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Motorcycle Rider Perceptual Countermeasures

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Abstract

A trial was conducted to evaluate whether a suitable road-based perceptual countermeasure (PCM) could influence the travelling speed as well as lane position of motorcyclists to induce a safe curve negotiation. The motorcyclist PCM selected for the trial was a modified version of a peripheral transverse line marking with incrementally wider painted blocks through the curve apex. The PCM was trialled at two curves characterised by either high or low curvature along a popular route amongst motorcyclists with a known crash history. Two additional curves on the same route were used as control locations. Only the travel lane with right-hand curvature was treated and evaluated since the PCM design specifically aims to reduce intentional centreline crossing due to cutting through the curve chord. At each site, travel speed was measured at the curve apex and motorcycle lane position at both the entry and the apex of the curve.

A larger proportion of motorcyclists tended to position further away from the centreline compared to before the treatment. Motorcycle travel speed at the apex of both treated curves tended to decrease. Moderate reduction in travel speed at the apex of the treated curves was also observed for light and heavy vehicles. The trialled PCM design has high potential to enhance motorcyclist safety at critical curves along regional and rural routes and is compatible with various pillars of the safe system approach to road safety. Nonetheless, additional research is required to confirm the long-term effects observed in this trial as well as to investigate potential additional benefits or side effects. High-friction paint or thermoplastic film is suggested for future implementations.

Keywords

Motorcyclists, countermeasure, perceptual, speed, crash risk

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Transport for NSW
- Department of Transport and Planning Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department for Infrastructure and Transport South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Department of Infrastructure, Transport, Regional Development, Communications and the Arts
- Australian Local Government Association
- Waka Kotahi NZ Transport Agency.

Summary

Background - Single-vehicle motorcycle crashes are known to often occur on curved sections of road. Enhancing the delineation of the curve is one of the countermeasures that can potentially reduce the likelihood of motorcycles failing to maintain lane position on curves, running off the road or colliding head-on with other vehicles. Given the common involvement of excessive speed among serious motorcycle crashes, reducing travelling speed is likely to be another means by which motorcycle crash risk on curves can be addressed. This project is concerned with using road-based treatments as a countermeasure to influence motorcyclist perceptions of speed and lane width in order to incentivise a safe approach when negotiating critical curves on regional and rural roads. A trial was performed to assess whether a specifically designed lane marking layout can alter travelling speed and/or lane position of motorcyclists when negotiating curves along rural roads on a recreational riding route in Queensland, Australia.

Methodology - A suitable design for a motorcyclist perceptual countermeasure (PCM) was identified through an initial search of perceptual treatments found in the literature and a subsequent iterative refinement process, which was based on discussions with stakeholders during a dedicated workshop and further feedback from the Project Manager at Queensland Transport and Main Roads. The PCM design selected for the trial was a modified version of a peripheral transverse line marking treatment with incrementally wider painted blocks through the apex of the curve. The trial was conducted on Mt Mee Road, a popular route amongst motorcyclists with a known crash history. The PCM was trialled at two curves characterised by high and low curvature, respectively. Additionally, two other curves matched to each of the treated curves were used as control locations during the trial. Since the trialled PCM design specifically aims to reduce intentional crossing of the centreline due to cutting through the curve chord, only the travel lane where the curve is bending to the right-hand side was treated and evaluated. Travel speed at the curve apex and motorcycle lane position at both the entry and the apex of each trial curve were measured. Only vehicle detections that matched the following criteria were considered in the analysis: dry road surface, a free speed, and no oncoming traffic. Note that this trial was limited to a small sample size of two treated sites, which did not allow to draw any conclusions about the statistical significance of the results.

Results - The proportion of motorcyclists riding in the monitored lane segment closest to the centreline after the installation of the treatment decreased from 55.3% to 4.5% at the apex of the tight curve and from 29.1 to 6.2% at the apex of the shallow curve. After accounting for the change at the paired control site, the before-after variation was -43.1 percentage points for the tight curve and -17.2 percentage points for the shallow curve. Additionally, the trialled PCM treatment induced motorcyclists to conservatively position themselves within the lane with an additional safety margin, as indicated by a considerable post-treatment increase in the proportion of motorcyclists riding within the left most 2/3 of the lane while they were negotiating through the apex of the treated curves (from 6.8% to 46.6% at the tight curve, and from 27.5% to 51.3% at the shallow curve). After adjusting for the change at the paired control site, the post-treatment increase in those proportions are 40% at the tight curve and 23.8% at the shallow curve.

Generally, both the mean and 85th percentile travel speeds at the curve apex tended to decrease at each of the two treated curves, with a much more marginal reduction occurring at their paired control curves. After accounting for the variation at the control sites, the mean speed reduced by 1.8 km/h at the tight curve and 3.8 km/h at the shallow curve. Similarly, the 85th percentile speed at the tight and shallow curves reduced by 1.2 km/h and 3.5 km/h, respectively. This trend was also observed for all of the broad motorcycle categories considered in this analysis except for sport motorcycles, the travel speeds of which increased at the treated tight curve after the installation of the PCM. Moderate reductions in the mean travel speed were also found for light and heavy vehicles after the PCM installation, as indicated by post-treatment reductions in the controlled mean travel speed, varying between 0.3 km/h and 2.9 km/h (depending on the vehicle type and specific site). However, after the PCM installation, a slight increase in the controlled 85thpercentile speed was observed for heavy vehicles travelling at the apex of the shallow curves. The observed speed-related effect on light vehicles was partially expected. Indeed, the peripheral blocks used for this PCM may likely induce in drivers a lateral friction effect similar to other perceptual line marking used for traffic calming purpose such as the dragon's teeth. However, it should also be noted that this PCM has been trialled in a different environment compared to the dragon's teeth (i.e., curves along a rural route as opposite to urban roads with high pedestrian activity).

Most importantly, after the installation of the PCM there was a general increase in the proportion of motorcyclists who were riding through the apex of the treated curves at or below a speed threshold equal to 10 km/h below the posted speed limit (i.e., 50 km/h at the tight curve and 90 km/h at the shallow curve). The post-treatment increase in the proportion of motorcyclists riding at or below this threshold was 13.6 percentage points at the tight curve and 14.5 percentage points at the shallow curve. Additionally, the control-adjusted proportion of motorcyclists who travelled through the apex of the treated curves over the posted speed limit reduced by 3 percentage points at the tight curve (posted speed limit of 60 km/h) and by 6.5 percentage points at the shallow curve (posted speed limit of 100 km/h).

Based on the analysis of the trial results, the proposed PCM treatment appears to deliver both safety effects for which it was designed. The major and most desired effect is that of inducing most motorcyclists to maintain a safe distance from the centreline when travelling through the apex of a right-hand curve. The second but more marginal effect of the PCM treatment is to mitigate the travel speed of motorcyclists as well as that of other road users at the apex of the treated curves. Both of these effects have been observed at the tight as well as the shallow trial curves. No side effects were identified in the analysis of the data collected during this trial. In general, most of the outcomes from this evaluation are consistent with results reported in other recent trials on perceptual treatments that specifically targeted motorcyclists.
Additionally, the proposed PCM design may provide the following further safety benefits, which have not been investigated in this trial and therefore would need to be confirmed by future investigations:

- increased conspicuity of the treated curves at night-time and in low-light conditions
- providing a complementary reference to traditional features typically used by road users when negotiating a curve during the day but which may not be clearly visible at night
- discouraging motorcyclists from riding too close to the edge of the lane, which typically tends to be slippery due to accumulation of dirt and gravel.

Conclusions - The proposed PCM design appears to have high potential to enhance motorcyclist safety at critical curves in regional and rural areas. Its design can be quickly installed on existing roads with minimal work and would be compatible with practically any of the existing road infrastructure that may be present on regional and rural roads, such as vehicle restraint systems, line marking or signage. It is an appropriate low-cost and low-maintenance secondary treatment to improve and complement existing primary treatments such as standard line marking and signage. In addition, the treatment is compatible with three pillars of the Safe System approach to road safety, namely safe road user, safe speeds and safe roads. Nonetheless, additional research is required to expand the currently limited sample size of trialled sites, which is required to obtain statistically significant conclusions. Future trials are also required to confirm the long-term duration of the behavioural changes observed in this short-term trial as well as to investigate potential side effects such as inducing drivers to drift along treated shallow curves or creation of visual-clutter due to overlapping with existing road visual treatments like signs or curve aligned markers (CAMs). In particular, it is critical to ensure that PCMs do not have unintended consequences for other road users, including cyclists, as well as interference on vehicle safety technologies that rely on line marking. Additionally, improvements to the current PCM design such as the use of high-friction paint or alternative thermoplastic material should be considered for future installations. Thermoplastic material may provide additional logistical benefits compared to paint due to the faster application times and higher durability. The use of high-friction material to implement the PCM will likely increase the acceptance of this type of treatment by the motorcyclist community as well as help to prevent potential side effects on cyclists.

