Development of a Device Suitable for Naturalistic Studies of Passing Distances between Cyclists and Vehicles

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Abstract

There is little understanding of how minimum distance passing laws affect the distance that drivers choose to overtake cyclists in various traffic environments. The Centre for Automotive Safety Research has designed a device intended for use in naturalistic studies of passing distances between cyclists and vehicles. Ten of these devices were built and deployed in a small trial to evaluate their effectiveness. This paper describes the device and its data collecting capabilities along with its performance during the trial. Performance was based on analysing objective data collected from the device as well as survey responses from the participants. Potential improvements to the design of the device for its implementation in naturalistic studies are identified.

Background

For cyclists who ride on the road, being passed by a vehicle is a common occurrence. However, if the lateral distance between the cyclist and the passing vehicle is too small a collision can occur. Research has shown that crashes resulting from a vehicle passing a cyclist too closely are more likely to result in severe injuries compared to other types of crash between cyclists and vehicles (Stone & Broughton, 2003; Raslavičius et al., 2017).

Even without a physical collision, a vehicle passing too closely may cause a cyclist to become unstable and fall. Furthermore, the mere sensation of being passed by a vehicle too closely has been identified as one of the most uncomfortable experiences for a cyclist (Guthrie, Davies, & Gardner, 2001; Parkin, Wardman, & Page, 2007; Heesch, Garrard, & Sahlqvist, 2011).

Along with improved cycling infrastructure, a commonly proposed measure for addressing cyclist casualties is the implementation of a minimum passing distance law, which requires drivers to provide a certain amount of lateral distance between their vehicle and a cyclist's handlebars as they pass. A commonly required lateral distance is one metre, or three feet in countries that use imperial systems. Some passing distance laws also dictate a greater distance on roads with a higher speed limit. Many passing distance laws grant drivers permission to cross the centreline of the road, when safe, in order to comply. Such laws have been implemented in numerous Australian states (QLD, SA, TAS, WA, NSW, and ACT) and countries around the world.

However, it is not yet clear how a minimum distance passing law affects cyclist safety. Haworth and Schramm (2014) noted that there is limited knowledge regarding what affects the lateral distance at which a driver chooses to pass a cyclist and what effect the introduction of these passing laws may have on this distance.

Several previous studies have investigated the distance at which cyclists on the road are passed by vehicles (Walker, 2007; Duthie, Brady, Mills, & Machemehl, 2010; Parkin & Meyers, 2010; Love et al., 2012; Savolainen, Gates, Todd, Datta, & Morena, 2012; Chapman & Noyce, 2012; Chuang, Hsu, Lai, Doong, & Jeng, 2013; Walker, Garrard, & Jowitt, 2014; Kay, Savolainen, Gates, & Datta, 2014; Llorca, Angel-Domenech, Agustin-Gomez, & Garcia, 2015; Mehta, Mehran, & Hellinga, 2015). These studies have investigated how passing distance is altered by factors such as the sex of the cyclist, the presence of a bike lane, the clothing of the cyclist, the lateral position of the bicycle, and the use of a helmet by the cyclist. However, many of these studies utilised a bulky instrumented bicycle that was ridden by only one cyclist (Walker, 2007; Chapman & Noyce, 2012; Walker et al., 2014; Llorca et al., 2015; Mehta et al., 2015), or just a few cyclists (Parkin & Meyers, 2010; Love et al., 2012; Chuang et al., 2013). Additionally, several studies restricted data collection to a small number of streets or routes where infrastructure details such as road width, bike lane presence, and bike lane width were manually recorded prior to the study (Duthie et al., 2010; Parkin & Meyers, 2010; Love et al., 2012; Chapman & Noyce, 2012; Chuang et al., 2013; Walker et al., 2014; Llorca et al., 2015; Mehta et al., 2015).

Because of these limitations, the results of such studies cannot claim to be representative of the typical cyclists' riding experience or crash risk. Cyclists provided with an instrumented bicycle are unlikely to ride in the same way that they would on their own bicycle (e.g. a cyclist who is used to a light weight racing bicycle may ride differently when provided with an instrumented bicycle that is heavy and less responsive). Furthermore, the routes that cyclists travel, and their familiarity with the route, will have an added effect on their riding style.

