateral distance reading valid or is it a noisy sensor reading?

Our original detection method depended on algorithmic decisions made based on the information about the neighbourhood of each lateral distance reading. A set of such local rules governed the detection of a "subsequence" (not necessarily contiguous) of relatively low lateral distances in the overall sequence of default lateral distances (when the road to the left of the cyclist is empty). Naturally, this method did not perform satisfactorily.

Hence, we abandoned our original approach and opted for a more robust method described in Section 4. Figure 23 illustrates how minimum overtaking distances are significantly underestimated if noisy readings are not treated. Notably, the share of lateral distance readings of under 1.0 m was 10.9 per cent and the share below 1.5 m was 21.2 per cent using this approach. The median was 2.08 m. Especially the values in the low passing distance ranges differ substantially from the values obtained with the more sophisticated detection methodology. The detection methodology therefore seems to be of particular interest within this topic and will receive our further attention in the future.

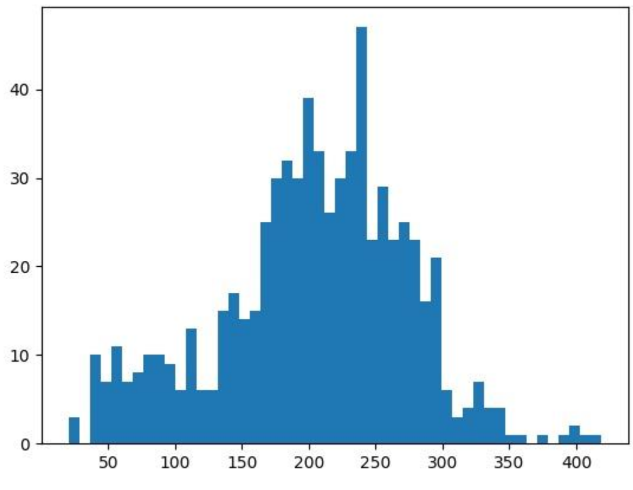


Figure 23. Distribution of lateral distances resulting from the detection method used initially.

5.3 Potential for data enrichment based on external databases

Via the GPS signal, the location for each event can be determined. This gives access to information about road features like width, posted speed limit, number of lanes, traffic volumes, etc., which can be extracted from the national road database[4].

In combination with a Garmin radar, it is also possible to access the distance to a vehicle approaching from behind, and the speed of the vehicle (see Figure 24).