Finally, the trialled PCM is expected to be used for treating curves which are deemed to be dangerous in case motorcyclists voluntary cross the centreline. Given the specific focus of the PCM on motorcyclists, application of this treatment should be limited to motorcycles routes in regional and rural areas. Under this suggested application scenarios, it is expected that motorcyclists would associate this PCM to curves at risk of head-on crashes on popular motorcyclist routes. Therefore, installation of the PCM should be avoided on curves where the risk of head-on crashes is limited. An otherwise indiscriminate extension of this PCM to non-critical curves may induce motorcyclists to lose confidence in this treatment. The adoption of consistent warrants/criteria to identify critical curves that require this type of treatment is essential to create appropriate expectations among motorcyclists regarding the level of risks associated to those treated curves. A consistent and targeted implementation of this PCM is expected to help achieve a good level of compliance to this treatment thanks to a perception by road users that the treatment is applied only when required.

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1. Introduction

Riding a powered two-wheel vehicle is a high-risk mode of transportation, with considerably higher rates of serious or fatal injuries than other road users (Chang and Yeh, 2006; Lin and Kraus, 2009). Despite motorcycles comprise a fraction of the total registered vehicles (4.5%) and account for a small portion of the total number of vehicle miles travelled in Australia (0.9%), motorcyclists are heavily overrepresented in the crash statistics accounting for 15% of the road deaths and a greater proportion of seriously injured road users (Johnston et al., 2008). It was found that motorcyclists have much higher odds of fatality (30 times) or serious injury (41 times) per kilometre travelled compared to car occupants. Even in those countries where motorcycles and cars have similar crash rates, such as Norway, serious injuries occur with greater frequency for motorcyclists (Van Eslande and Elvik, 2012).

Given the high risks associated with motorcycling, and their continued popularity both for commuting and recreation, it is necessary to develop countermeasures to reduce crash numbers and injury rates for motorcyclists. Countermeasures are needed across multiple pillars of the Safe System (Baldock, 2018), including licensing, rider protective clothing, improved vehicle technology (motorcycles and other vehicles), police enforcement, and road infrastructure. Single-vehicle motorcycle crashes often occur on curved sections of rural roads. Enhancing the delineation of the curve is one of the infrastructure countermeasures that can potentially reduce the risk of failing to maintain lane position on curves and consequently running off the road or colliding head-on with oncoming traffic. Given the common involvement of excessive speed among serious motorcycle crashes, reducing travelling speed is likely another means by which motorcycle crash risk on curves can be mitigated.

Perceptual countermeasures (PCMs) represent a particular type of treatment that can be used to reduce loss-of-control crashes on curved roads. These countermeasures involve the use of modifications or additions to the road, or the surrounding environment, in order to subconsciously alter the motorist perception of the road environment and/or their travel speed (hence, their definition as ‘perceptual’). Such perceptual change can be used to positively change their behaviour. A common aim of PCMs is to cause motorists to reduce their travelling speed (McCauley et al., 2002). However, recent pilot application of PCMs on curves have proven the potential effectiveness of this approach also for inducing road users to select preferred type of trajectories by avoiding specific painted portions of the lane (Hirsch et al., 2018; Mulvihill et al., 2008). Therefore, Austroads has decided to sponsor further research aimed at evaluating whether an infrastructure-based perceptual countermeasure can be used to alter motorcyclist behaviour on curved roads on a recreational riding route by influencing their choice of a safe path while also moderating their travel speed.

In this project, a trial was conducted to investigate whether line markings can be used to affect motorcyclist perception of travel speed as well as induce the choice of a safe path through a curve. A specifically designed lane marking layout was trialled along Mt Mee Road, a popular motorcyclist recreational riding route in Queensland. A controlled before-after investigation on the speed and lane position measured during the trial was conducted to evaluate the potential effect of the proposed perceptual line marking treatment on the travelling speed and/or lane position of motorcyclists when negotiating the trial curves.

2. Literature Review

A literature review was conducted on previous PCM's studies and is presented below. The presented countermeasures include those for both vehicle drivers and motorcyclists. This section also provides an overview of motorcycle types, motorcycle types in relation to rider age, speed and risk-taking behaviour, motorcycle personal protective equipment, motorcycle characteristics, and road delineation in relation to motorcyclists.

This literature review provides an initial summary of the nature of motorcycle types and risks and the potential for infrastructure treatments to reduce motorcycle speeds and/or improve lane positioning through curves. A detailed review is then provided for a variety of PCM countermeasures that have been previously investigated which have been identified in the literature. Since there have been very few motorcycle-specific perceptual countermeasures studies performed to date, this review also considered those studies which examined the effects of PCMs on passenger vehicles. Note that a few additional recent trials on motorcyclist-related PCMs were identified at a late stage of this project, when the trial of a selected PCM design was already initiated. Those additional trials are described in a specific section at the end of this chapter to make clear that none of those trialled designs and the reported results were known or available when a decision was made on which PCM design to trial as part of this study.

The PCMs reported in this literature review have been identified through a variety of sources, including:

- **Australian Transport Index (ATRI)** - Road transport resources. Subjects: road safety, traffic accidents, vehicle design, road design, human factors, speed and speed limits.
- **TRID**: Transport resources. Subjects: road safety, traffic accidents, human factors.
- **Academic Search Premier:** A Multi-disciplinary database.
- **PsycINFO**: psychological literature including peer reviewed journals and complete books or book chapters. Subjects: behavioural science, human factors, cognition.
- **PsycARTICLES:** Full range of APA peer reviewed journal papers. Subjects: behavioural science, human factors, cognition.
- **Cochrane Library:** Includes the Cochrane database of systematic reviews in areas such as injury prevention and also addresses numerous aspects of road safety for vulnerable road users.
- **SCOPUS:** A core multidisciplinary database that is the largest abstracts database of peer-reviewed literature including journals, book chapters and conference proceedings.
- **Web of Science:** A core platform of multidisciplinary and scientific abstracts databases, including Web of Science Core Collection.

Additionally, a general search for relevant research or examples of perceptual motorcycle countermeasures were also conducted using the Google and Google Scholar search engines. The search identified peer reviewed research, including journal articles and conference papers. Grey literature, including reports by government and other relevant agencies, technical papers, conference proceedings, and any other relevant materials (e.g., news and magazine articles) were also identified. The grey literature was obtained from searches of relevant agency websites including Austroads, university research centres and via online search engines. Finally, both published and not-published information (e.g., internal reports or interim reports on current projects) was provided by stakeholders consulted in the course of this project as well as by project team members. These networking sources included direct contact with some road agencies in Australia and New Zealand.

The literature search included, but was not limited to, keywords such as perceptual countermeasure, perceptual counter measure, motorcycle perceptual counter measure, motorcycle perceptual countermeasure, road perceptual countermeasure, vehicle perceptual countermeasure, road line marking, motorcycle road line marking, motorcycle reflector guide posts, motorcycle reflector guide post, peripheral line marking, and motorcycle peripheral line marking.

2.1 Motorcycle User Groups and Risks

2.1.1 Introduction to Motorcycle Types

Motorcycles can be categorised under the following classes (IIHS, 2019; Teoh & Campbell, 2010):

- **Standards** have basic designs and upright riding positions, with low power-to-weight ratios that result in a user-friendly motorcycle (IIHS, 2019).
- **Cruisers** mimic the style of American motorcycles from the 1930s to 1960s, such as Harley-Davidsons and Indians (IIHS, 2019). The riding position usually involves the feet being forward of the body and the hands being up high on the handlebars.
- **Touring** motorcycles are designed to be ridden long distances. They have big engines and fuel tanks plus room to haul luggage. They're often outfitted with antilock brakes, audio systems and cruise control (IIHS, 2019) and are designed with rider ergonomics in mind.
- **Super-sports** are consumer versions of racing motorcycles. Reduced weight and increased power allow for quick acceleration, nimble handling and high speeds (IIHS, 2019).
- **Sport** motorcycles are closely related to super-sports. Sport bikes are capable of high speeds but don't have the acceleration, stability and handling of super-sports. They generally have lower power-to-weight ratios than super-sports (IIHS, 2019).
- **Sport-touring** motorcycles are similar to sport bikes but tend to be heavier and equipped with touring features such as saddlebags, a rear trunk and larger seats. Typically, they have more substantial windshields and wind-deflecting fairings than sport bikes (IIHS, 2019).
- **Unclad sport/Naked** motorcycles are similar to sport bikes and super-sports in design and performance but without plastic body fairings or windscreens (IIHS, 2019).
- **Off-road** motorcycles generally are light weight with small displacement engines. Many off-road motorcycles are produced strictly for recreational or competitive use and are not street legal (Teoh & Campbell, 2010).
- **Dual-purpose** motorcycles are similar to off-road motorcycles. However, they are equipped with road-ready features such as turn signals, brake lights, and horns. They generally have larger displacement engines than off-road motorcycles, as well as a more comfortable riding position (Teoh & Campbell, 2010).
- **Scooters** are notable for their step-through rather than step-over design. They have small wheels, automatic transmissions and small engines, although larger scooters are becoming more popular (IIHS, 2019).