Naturalistic studies of vehicle-bicycle passing distances, in which cyclists ride their own bicycles and select their own routes, would provide results that are free from the bias of the earlier studies and provide mass data for improved statistical analysis. Dozza and Werneke (2014) explored the potential for naturalistic studies involving cyclists (which previously have been conducted almost exclusively with vehicle drivers) and concluded that useful results could be obtained.

To enable the naturalistic study of passing distances between cyclists and vehicles, the Centre for Automotive Safety Research (CASR) is developing a passing distance measurement device (PDMD). The PDMD is designed to be low cost, easy to use, mountable to a cyclist's personal bicycle, and capable of collecting data while a cyclist rides their usual routes.

This paper presents details about the development of the PDMD in several sections. First, the hardware and functionality of the PDMD is described. Second, a description of the analysis tools that were developed to process the data recorded by the PDMD is presented. Then the performance of the PDMD in a small trial with ten volunteer cyclists is reviewed. Finally, some discussion of the suitability of the PDMD for naturalistic studies and the future development goals is provided.

PDMD hardware and operation

The PDMD system consists of two separate boxes, connected by a cable, which contain the following major parts:

- A microcontroller which controls the device
- A low power GPS receiver that detects the cyclist location and speed
- Two ultrasonic sensors which measure lateral distance to the closest object on the right
- A data logger that records the GPS and ultrasonic data to an SD memory card
- A motion sensor which is used to detect when the device is moving
- A power button for switching the device on and off
- An indicator LED to display the current operating mode
- A rechargeable battery with enough capacity to last for several weeks on a single charge

Figure 1 shows the two boxes comprising the PDMD. The larger main box houses the microcontroller, GPS receiver, battery, data logger, motion sensor, and one ultrasonic sensor. The main box is also fitted with the power button for controlling the device and the indicator LED that displays the current operating mode. The second ultrasonic sensor is housed in the secondary box, which transmits data back to the main box via the cable connection.

The second ultrasonic sensor is used to improve the accuracy of lateral distance measurements by providing a pair of readings that can be compared for consistency and act as a redundancy if one sensor is momentarily blocked. Furthermore, by mounting one sensor towards the front of the bicycle and the other towards the rear, it is possible to determine whether a vehicle is passing the cyclist (rear detection followed by front detection) or the cyclist is passing a vehicle (front detection followed by a rear detection).

The PDMD boxes were custom designed and 3D printed in plastic. The boxes were designed to be resistant to light rain and incorporated features suitable for mounting to common types of bicycle using zip ties; the main (larger) box mounting to the seat post and the secondary (smaller) box mounting towards the front of the bicycle in a location where the cyclist's arms will not block the ultrasonic sensor (see Figure 2). The rear of the main box was also designed with an attachment point for tail-lights, which can be seen in Figure 2.

Once installed, the PDMD is immediately ready to use. The PDMD is controlled via the power button on the side of the main box. Surrounding the power button is the indicator LED. When the power button is in the neutral (undepressed) position, the PDMD is OFF. While the PDMD is OFF, the indicator LED will be off and no data will be recorded. When the power button is in the depressed position, the PDMD becomes active and the indicator LED will display the current operating mode. There are three possible operating modes while the PDMD is active:

- When the indicator LED is off, the PDMD is in SLEEP mode and no data is recorded. The PDMD will remain in SLEEP mode until it senses motion.

- When the indicator LED is flashing, the PDMD is in WAIT mode and attempting to obtain a GPS fix. While the PDMD is in WAIT mode, no data is recorded. If no motion is detected for approximately two minutes, the PDMD will automatically switch to SLEEP mode.

- When the indicator LED is solid, the PDMD is in RECORD mode and has a GPS fix. In this mode, the PDMD will collect and record distance data from both ultrasonic sensors approximately 60 times a second, and GPS data once a second. All collected data is immediately recorded onto the internal SD card. If no motion is detected for approximately two minutes, the PDMD will switch to SLEEP mode. If the GPS fix is lost then the PDMD will switch to WAIT mode.

The manufacturer of the ultrasonic sensors used by the PDMD specify an operational range between 20 cm and 765 cm with an accuracy of 1 cm. There was no independent assessment performed to validate the accuracy of the sensors in their application of measuring passing distances during this study.