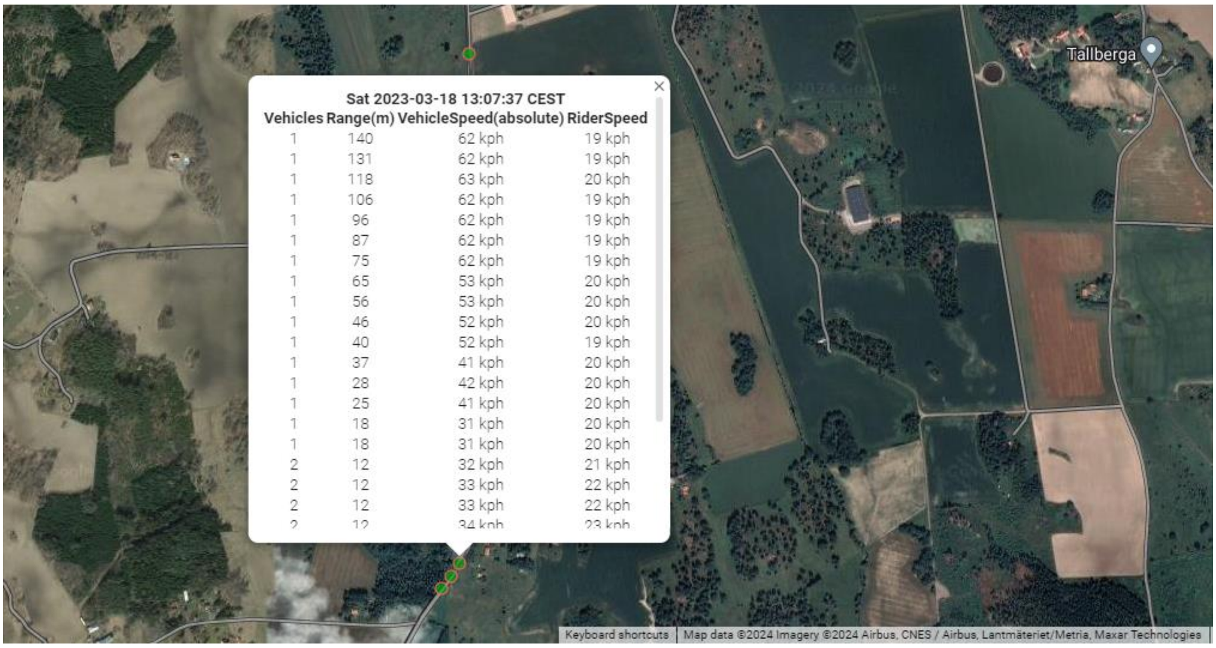


Figure 24. Screenshot of a localisation of three overtakes as determined by the Garmin radar. The distance to the next vehicle approaching from behind and the approach speed are given. Screenshot from the website mybiketraffic.com by Brian Toone, who also programmed the widget to log the information provided by the Garmin radar.

5.4 Comparison of the prototype LDMD and RADARIDE

In Table 1 a comparison is made between the prototype LDMD used so far and the RADARIDE device built as part of this project.

Table 1. Comparison of the prototype LDMD and RADARIDE.

	prototype LDMD	RADARIDE
Components	three separate devices, with the core being the actual LDMD (Arduino-based, ultrasonic sensor, GPS, accelerometer); Garmin Varia radar with built-in camera connected to a	currently three separate devices, with the core being the actual LDMD (Raspberry pi-based, lidar sensor, GPS); Garmin Varia radar with built-in camera connected to a Garmin head unit on which the

[4] https://nvdbpakarta.trafikverket.se/map

	Garmin head unit on which the mybiketraffic widget is installed to log overtaking vehicle speed • Adafruit M0 Adalogger • Adafruit ultimate GPS • 240-071 - PmodMaxSonar, Modul UART, Digilent	mybiketraffic widget is installed to log overtaking vehicle speed • Lidar sensor TFmini-S • 12V till 5V dc/dc converter • Raspberry pi zero 2 w • L76X Gps hat
Mounting, handling	mounted on a rack attached to the seat railings and the seatpost, some limitations making it difficult to attach in a good way to some bike types; time to attach varies between 5-15 minutes	flexible mounting via customised attachment points to the 3D-printed box
Robustness	not fully rain-proof; several issues after a period of use, mostly related to vibrations affecting soldered connections	rain-proof construction
Log frequency	log frequency of lateral distance ca. 22 Hz log frequency of the radar-based information 1 Hz	log frequency of lateral distance set to 50 Hz (up to 200 Hz is possible) log frequency of the radar-based information 1 Hz
Event button	one button, microswitch for finger or handlebars, either not pressed (0) or pressed (1)	two buttons, microswitch for finger or handlebars, either not pressed (0) or pressed (1)
Data quality	sensor locks up in fog, rain and when roads are wet and passing cars spray water on the sensor	not enough data available for evaluating signal robustness in various weather conditions
Data upload	manual, by extracting the micro-SD-card from the device and copying the data	via wifi
Data synchronisation	partially manual between the LDMD file and the radar file	so far partially manual between the LDMD file and the radar file

Battery	phone-type battery, lasted for approximately 6 h maximum	hand-drill type battery, come in different sizes, can last for 8 h and more

5.5 Comparison with similar projects

Numerous studies have used different types of bicycle-mounted LDMDs to register passing distances of overtaking motor vehicles. Here, we briefly compare our approach with a selection of those projects, focusing on different constructions of LDMDs and the related post-processing. Information about data collection in associated projects and results can be found in the referenced articles.

Most of the teams conducting studies, except for the Open Bike Sensor platform, purpose-built their measuring devices and their data collection setup, which might also include cameras (Beck et al., 2019; Dozza et al., 2016; Duran Bernardes & Ozbay, 2023; Henao et al., 2021; Llorca et al., 2017; Nolan et al., 2021; Schimansky et al., 2024; Schuch, 2023). Also, Open Bike Sensor does not make a ready-to-use sensor available, but provides instructions on how to build it. Off-the-shelf sensors are under development or potentially already being used[5]. Most projects and the commercial manufacturers do not fully disclose their algorithms for identifying overtakes and the associated lateral distance measurement.