Motorcycle class, and speeding and risky behaviours are among the risk factors that have been associated with crashes resulting in fatal and serious injuries. These risk factors are discussed in more detail below.

2.1.2 Motorcycle Types Mostly Involved in Crashes

A study performed by Teoh & Campbell (2010) in the United States of America (USA) on motorcycle class found a very high fatality rate associated with super-sport motorcycles. The fatality rate for super-sport motorcycles was 22.3 fatalities per 10,000 registered vehicles, compared with 5.1 fatalities per 10,000 registered vehicles for cruiser and standard motorcycles. Their study also found that sport touring motorcycles have the lowest fatality rate of 4.3 fatalities per 10,000 registered vehicles. It is likely that the high fatality rate for super-sport motorcycles is related to the high speeds and accelerations that are possible with these bikes, but also may be related to the types of riders who choose to rider them.

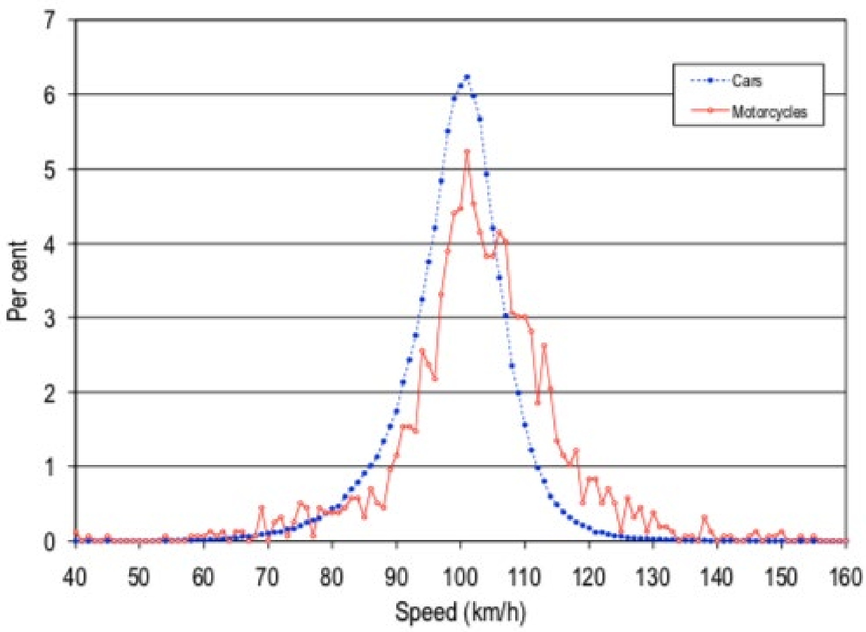
Within an Australian context, a study conducted in regional and metropolitan Victoria by Baldock et al. (2010) found that sports motorcycles (including super-sports motorcycles) were the most common in both areas (38% in regional areas and 35% in metropolitan areas). They also found that cruisers were more common in regional Victoria (27%), while scooters (27%) and standard and naked motorcycles (21%) were common in metropolitan areas. They also noted that there were few scooters in regional areas. An analysis conducted in NSW, partly based on data collected as part of the Austroads In-Depth Motorcycle Crash Study, found that riders of sports motorcycles were over-represented in crashes (Brown et al., 2015).

In a New Zealand context, a survey conducted into motorcycle use (New Zealand Ministry of Transport, 2015) found that high powered motorcycles (>600 cc) were used for 32 percent of motorcycle trip legs, but 52 percent of time travelled and 66 percent of distance travelled. Lower powered motorcycles were used more for shorter, slower trip legs. Analysis of motorcycle use by age of rider found that older riders (30-44, over 45) were more likely to ride higher powered motorcycles, especially those with an engine capacity of 1,000 cc, than younger riders (15-29).

2.1.3 Speed and Risky Behaviour

The study conducted by Baldock et al. (2010) reported that the mean and median speeds for motorcyclists were above the speed limit in both regional and metropolitan areas in Victoria. A comparison of the speed distributions for both cars and motorcycles is shown in Figure 2.1. Furthermore, they found that over 20% of motorcyclists were exceeding the speed limit by 10 km/h or more, which is in contrast with a corresponding proportion of less than 7% for cars.

Figure 2.1: Speed distribution of cars versus motorcycles in a 100 km/h zone



Source: Baldock et al. 2010.

Similar findings to that by Baldock et al. (2010) was reported in a study performed in Belgrade, Serbia, by Jevtic (2014). The study found that, on average, motorcyclists ride faster than passenger vehicle drivers and extreme speeding occurs 2.3 times more often by motorcyclists than by passenger vehicle drivers. Their study also noted that sport motorcycles were observed to travel fastest and that standard, touring, and cruiser motorcycles travelled with speeds that were not significantly different to that of passenger vehicles from a statistical point of view (Jevtic, 2014).

It has also been suggested that excessive travel speed on bends can result from misperception of bend curvature, and that this can contribute to crashes (Millevelli-Pennel, 2006; Charlton, 2007). This suggests that affecting curve perception may be a useful means of reducing travel speeds.

The Austroads Motorcycle In-Depth Crash Study (Austroads, 2015) attributed some of the crashes to rider factors including inappropriate speed (15%), ineffective braking (36%), unfamiliarity with the motorcycle (10%), incorrect line through the curve (5%), inappropriately powered motorcycle for the rider’s experience level (9%), unfamiliarity with the road (3%), cornering errors related to rider fatigue (9%), unfamiliarity with both the motorcycle and the road (7%), general inexperience (11%), rider distraction (5%), and travelling too close to the rider in front (13%).

In regard to other risky behaviours, Teoh & Campbell (2010) found that fatally injured riders of super-sport motorcycles exhibited a lower prevalence of alcohol impairment and higher prevalence of helmet use compared with riders of cruiser, standard and touring motorcycles. However, super-sport motorcycle riders were also most likely not to be properly licensed. The overall safer behaviour reported for riders of super-sport motorcycles compared to riders of other types motorcycles may be evidence of risk homeostasis (i.e., an increase in the level of risk taken by a lower risk cohort such as riders of cruiser and touring motorcycles whilst a higher risk cohort such as riders of superbikes tend to reduce their risk level, due to both cohorts aiming to reach a similar target risk level starting from opposite ends of the risk spectrum). However, the authors of that research did not mention this in their research.

2.2 Engineering Countermeasures for Motorcycle Crashes

2.2.1 Introduction

Traditionally, engineering-based countermeasures that address speed and vehicle use are designed primarily to cater for passenger vehicles, with consideration also given to the needs of heavy vehicles (e.g., lane widths and turning needs) (Winkelbauer et al., 2012). While such measures are able to accommodate motorcycles, they may contain features that can be hazardous to them, given the handling and stability characteristics of motorcycles described below. Australia and other jurisdictions have recognised the special needs of motorcycles in the design of engineering treatments, and several guides have been developed that highlight the manner in which the needs of motorcycles can be integrated into existing design manuals. One of the most comprehensive of these is Austroads report AP-R515-16 (Austroads, 2016).

This section provides a summary of the general considerations for engineering countermeasures in regard to the needs of motorcyclists and is mainly concerned with delineation and surface markings. For technical descriptions and guidelines for installing delineation and other treatments, Austroads report AP-R515-16 (Austroads, 2016) provides a comprehensive guide for best practice for road design and delineation to enhance motorcycle safety.