PDMD data analysis tools

As described above, the PDMD records data from both ultrasonic sensors and the GPS receiver onto an internal SD card. Each time the PDMD is activated, a new file is created on the SD card and all recorded data is logged to that file until the PDMD is turned off or switched into SLEEP or WAIT mode. Thus, each individual file usually represents the data collected during a particular journey, or a segment of that journey (in the case where the PDMD is switched off or has lost GPS signal).

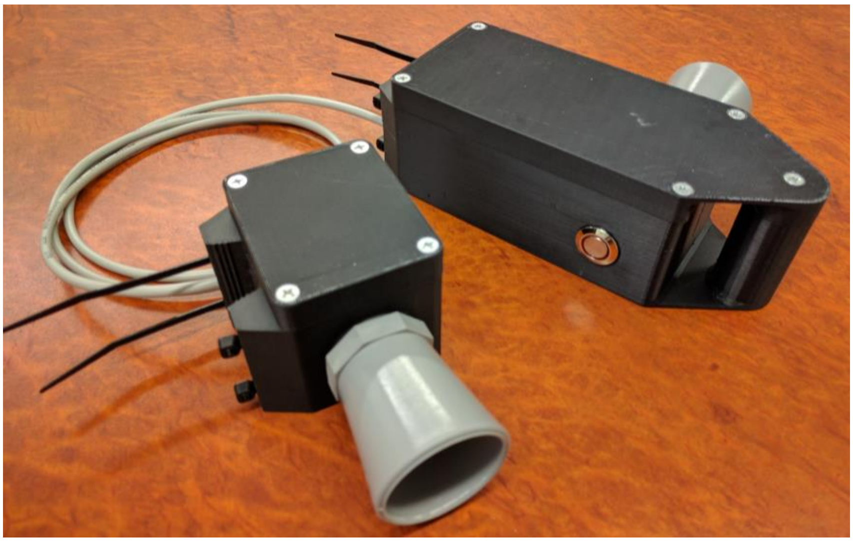

Figure 1. The PDMD

Figure 2. The PDMD attached to a bicycle

The recorded data can be accessed by opening the main box, removing the SD card, and copying the files to a computer using a card reader. Once downloaded, the data from each PDMD is saved into a database and automatically tagged with a unique device ID. Concurrently, the individual files for each PDMD are also tagged with a unique journey ID. The data is then further processed in several steps using specifically developed software tools.

First, the GPS data (which is collected once a second) is interpolated to define a location and speed for each point of lateral distance data (which is collected approximately 60 times a second). An example of the lateral distance and speed data obtained from a single file is shown in Figure 3 with annotations highlighting notable events. The associated location details for the same journey are shown in Figure 4.

Next, the recorded GPS data is matched to digital map data. Raw GPS data have an accuracy of approximately five metres but this is often degraded further by interference from nearby objects such as buildings or trees. As such, the latitude and longitude data reported by a GPS receiver will often drift from the true position by several metres (e.g. see Figure 4). However, with the knowledge that the GPS receiver was travelling along a road, the recorded path can be ‘corrected’ using digital map data. This is done by applying route analysis algorithms, commonly used in GPS navigation systems, to ‘snap’ the recorded path to the appropriate road or path section.

These route snapping algorithms utilised a service called TrackMatching (https://mapmatching.3scale.net/) to correct the recorded GPS data from the PDMD to road sections from Open Street Map (https://www.openstreetmap.org/). The Open Street Map data can also provide details about the characteristics of the road sections that were travelled, such as the speed limit or the presence of a bike lane. The accuracy and completeness of the Open Street Map data is questionable as it is provided ad-hoc by volunteers. However, once the route has been snapped to a road section it can be augmented with other geospatial data from reputable sources (although this was not performed as a part of this study).

Note that the route snapping methodology described here is not able to discern between the cyclist traveling on the road and the adjacent footpath or dedicated cycleway.