With the construction of RADARIDE and a fully transparent data reduction strategy we aim at providing the possibility to compare the quality of our data to other projects. To achieve a highly reliable identification of overtaking (and oncoming) passes, we utilised the push button, which is also used by Open Bike Sensor, for example. We used a sensor that covers a range that also detects oncoming traffic, such that the lateral distance of oncoming passes can be logged reliably. In none of the other studies we know of, the lateral distance to oncoming traffic was measured. We added the radar to measure the speed development of the overtaking vehicles and use its camera as added benefit, firstly for manual confirmation while refining the data reduction process, and secondly for a potential future image-recognition based identification of overtaking and oncoming vehicles.

Physically, we aimed for a lightweight and portable solution, which was the case in most other projects, too, except for the study by Dozza et al. (2016), which used a highly equipped electric bike with special mounts and equipment. Also, we aimed for an inconspicuous solution, similar to most projects except potentially the Dozza-study.

For many projects there is no detailed description of how the lateral overtaking distance was extracted from the log data. The sensor data from the prototype LDMD produces a sometimes noisy signal especially under certain conditions (as explained

[5] https://www.dashbike.de/en/; https://www.tether.bike/

above), which can lead to erroneous distance extractions if simple methods like picking the minimum value or computing the average are used. We aimed at achieving high certainty in the extraction of the correct lateral distance and to be transparent about the employed method.

6 Conclusions, Lessons Learnt and Next Steps

The analysis of the crash data shows that crashes on rural roads involving motorised and active road users often lead to severe injuries for the active traveller, and that – at least compared to inner city crashes – this is not mainly related to the active road user not being seen. The estimated driving speed is typically (substantially) higher than 30 km/h, which is associated with a kinetic energy likely to cause severe injuries. Most of the differences in the variables associated with rural and urban crashes could be a result of differing preconditions for these environments – however, this also shows that dedicated research into the rural traffic situation for active road users is needed.

The development of RADARIDE and of a reliable method to assess various aspects of oncoming and overtaking passes is an important step to collect more information on the current situation. Compared to previous attempts, the inclusion of oncoming passes is a step forward, and the robustness of the lateral distance identification provided as open source delivers accurate data on speed and lateral distance distributions.

The RADARIDE can be used in future on-road studies concerned with assessing various aspects of motor vehicles overtaking cyclists. Potentially it can also be used for studies on cycle paths and mixed paths, and for the assessment of the lateral distance cyclists keep to static objects. A modification would allow lateral distance logging to both sides. Additional sensors could cover further aspects of the traffic environment.

An additional improvement would be to find a way to automatically assess the cyclist's lateral position relative to the road edge. Furthermore, a development of the measurement equipment for usage also for other active road user types would make its deployment more versatile.

The post-processing effort was more complex than expected, not least due to the noisy signal of the prototype LDMD. It is not straightforward to extract the correct data points that belong to the overtake or oncoming pass, even though the approximate location in the data stream was marked in real-time with a button press. This is a fundamental issue to solve. How the post-processing was done is not described extensively for other projects, which casts some doubts on the reliability of the results and makes benchmarking difficult.

Even with a perfect signal, it must be decided and described clearly which values are considered in analyses. Often, the measurement device is mounted on the rack or frame, not always with the sensor exactly in the middle of the bicycle and rider. Sometimes the

sensor is mounted on the outside of the handlebars. While it is relatively simple to consider the cyclist's width and adjust the measured value accordingly, it is more difficult for the vehicle, as it is not always clear whether the most protruding parts are registered by the measuring device. Wing mirrors can be of different heights, and there could be other objects protruding from the side of the vehicle, like indicators or a load. Also, the bicycle may sway slightly during the overtake, which could affect measured values, albeit probably only in the range of centimetres. Still, all these factors taken together can affect the reported value enough to make datasets difficult to compare if the data treatment procedure is not known.

The crash data analysis in this report adds to previous studies in that a sample of car-to-cyclist/pedestrian crashes of all injury severity levels were investigated. This provided a broader view of rural road crashes including the distribution of conflict situations, a description of car drivers and insights into environmental factors that can provide a frame for future data collection projects with the RADARIDE.

Identification of rural roads in crash databases is not straightforward (European Transport Safety Council, 2024). This is problematic, as the quantification of traffic safety issues on these roads become uncertain. Future crash data collection should have this issue in mind and provide better definitions of various road environments.

7 Dissemination and Publications

RADARIDE will be used as the main LDMD in a study on High Capacity Transport trucks in real traffic. Another project application where RADARIDE will be the LDMD has been submitted.

8 Acknowledgement

We are grateful for the funding from SAFER (Grant FP17) and the support from If and VTI. Most of the effort that went into this project was voluntary work by the authors, who soldered, coded, and cycled in their free time to make this possible.

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