2.2.2 The Characteristics of Motorcycles

Motorcycles are two-wheeled single-track vehicles, the manoeuvring and braking of which are greatly influenced by the skill of the rider (Austroads, 2016). Compared to four-wheeled vehicles, they have a greater reliance on road friction, particularly when braking and when the road is wet (ACEM, n.d.; IHE, n.d.). Most braking and steering input occurs through the front wheel, and consequently riders try and avoid use of brakes when turning (ACEM, n.d.; IHE, n.d.). Heavy braking during turning manoeuvres tends to cause the motorcycle to decelerate in a straight line tangential to the curve (Austroads, 2016). Therefore, avoiding hazards or changing paths while negotiating a bend is not ideal for motorcyclists. When traversing bends, motorcyclists follow a different trajectory to cars, making use of the whole lane width to maximise grip while minimising steering input (ACEM, n.d.; IHE, n.d.). At the beginning of a curve the motorcyclist will commence the turn from the outside of the lane and move towards the inside at the apex of the curve, finally positioning to the outside of the lane when exiting. The motorcycle is also subjected to centrifugal forces that push the vehicle towards the outside of the curve, so riders lean to the opposite side in order to compensate for this (ACEM, n.d.; Austroads, 2016). If done close to the middle of the road, leaning may place the rider in the path of oncoming traffic. A motorcycle accelerates via the rear wheel and so a loss of grip for this wheel may result in a loss of control (IHE, n.d.). A poor road surface or engineering treatments such as speed humps can also lead to loss of control, as the front wheel loses contact with the road surface (ACEM, n.d.; Austroads, IHE, n.d.). A more detailed description of motorcycle handling dynamics and characteristics is provided in Austroads AP-R515-16 (Austroads 2016).

2.2.3 Engineering for Motorcycles

Road delineation

In order to safely negotiate the road, motorcyclists need to have sufficient information to select an appropriate speed and riding line, particularly through curves. Much of this information is observed directly by the motorcyclist but, where sightlines are restricted, other measures are required to assist the rider. Delineation and signs provide this assistance but, if used appropriately, may also enhance safety further by influencing the rider’s speed and lane positioning. Guidelines for road design for motorcycles recommend designs that adhere to the principles of self-explaining roads. Essentially the provision of warning signs and delineation should be consistent throughout the road network or along a particular route, such that a rider is able to determine the severity of upcoming hazards (e.g., curves) based on the delineation and signs present (ACEM, n.d.; Austroads, 2016; IHE, n.d.; OECD, 2015).

Delineation is one of the primary means through which road alignment is communicated to drivers and riders. Road delineation through the use of road markings and vertical elements (e.g., guide posts, curve alignment markers) is important to motorcyclists because it enables them to make important decisions about riding path, especially when sightlines are restricted or at night (Austroads, 2016; IHE, n.d.; OECD, 2015; Winkelbauer et al., 2012). Delineation communicates important information about road alignment and curves, including direction, sharpness, and type. Due to the manner in which motorcycles are steered, longitudinal markings such as edge lines and centre lines are relied upon as navigation aids, particularly at night and other low-light conditions (Austroads, 2016). They also allow riders to adopt travel paths that are a safe distance from the edge and centre of the road; enhanced treatments such as wide centre line treatments may have additional benefits by increasing separation from oncoming traffic (Winkelbauer et al., 2012). This is particularly important as leaning while steering can put the rider in the path of oncoming vehicles.

Another guiding principle of design is based on the notion that motorcyclists typically steer through a curve in a manner described as ‘where you look is where you go’ (WYLIWYG; OECD, 2015; Winkelbauer et al., 2012). The principle here is that cornering motorcyclists should be directed to focus on the vanishing point of the curve (which moves continually as they travel through the curve) to safely negotiate it. Removing objects that may fixate a motorcyclist’s attention away from the vanishing point or providing features that assist riders in finding and following the vanishing point may be of benefit. Countermeasures specifically designed on the WYLIWYG principle are discussed further in the dedicated Section *Where You Look Is Where You Go (WYLIWYG)*.

Vertical delineators (i.e., guideposts and chevron-style curve alignment markers (CAMs)) are further elements that assist with highlighting road alignment and can serve as valuable navigation aids. Guideposts can help clarify road alignment but do not explicitly communicate the direction of a curve, whereas CAMs do. While CAMs provide a clear indication of the direction and sharpness of a curve from a distance, at night while leaning through a turn they may not be visible in the motorcycle's headlight, so other delineators are necessary, particularly edge and centre lines (Austroads, 2016). According to published guidelines (ACEM, n.d.; Austroads, 2016; IHE, n.d.; OECD, 2015), CAMs should be installed on the outside of all sharp to very sharp curves but, given that objects in this location may be struck during a crash, they should be constructed of flexible and frangible materials to minimise the harm to riders. This does pose a challenge, given that poles that may be frangible from the perspective of an impact with a car may not be as forgiving when struck directly by a rider ejected from a motorcycle. Placing the poles behind barriers fitted with under run protection such as rub rail is an ideal option if possible.

Warning signs, such as curve warnings and speed advisory signs, also provide information to the rider about direction and sharpness of the curve. Where there are hazards of particular concern for motorcyclists, such as poor road surface (due to damage or debris) or curves with tightening radii, motorcycle-specific signs should be considered (ACEM, n.d.; Austroads, 2016 IHE, n.d.). Warning signs should be positioned such that they provide a sufficient warning to the rider to enable them to prepare for the hazard (e.g., slowing and/or correcting trajectory) without the need to undertake evasive manoeuvres while travelling through the hazard. The presence of motorcycle specific signs may also raise awareness among other road users that motorcyclists are common on the route they are driving (Winkelbauer et al., 2012).

Any additions to the road or roadside have the potential to influence motorcycle stability and, therefore, safety. Road markings such as paints or thermoplastic rarely provide the same level of friction as the road surface and will deteriorate at a faster rate than the road surface. Other delineators such as raised retroreflective pavement markers (RRPMs) may also impact the stability of motorcycles, and audio-tactile line markings (ATLMs) may also further reduce the friction of the road surface. As a general rule, surface markings should not be placed across lanes or in places where the motorcycle can be expected to ride (ACEM, n.d.; Austroads, 2016; IHE, n.d.; OECD, 2015; Winkelbauer et al., 2012). However, there are some possible exceptions to this rule, which are discussed further in the next section (*Road markings*).

It is also important that objects installed at the roadside do not further endanger motorcyclists. Good practice delineation regarding the use of CAMs recommends placing these signs on the outside of curves (ACEM, n.d.; Austroads, 2016; IHE, n.d.; OECD, 2015), which means placing them in a position where they become a hazard to motorcyclists who lose control in the curve. As such, flexible and frangible materials should be used to reduce harm to the rider. Objects on the inside of curves should be removed or placed a suitable distance from the edge of the road to ensure they are not in the leaning zone of riders.

Road markings

While it is generally recommended (see Section *Road delineation* above) that surface markings should not be placed across the width of a road or in curves, if done with due attention to the potential impact on motorcyclists, such interventions have the potential to enhance motorcycle safety. More recent approaches to motorcycle safety measures have adopted this approach. For example, transverse markings (see Section *Transverse and herringbone line markings* below) may be suitable if they are installed on straight sections of road, are a suitable distance from a curve to allow safe braking and steering, and there is a suitable gap between the lines to increase surface friction at treated sites, then the hazard to motorcyclists may be reduced (IHE, n.d.; OECD, 2015; ROSA, 2011). Peripheral transverse markings (see Section *Peripheral transverse lines* below) have also been used and may be a suitable countermeasure (NZTA, 2017).

2.3 PCMs to Reduce Travel Speed and/or Correct Lane Position

This section provides a review of previous evaluations for a variety of PCMs that that have been used to reduce travel speeds, correct lane position, or a combination of both.

PCMs are generally low-cost and non-obtrusive road markings or roadside furniture designed to either reduce travel speed and/or improve vehicle alignment. They do this by influencing the vehicle operator's chosen speed and/or vehicle alignment perception (Godley et al., 1999, Fildes & Lahausse, 2008).

PCMs are becoming increasingly preferred compared to traditional speeding countermeasures, given that their unobtrusiveness is less likely to frustrate or interfere with drivers, and they are typically inexpensive, simple to install, and can easily be removed if required (MassSAFE, 2004).

2.3.1 Post-mounted Delineators

Chevrons and hazard marker posts, also known as post-mounted delineators, are devices used at the roadside to delineate the road. The main purpose of a delineating device is to outline the path of the road to a road user by providing them with visual clues (Charman, 2010). The advantage of having post-mounted delineators in addition to line markings is that they remain visible in adverse weather conditions and at night. They can also assist road users when there is a change in the road vertical alignment on an approach to a curve (Charman, 2010).

An example of a post-mounted delineator commonly used in Australia are the chevron-style curve alignment markers (CAMs), which are shown in Figure 2.2. They are generally installed as a series of single chevron signs rather than a single individual sign with multiple chevrons, which is common in the UK. The single chevron signs installed in a series are placed at a constant height and at regular intervals and have been reported to be effective in enabling road users to select an appropriate speed on bends (Charman, 2010).