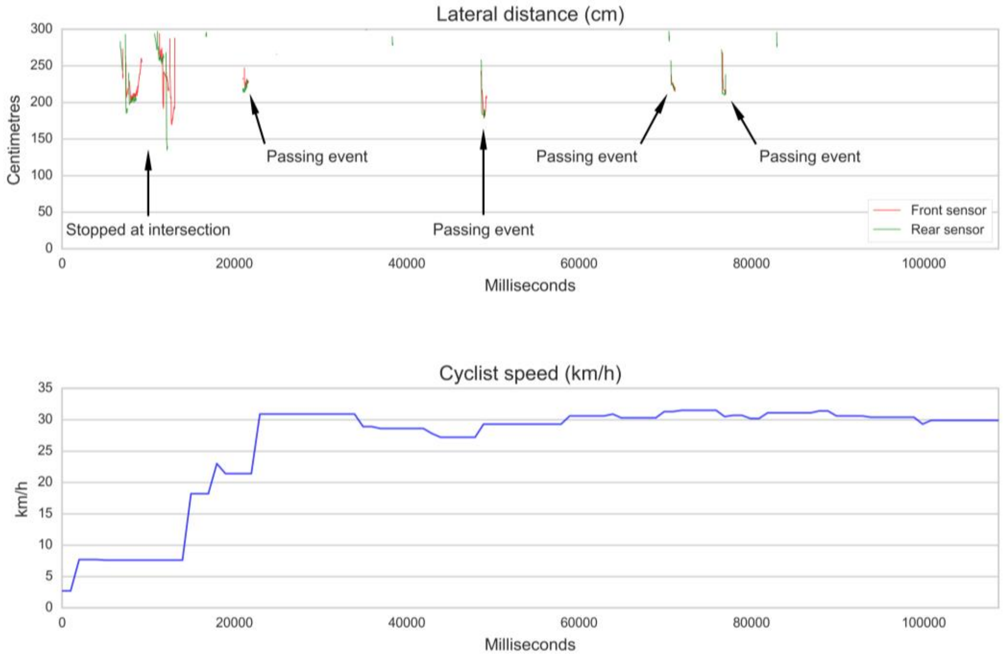

Figure 3. Lateral distances and speed recorded during journey using the PDMD (points of interest are annotated)

Figure 4. Path of journey recorded using the PDMD, starting at green dot and ending at red dot (background map created using Google Maps)

Finally, a search algorithm is utilised in order to identify individual passing events within the lateral distance data. A passing event occurs when a vehicle overtakes a cyclist. This is recorded by the PDMD as a reading on the ultrasonic sensors; initially at the rear, followed by a similar reading at the front. Manually searching through the lateral distance data of hundreds of journeys is not feasible, and so an algorithm was developed to automatically detect these events. The passing event detection algorithm operates by identifying instances where the following conditions are met:

- The bicycle is moving faster than 4 km/h.
- The front and rear sensors are reporting the same constant value, within +/- 10 cm for at least three consecutive readings.
- There is no reading from either sensor before and after the series of consecutive readings (i.e. the passing object appears and then disappears).
- The reading from the rear sensor appears prior to the reading from the front sensor.
- The reading from the rear sensor disappears prior to the reading from the front sensor.

The conditions of the passing event detection algorithm were selected through trial and error to maximise the number of true detections and minimise the number of false detections. There is the potential to develop a more sophisticated algorithm that assesses more factors or the profile of passing events in the future.

An example of an automatically detected passing event is shown in Figure 5. The passing vehicle is first detected by the rear sensor and then by the front sensor. The average measured distance of both sensors is displayed, along with the handlebar distance that was noted for the bicycle on which the PDMD was mounted. The passing distance is calculated by subtracting the handlebar distance from the measured distance (in this case 194 cm).

Once the above processing steps are complete, the resulting data can be analysed with regards to factors such as the number of passing events for each PDMD, the location of passing events for an individual PDMD or globally across many devices, and the average lateral distance of passing events under different traffic conditions (e.g. road type, speed limit, or presence of bicycle lane).

PDMD performance

Through a grant from the Royal Automobile Club of Victoria (RACV) a small trial of the PDMD was conducted. The objective of the trial was to assess the performance of the PDMD in a naturalistic setting. Ten PDMD units were constructed and mounted to the bicycles of volunteer cyclists in Melbourne (7) and Adelaide (3) for a period of two weeks. The ability of the PDMD units to collect relevant data that could be processed easily was assessed, along with the volunteer cyclists' attitudes to using the devices and having them attached to their bicycles. The goal was not to collect mass data, but rather to field test the PDMD and determine its suitability for future, larger scale, projects.

Because the trial involved volunteer cyclists, an ethics application was provided to the University of Adelaide Human Research Ethics Committee and approval was granted prior to the start of the trial. The ethics approval number is H-2016-266.