Figure 2.2: Example of a typical application of CAMs

Source: Safe System Solutions Pty Ltd.

2.3.2 Rumble Strips

Rumble strips are narrow raised lines laid transversely across the road which result in a haptic and auditory effect in vehicles that are driven over them (Figure 2.3). They are used to alert road users to the presence of a road hazard and can be installed in a single group or in a series of groups (Charman, 2010). Although they can be installed on the approach to bends, it is noted that rumble strips have a lower coefficient of friction than asphalt and so may negatively affect the braking and steering capabilities of motorcycles.

Figure 2.3: Example of typical application of rumble strips

Source: Charman, 2010.

2.3.3 Transverse and Herringbone Line Markings

Transverse line markings

Transverse lines are somewhat similar to rumble strips but do not result in a haptic and acoustic effect in vehicles that are driven over them. Instead, they work by drawing a road user's attention to the line markings which, in turn, are designed to alert the road user to a road hazard. They have been reported to result in low-to-moderate speed reductions (Fildes & Lahausse, 2008). In a more recent trial in the Adelaide Hills, transverse line marking initially resulted in reduced approach speeds, but further speed measurements six months after their implementation showed an unexpected long-term increase in travel speeds (Stokes & Woolley, 2017). Note that this trial was limited to a single site and no control was adopted.

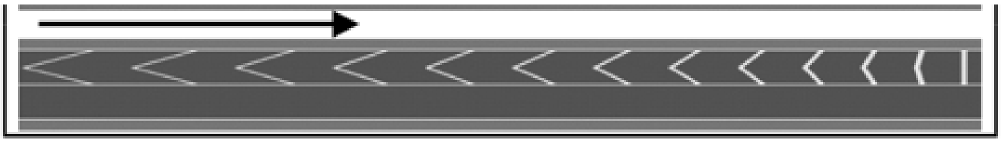
As with rumble strips, transverse line markings will have a lower coefficient of friction than asphalt and may negatively affect the braking and steering capabilities of motorcycles. As noted above (see section *Road markings*), their application should therefore follow certain principles, such as not being placed on a curve, and having sufficient gaps between them that surface friction can be optimised.

Herringbone line markings

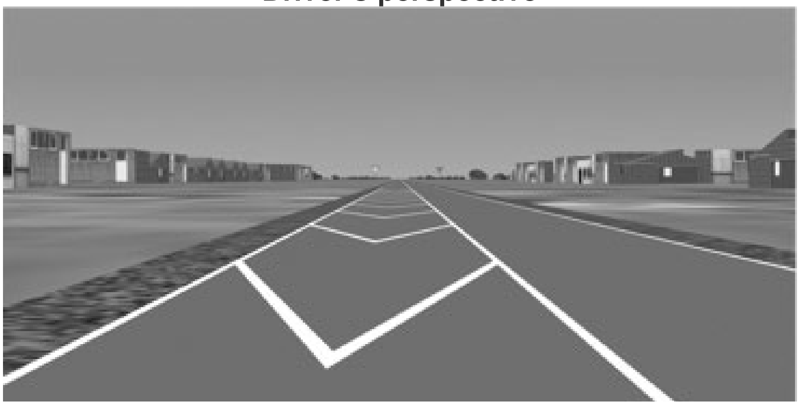
Herringbone line markings are a form of transverse line marking but with the lines painted in a herringbone pattern (Figure 2.4). A literature review conducted by Fildes & Lahausse (2008) on the effectiveness of herringbone line markings noted that they did not produce any significant speed reductions on curves unless they are combined with warning signs and/or CAMs. However, a study in New Zealand found that herringbones line markings produced significant improvements in drivers' lane positions by flattening the drivers' paths through the bends (Charlton, 2007).

Figure 2.4: Typical herringbone transverse line marking design: overhead view and driver's perspective

Overhead view



Driver's perspective



Source: Godley et al., 1999.

As with rumble strips and transverse line markings, herringbone line marking strips have a lower coefficient of friction than asphalt and may negatively affect the braking and steering capabilities of motorcycles.

2.3.4 Peripheral Transverse Lines

Peripheral transverse line markings

Peripheral transverse line markings are square or rectangular lines painted at intervals perpendicular to the road edge and centre line (Figure 2.5). They are usually 60cm wide with regular or decreasing intervals and are painted over lengths of 400 m to 50 m on approach to a hazard. An Australian Transport Safety Bureau sponsored study (Godley et al., 1999) using a driving simulator found that, for straight section of roads, peripheral transverse line markings were effective at reducing speeds by 11 km/h, which is a level similar to that achieved by full-width transverse line markings. However, it is not clear if both peripheral and full-width transvers lines have a long-term effect on speed reduction. It was also noted that decreasing spacing between the transverse lines did not have an effect on vehicle speed (Godley et al., 1999).

Figure 2.5: Typical design of peripheral transverse line markings

Source: Godley et al., 1999.

Peripheral transverse lines have also been reported by Fildes and Lahausse (2008) to result in low to moderate speed reductions and improved lane-keeping behavior, whilst a case-control motorcycle specific PCM study by Mulvihill, Candappa & Corben (2008) in Victoria found that peripheral transverse line markings resulted in a small but significant 85^{th}percentile speed reduction of 0.53 km/h. The peripheral line marking design trialled in Victoria is shown in Figure 2.6.

Figure 2.6: Peripheral transverse line marking trialled in Victoria: Treated curve and design specifications

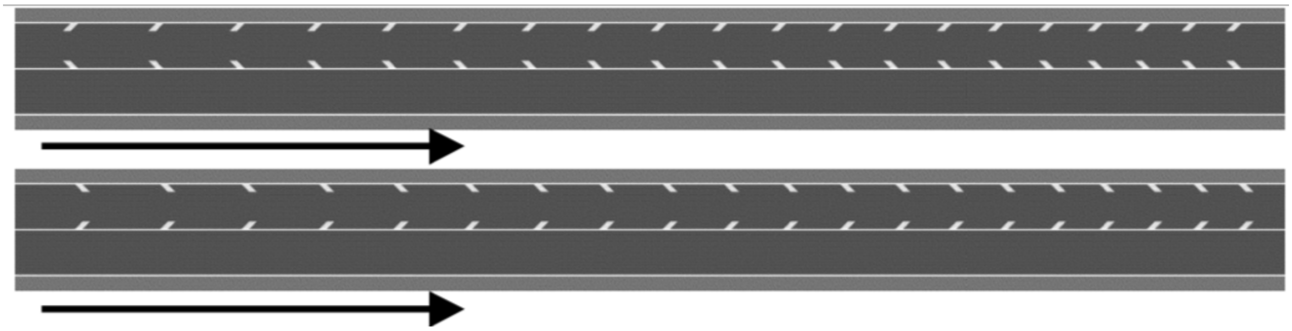
Treated curve **Design specifications**

Source: MUARC, 2008.

Peripheral herring lines

Peripheral line markings may also be of the herringbone configuration and are known as peripheral herring lines (Figure 2.7). Godley et al. (1999) hypothesised that peripheral herring lines would give road users an impression of an approaching lane width narrowing and, thus, the road user may reduce their travel speed. Herring lines pointing inwardly backwards should produce an illusion that the lane is narrowing at the end of the treatment (at least from a plan view perspective). Conversely, herringbone pattern with lines pointing forward should produce the illusion of an increasing lane width. The latter pattern was compared against the pattern with lines pointing inwardly backwards to investigate whether any lane narrowing illusion could occur because of the line orientation, rather than from the narrower unpainted pavement area. In their study, which was conducted in a simulator with straight sections of roads, Godley et al. (1999) did not found evidence that any of the treatments evaluated gave drivers an illusion of a narrowing lane width ahead. Nonetheless, it was found that there was a reduction in vehicle travel speed when these lines were present. However, the speed reduction was not greater than that of transverse line or peripheral line markings. This finding is similar to that of other studies conducted by Charlton (2003) and Arien et al. (2017).

Figure 2.7: Herringbone transverse line markings: backwards facing (top) and forward facing (bottom)



Source: Godley et al., 1999.

The aforementioned peripheral line markings studies with both passenger vehicles and motorcycles indicate that these line markings may have an effect in reducing vehicle travel speed and, on that basis alone, should be considered for this study. However, such line markings, in addition to assisting with speed, may also assist with motorcyclist lane position through curves.

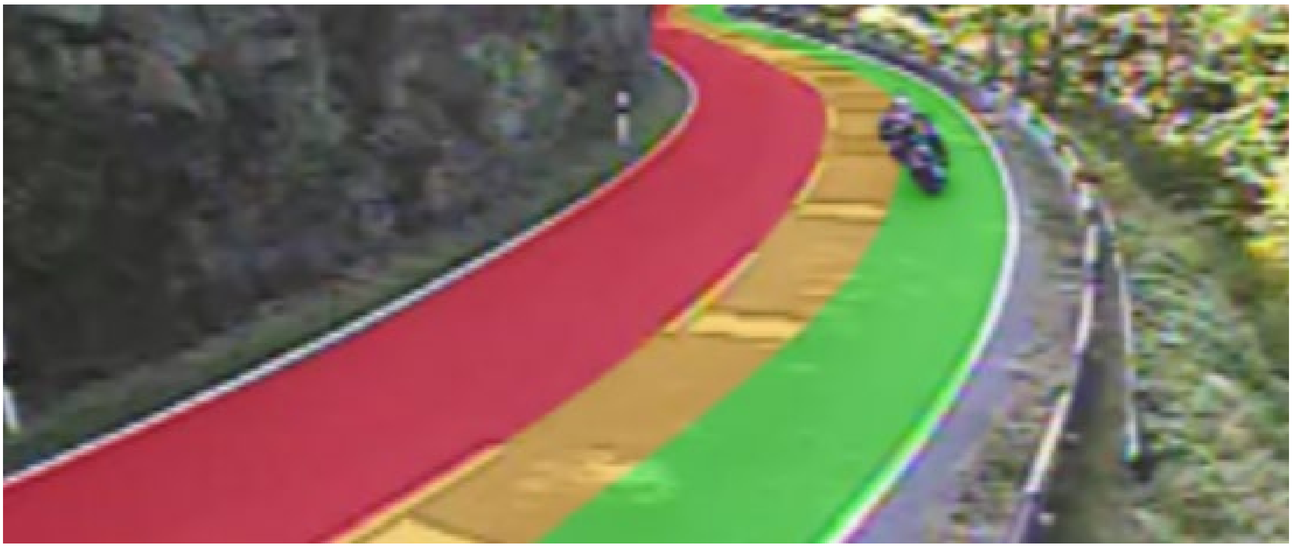
Surface markings are considered hazardous by motorcycle riders such that they avoid riding over markings as much as possible. Interventions that take advantage of this have the potential to channelise riders along a desired path and may also aid in lowering motorcycle speeds through curves. In Luxembourg, special surface markings positioned along the centre line have been trialled with the aim to increase motorcycle separation with on-coming traffic. The peripheral line marking design implemented in Luxembourg is shown in Figure 2.8.

Figure 2.8: Peripheral line marking installed to increase lane separation in Luxembourg

Source: https://travaux.public.lu/fr/actualites/articles/2018/n25-marquage-special-motocyclistes.html.

Evidence posted on the website of the Luxembourg government department responsible for managing roads and bridges appears to demonstrate they are effective (*L'Administration des ponts et chaussées, 2018*). The approach used to determine motorcycle lane position during the trial in Luxembourg is shown in Figure 2.9. Compared to before the treatment was installed, the proportion of motorcycles riding on the path closer to the centreline (i.e., the left most path) decreased from 12% to 1%, Additionally, the proportion of motorcyclists riding on the path located the furthest from the centreline increased from the 10% before the treatment was installed to 53% after the surface markings were installed. Winkelbauer et al. (2012) suggest the benefits of increased separation are expected to be high and that such treatments should be installed at all motorcycle black spots and motorcycle roads. They also note that these types of treatments may also lower motorcycle speed through curves.

Figure 2.9: Approach used to evaluate motorcycle lane position in the Luxembourg trial

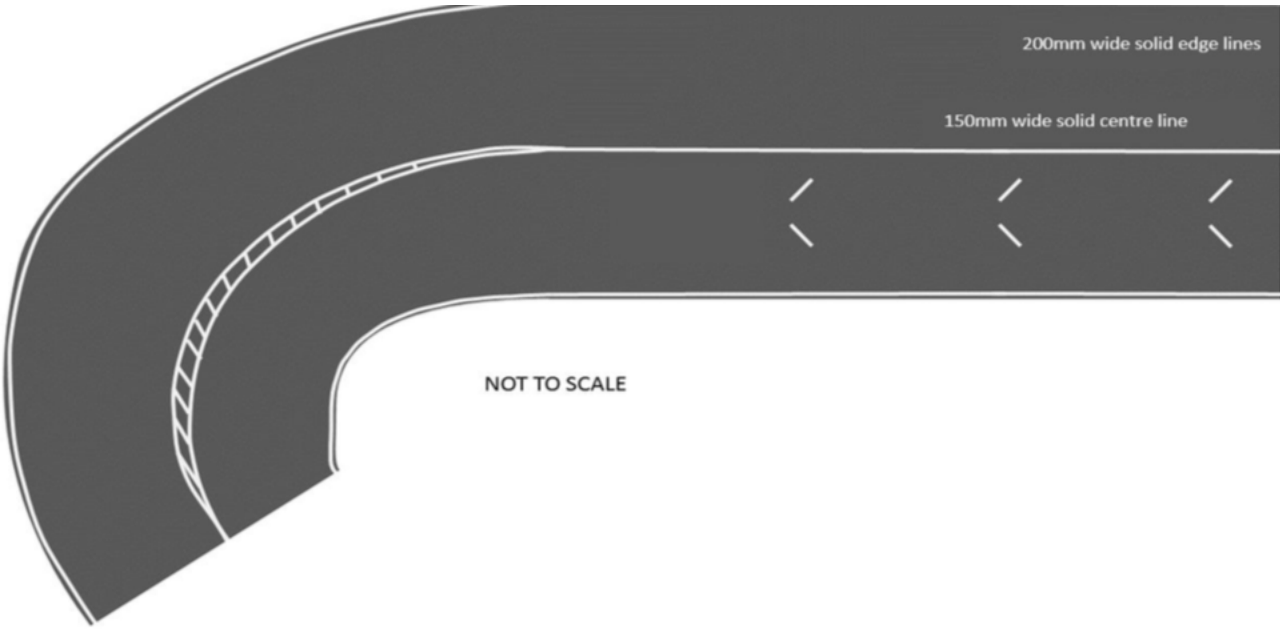


Source: L'Administration des ponts et chaussées, 2018.

In New Zealand several innovative approaches to motorcyclist safety have been adopted along a popular motorcycle route known as the Coromandel Loop (Mackie et al., 2017). The study trialled a chevron line marking design (Figure 2.10) as well as a peripheral transverse line marking design (Figure 2.11). A narrow-separated median and continuous centreline and wide edge line markings were used in conjunction with each of the two designs. Chevron line markings, which were designed to channel motorcycle riders through the gaps, resulted in a 3km/h decrease in the 85thpercentile speed and a decrease in modal speed from 75 km/h to 65 km/h. The peripheral line markings, which were designed to alter a rider's lane position, was effective in this regard. The latter two treatments were also found to be effective in altering motorcycle mid-corner lane positions away from the centreline. Mackie at al. (2017) suggested that the trialled PCM treatments might further be enhanced through the inclusion of CAMs, guideposts, and warning signs.

Figure 2.10: Transverse line marking designs in combination with a narrow-separated median trialled in New Zealand

Treated curve

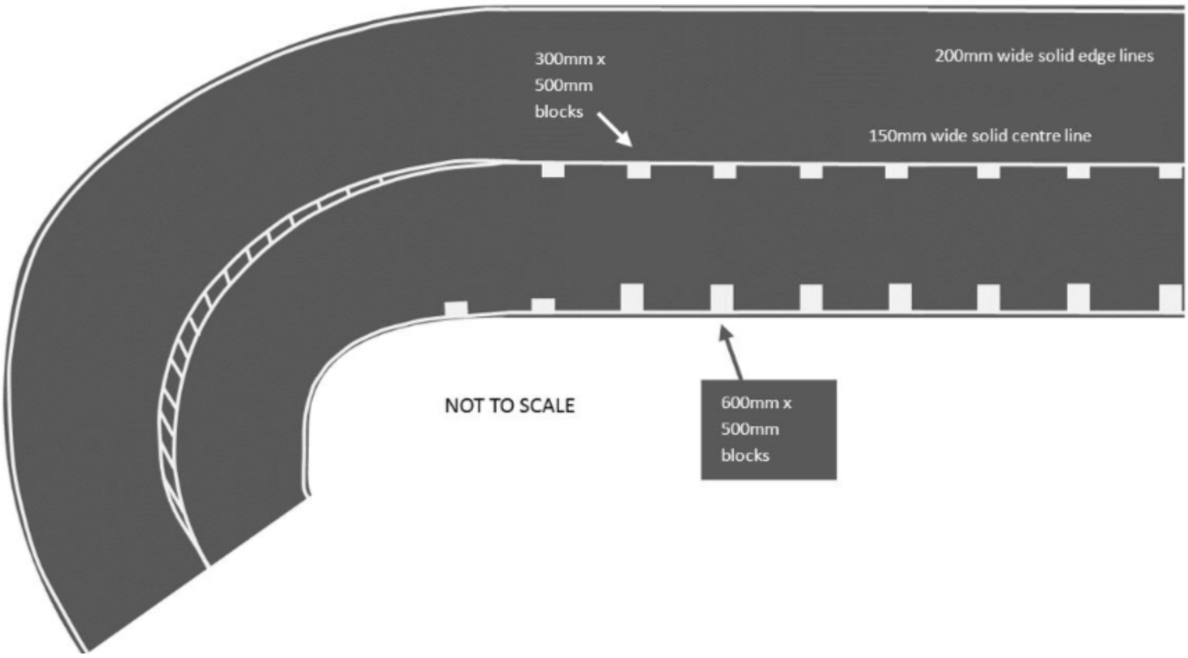


Design overview

Source: Mackie et al., 2017.