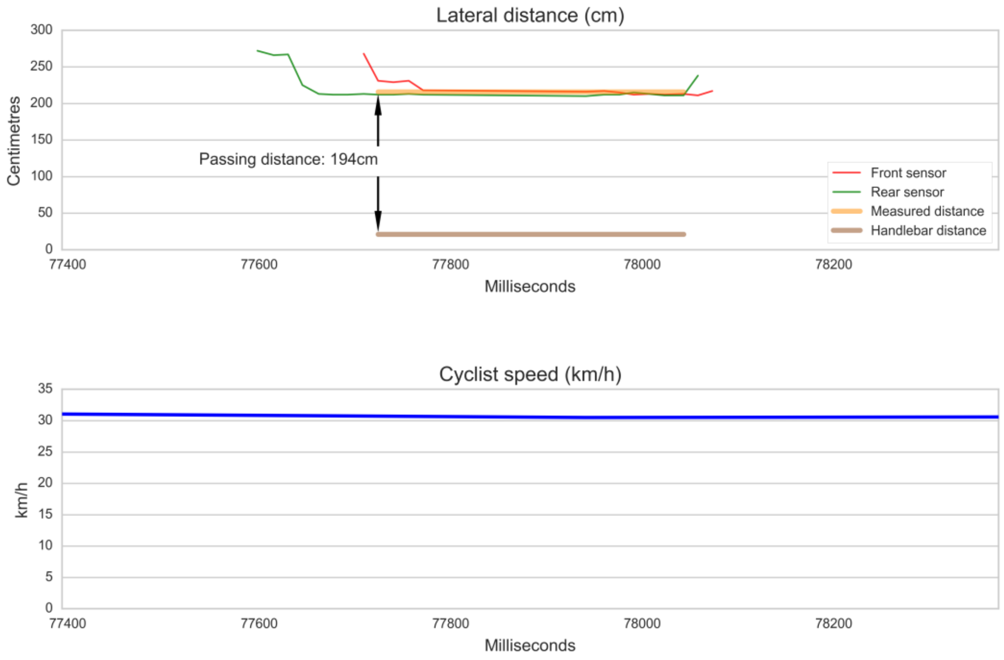

Figure 5. Lateral distances and speed during a detected passing event

Volunteer cyclists were recruited to participate in the trial from RACV and CASR staff. Each participant had a PDMD attached to their personal bicycle and were provided with a pre-trial survey. The pre-trial survey requested details regarding the participant's general demographics, their riding experience, their thoughts about being passed by vehicles while riding, and their opinions about minimum distance passing laws.

After a period of two weeks, the PDMD units were removed from the participant's bicycles. The participants were then provided with a post-trial survey to collect details on their opinions about using the PDMD during the trial period, including whether they found the PDMD easy to use, experienced any issues with the PDMD, or had any suggestions for how the PDMD could be improved.

Data from the ten PDMD systems was then processed, along with the responses to the pre- and post-trial surveys. An additional reason for the trial was to assess the effectiveness of the procedures that were used to collect and analyse the data, including the installation and removal of the PDMD systems, the administration of the surveys, and the processing of the recorded data.

The installation of the PDMD was simple and quick, taking approximately 10 minutes to attach and 5 minutes to remove. The attachment and removal process did not result in any damage to the participants' bicycles. However, the mounting mechanisms were not sufficient, with one PDMD detaching due to a broken zip-tie. Other participants also reported that the zip-ties securing their PDMD had degraded to the point of breaking (without resulting in a detachment) towards the end of the two-week trial. This suggests that a redesign of the mounting mechanism is required, particularly if the devices are to be deployed for more than two weeks.

Some twisting of the PDMD boxes, such that the ultrasonic sensors were no longer correctly aligned laterally to the right, was also noted by the participants which further emphasises the need for a more secure mounting mechanism.

The performance of the PDMD units during the two-week trial period was mixed. As mentioned above, there were issues with the mountings that resulted in a detachment and some twisting. In addition, one of the PDMD units completely failed to operate (for unknown reasons). Some participants reported that their knee would contact the ultrasonic sensor mounted at the front when they were riding 'out of the saddle' (e.g. when riding uphill). The positioning of the ultrasonic sensors will thus require review.

Apart from the aforementioned issues, the participants found the PDMD easy to use and understood how to switch the system on and off. They were mainly supportive of the PDMD and its features, but suggested that it should be less bulky and more attractive.

Downloading the data from each PDMD was a success and individual journeys were tagged and stored in a database without encountering any problems.