Figure 2.11: Peripheral line marking in combination with a narrow-separated median trialled in New Zealand

Treated curve



Design overview

Source: Mackie et al., 2017.

2.3.5 Warning Signs and Line Markings

Warning signs and peripheral herring lines have been combined in a vehicle simulator study by Charlton (2007) to determine if this combination of PCM can be more effective than if the warning sign was used alone (Figure 2.12). The results from their study found that a combination of warning signs and peripheral herring lines was more effective in reducing vehicle travel speed than when a warning sign is used without herring lines. The reduction in vehicle travel speed was found to be between 2.74 km/h to 5.78 km/h, depending on the bend radius and sign posted speed. Furthermore, the study also found that this combination of PCMs improved lane positioning.

Figure 2.12: Simulated herringbone peripheral line marking and warning signs

Source: Charlton, 2007.

2.3.6 Low Visual Contrast Edge Lines

Low visual-contrast edge lines on straight roads were evaluated by Godley et al. (1999) in their driving simulator study (Figure 2.13). They hypothesised that the road user's perception of an increased crash risk may result in a decrease in travel speed. Although the study found that vehicle travel speed did decrease by an average of 1.88 km/h, the vehicles also travelled closer to the centreline. This placement of the vehicle closer to the centreline potentially increases crash risk but the risk has not yet been evaluated.

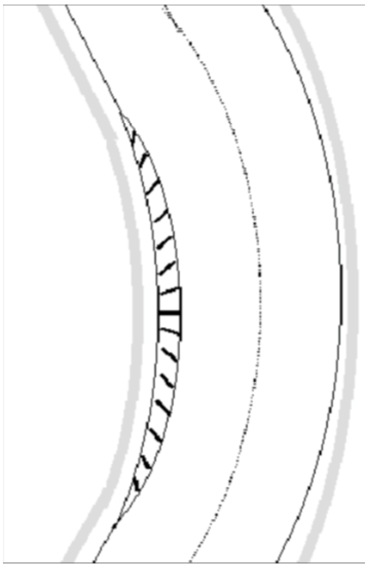
Figure 2.13: Low visual-contrast edge line marking

Source: Godley et al., 1999.

2.3.7 Hatched Edge Lines

The effects of hatched edge lines on road users were explored by Godley et al., (1999), as shown in Figure 2.14. Their hypothesis was that hatched edge lines create an illusion that the curve is tighter than it is. Their study found that hatched edge lines resulted in vehicles travelling between 25 cm and 38 cm closer to the centreline for both left- and right-hand bends. Furthermore, the enhanced centrelines had no effect on vehicle travel speed. The literature review performed by Fildes & Lahausse (2008) also reported that other edge line treatment studies did not result in travel speed reduction.

Figure 2.14: Enhanced edge line marking



Source: Godley et al., 1999.

2.3.8 Painted Chequered Edge Lines

Painted chequered edge lines were included in the study conducted by Godley et al. (1999), as shown in Figure 2.15. Their theory was that the chequered lines may influence the perceived travel speed by the road user and, thus, result in a reduction in vehicle travel speed. However, their study found that chequered edge lines had little to no effect on vehicle travel speed.

Figure 2.15: Chequered edge lines

Source: Godley et al., 1999.

2.3.9 Hatched Centre Lines

The effects of hatched centre lines on road users were explored by Godley et al. (1999), as shown in Figure 2.16. Their hypothesis was that hatched centrelines may accentuate the curvature in the bed and, thus, reduce vehicle travel speed. Their study found that hatched centre lines resulted in no change in travel speed but vehicles travelled further away from the centreline by 22 cm to 35 cm for right hand bends. No shift in vehicle position was reported for left hand bends.

Figure 2.16: Hatched centre line treatment

Source: Godley et al., 1999.

2.3.10 Edge Lines and Reflector Guide Posts

Godley et al. also experimented with painted edge lines and reflector guide posts installed on the roadside of bends (Figure 2.17) to determine if this combination of delineation may result in a reduction in vehicle travel speed (Godley et al.,1999). Their study involved placing reflector guide posts (1) on both sides of the road, (2) on the outside bend, and then (3) with ascending post height on the outside of bends. When posts were placed on both sides of the road, they reported that vehicle travel speeds increased by 1.5 km/h for left-hand bends and there was no change in speed for right hand bends. When the reflector posts were placed on the outside of bends, they reported that there was a 1.5 km/h decrease in speed for left-hand bends but there was a 2.1 km/h increase in speed for right-hand bends. When ascending height posts were placed on the outside of bends, there was a 1.4 km/h decrease in vehicle travel speed for both left- and right-hand bends. However, the study's authors noted that this 1.4 km/h decrease in vehicle travel speed was not statistically different to that of the case where ordinary guideposts were installed on the outside of the bend.

Figure 2.17: Edge line marking with reflector guide posts

Source: Godley et al., 1999.

2.3.11 Perceptual Lane Width Narrowing

The simulator study conducted by Godley et al. (1999) also included a study on the effects of narrow lane width on vehicle travel speed on straight roads (Figure 2.18). They found that narrow lane widths of 2.5 m reduced vehicle travel speed by 2.2 km/h compared to that of a 3.0m wide lane. They also noted that traffic separation can be maintained through the use of painted medians.

Figure 2.18: Painted hatched median and lane narrowing

Source: Godley et al., 1999.

The reported speed reduction by Godley et al. was also found in road tunnels where decreasing visual width line markings were applied to the road surface (Fildes & Lahausse, 2008). However, it is noted that, although lane width narrowing may result in a reduction of vehicle travel speed, it is possible that road users may position their vehicles towards the centreline, and, thus, result in an increased likelihood of a crash with oncoming vehicles. A wide painted median may reduce this likelihood, as reported by Godley et al. (1999).

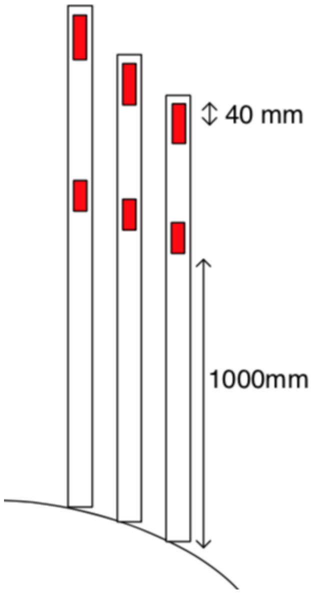
2.3.12 Peripheral Transverse Line and Reflector Guide Posts

The effects of a combination of peripheral transverse lines and reflector guide posts were explored in a case-control motorcycle study by Mulvihill, Candappa & Corben (2008). Peripheral transverse lines were installed on an approach to a single bend (Figure 2.19) and reflector guide posts were installed throughout a series of bends (Figure 2.20). The study found that this treatment resulted in an average speed reduction of 1.34 km/h compared to the control bends. The study also explored the effects of ascending guide post height on the approach to a single bend and through a series of bends. This treatment resulted in an average 1.49 km/h decrease in motorcycle travel speed compared to the control bends.

Figure 2.19: Peripheral transverse line markings and guide posts

Source: Mulvihill, Candappa & Corben, 2008.

Figure 2.20: Ascending height guide posts used in the study by Mulvihill et al.



Installed guideposts **Ascending design**

Source: Mulvihill, Candappa & Corben, 2008.