Analysis of the data uncovered some shortcomings in the performance of the PDMD during the trial. It was evident that the quality of the GPS data was extremely poor and there were many interruptions in the recorded data during journeys. It is suspected that the poor-quality data was a result of mounting the main box beneath the saddle of the bicycle. In this location, the cyclist's torso and thighs can interrupt and degrade the quality of the GPS signal before it reaches the GPS receiver contained within the box. This it also likely to have occasionally caused the GPS sensor to lose fix and cease recording. In addition, the motion sensor did not perform as expected and there were many instances where it appears that the PDMD switched to sleep mode prematurely, while the participant was still riding. In combination, these performance issues reduced the quality and quantity of data that could have been collected during the trial. In future, the GPS receiver will need to be mounted in an alternative location, away from the cyclist's body (e.g. the handlebars). The operation of the motion sensor will require review or it may be removed entirely given most participants suggested that they were willing to manually switch the PDMD on and off.

No issues were found with the recorded lateral distance data from the pair of ultrasonic sensors. Processing of the lateral data was smooth and it was a simple process to apply the passing event identification algorithms.

Due to the poor-quality GPS location data, it was not possible to match entire journeys to digital maps. However, it was possible to determine the location of passing events on digital maps to ascertain the associated road characteristics at the point where the pass occurred.

Discussion

The number of casualties involving cyclists riding on public roads has remained relatively constant in recent times, despite encouraging reductions in vehicle occupant casualties. One measure that has been pursued in an attempt to reduce the number of cyclist casualties is the implementation of a law that dictates a minimum distance that vehicles must provide when overtaking cyclists.

Many studies have investigated passing distances in specific circumstances; that is, for a particular rider, on a particular road, under particular conditions. However, there has been little research that explores the distance that vehicles generally provide when passing cyclists and how this distance changes under various traffic environments, such as when there is a dedicated bicycle lane or various speed limits.

A credible investigation of general passing distances will require a large-scale naturalistic study, in which a representative number of volunteer cyclists ride their own bicycles along their usual routes over the course of several weeks (or possibly months).

The Centre for Automotive Safety Research has designed a data collection device with this type of study in mind. The PDMD is relative cheap, able to be attached to common bicycle frames, and simple for the cyclist to operate. Processing procedures and algorithms have also been developed that are suitable for dealing with large amounts of data.

This paper describes the PDMD along with the data processing tools, and the results of a pilot study that investigated the use of the PDMD in a small trial with ten volunteer participants (seven in Melbourne and three in Adelaide).

Conducting the trial enabled an assessment of the processes and procedures that would be required to implement a larger study that utilised the PDMD. The PDMD was found to be easy to install and remove. Application of the data processing algorithms was successful at identifying individual passing events and the characteristics of the roads on which they occurred. The use of two ultrasonic sensors on the passing device (one towards the front of the bike and the other towards the rear) enabled the processing algorithm to successfully differentiate instances where the cyclist was passing a vehicle and only identify events where the cyclist was being passed.

It was also possible to evaluate the performance of the PDMD itself, and gather feedback from the participants who were using it. Overall, the participants found the PDMD easy to use and a valuable set of data was obtained. The successes of the trial highlighted the potential for a larger study that could explore factors pertinent to vehicles passing cyclists (including the effectiveness of a minimum distance passing law).

However, there were several aspects of the PDMD that were identified as requiring improvement prior to it being deployed in another study:

- The mounting hardware was not sufficient which resulted in detachments and twisting
- The quality of the recorded GPS data was poor due to the location of the GPS receiver beneath the cyclist seat
- The positioning of the front ultrasonic sensor was also a problem for some of the participants who reported that it would interfere with their knees when riding
- The recording of some journeys was cut short as a result of the motion sensor, which failed to operate as anticipated
- Many of the participants felt that the device was too large and did not like the way it looked on their bicycle
- The accuracy of the ultrasonic sensors in measuring passing distances from a moving bicycle should be independently assessed.

The findings from this trial have shown that further development of the PDMD is worth pursuing. The methodology and processes for implementing a naturalistic study that utilises PDMD have been developed and trialled. Addressing the aspects of the PDMD that were identified as requiring improvement will result in a greater capability to study passing events between vehicles and cyclists – which is hoped will lead to findings that result in a reduction in cyclist casualties.

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