2.3.13 3D Road Markings

Three-dimensional (3D) road markings, thus far, have been shown to have negligible effects on speed and driver behaviour in general but are yet to be thoroughly investigated. They could also create driver frustration if they feel 'tricked' and there is the potential that 3D road markings could result in erratic or avoidance manoeuvres which may negate any safety effects from these types of PCMs (Fildes & Lahausse 2008). As such, they have not been considered for this study. An example of the use of 3D transverse line marking for traffic calming in a high-pedestrian area in Singapore is shown in Figure 2.21.

Figure 2.21: 3D transverse line markings used for traffic calming in Singapore

Source: LTA, 2021.

2.3.14 Where You Look Is Where You Go (WYLIWYG)

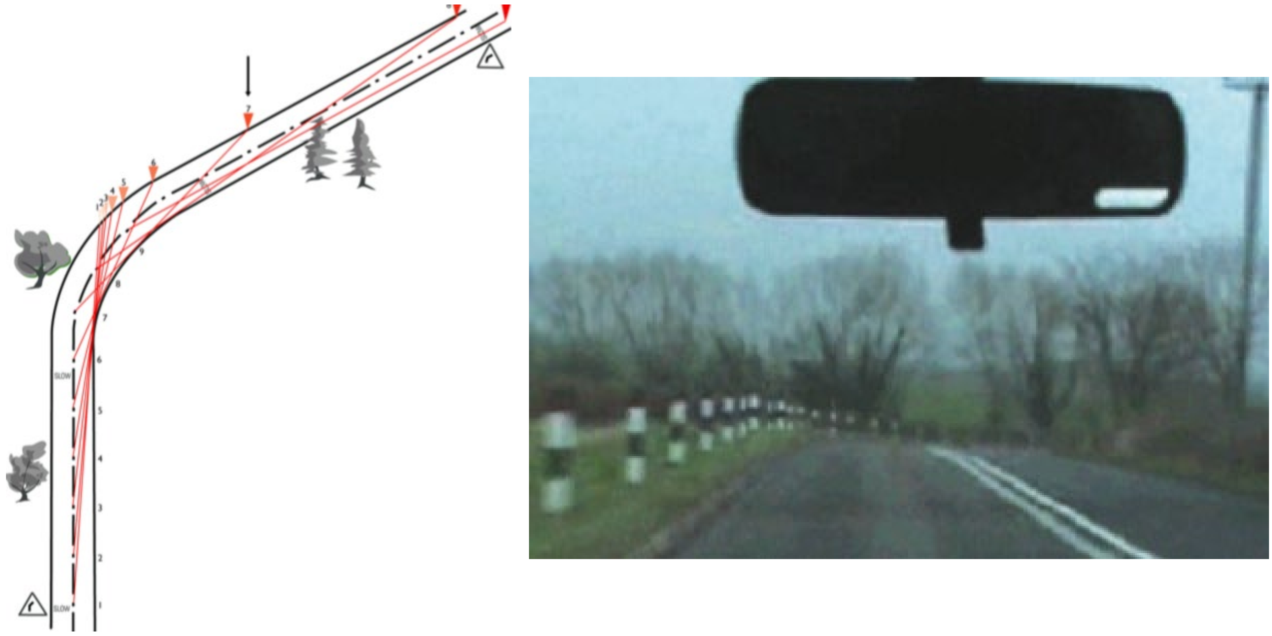
The “Where You Look Is Where You Go” (WYLIWYG) treatment was conceived in Buckinghamshire County Council. It is based on motorcycle riding techniques contained in the United Kingdom’s (UK) police book titled Motorcycle Roadcraft - The Police Rider’s Handbook to Better Motorcycling (James, 2007). The treatment is based on the recommended riding practice of looking where the motorcyclists wants to go, hence the ‘where you look is where you go’ name. In bends, motorcyclists are advised to look for the vanishing point of the curve which gives them a cue as to how sharp the curve is and the extent of the curve. Riders are also advised to reduce their speed on the approach to a bend to a speed at which they can travel safely around the bend. Once a rider is in a bend, they are advised to keep their eye on the vanishing point and steer their bike towards it. The treatment therefore uses conspicuous guide posts to drive the rider’s direction of gaze around a curve in such a way that the motorcycle follows an appropriate trajectory (Cairney & Beesley, 2012).

It is worth noting also that the recommended approach to a bend involves the motorcyclists riding at an appropriate speed for the anticipated curve radius. For a right-hand bend, the motorcyclist moves to the left of the travel lane. As the motorcyclist approaches the apex of the bend, they manoeuvre themselves to the right and towards the centre line. They then exit the bend to the left of the travel lane. For a left-hand bend, the procedure is the opposite of that described above (Cairney & Beesley, 2012).

Cairney and Beesley (2012) noted that a risk that riders face in negotiating the bend is that their visual attention may become fixated on some feature of the road scene, such as a gate or a prominent tree, rather than the vanishing point. As such, the continuous WYLIWYG delineation gives the eye a continuous reference so that riders are, in theory, less likely to be distracted.

The guide posts in WYLIWYG treatment are all the same height above the surface of the road (Figure 2.22). Nominally, this height is 920 mm. The effect of having a uniform height is that the posts provide the motorcycle rider with information on the super elevation of the road and, thus, allows the motorcycle rider to select an appropriate and safe speed and line to navigate the bend (Cairney & Beesley, 2012).

Figure 2.22: Plan layout and driver’s perspective of WYLIWYG posts



Plan layout **Driver’s perspective**

Source: James 2007.

A case-control study on the WYLIWYG treatment conducted by Cairney & Beesley (2012) involved the use of the *Vergemaster* guide posts (Figure 2.23). Two bends were chosen as treatment sites - one with chevron alignment markers, while the other had posts only. Two other bends were chosen as controls.

Figure 2.23: Vergemaster (left) versus Australian standard guide post (right)

Source: Cairney & Beesley, 2012.

The study found that, for both right-hand and left-hand bends, overall travel speeds were lower in the case sites compare to control sites. They also observed that motorcycle positioning in the travel lane did not place the motorcyclists at an increased risk of a crash with oncoming vehicles.

Their recommended future research includes:

- Does a WYLIWYG treatment consistently result in riders moving across the road away from it as was observed in their study?
- Does a WYLIWYG treatment consistently result in more consistent speed through a site, as observed in their study?

2.3.15 PCMs to Reduce Crash Risks in Tunnels

Austroads (2022) discussed several perceptual interventions aimed explicitly at tunnel environments. Both a literature review and experimental study were undertaken. The experimental study consisted of participants using a driving simulator to virtually drive through a series of tunnels that had been treated with a perceptual intervention. The Sydney Harbour tunnel was used as a model for the simulated environment. Four intervention scenarios were assessed in the study: a baseline (no interventions applied); painted striped wall patterns; pacemaker lighting; and audio-tactile line marking (referred to as rumble strips in the report). The results of this study indicated that the assessed treatments had only a modest, albeit sometimes significant, effect on driving speeds in tunnels. However, these results were isolated to only some sections of the simulated environment where the interventions were applied. No measurable effect on lateral lane control was seen. It is worth noting that for one of the interventions, the striped wall pattern, higher driving speeds were observed in some sections of the tunnels compared to the baseline scenario.

2.4 Conclusions

There have been very few motorcycle-specific PCM studies performed to date. In choosing candidate PCMs for motorcyclists based on the literature, it is necessary to consider the results of studies examining the effects of such countermeasures on passenger vehicles. Those that have been undertaken have mostly demonstrated modest effects on speed, while some have reported some indications of improved lane position.

To summarise briefly, reductions in travel speed have been found for the following countermeasures:

- Vehicle activated speed warnings (Charman, 2010)
- Transverse line markings (Fildes & Lahausse, 2008)
- Peripheral line markings (Godley et al., 1999; Mulvihill et al., 2008)
- Peripheral herring lines (Godley et al., 1999)
- Peripheral herring lines combined with curve warning signs (Charlton, 2007)
- Perceptual lane width narrowing (Godley et al., 1999)
- Peripheral transverse lines and guide posts (Mulvihill et al., 2008)
- Ascending height guide posts (Mulvihill et al., 2008)
- Where You Look is Where You Go treatments (Cairney & Beasley, 2012).

A number of the studies above did not consider motorcycles, and some used driving simulators rather than real-world measurements. Those that did use real-world measurement of motorcycle effects were Mulvihill et al. (2008) and Cairney and Beasley (2012).

In regard to lane position, this has been found to be improved by the following treatments (only the last two considered motorcycles specifically):

- Herringbone lines (Charlton, 2007)
- Peripheral line markings (Fildes & Lahausse, 2008)
- Peripheral herring lines (Luxembourg Government)
- Where You Look Is Where You Go treatments (Cairney & Beasley, 2012).

Overall, it is difficult to choose countermeasures to trial which have strong prior evidence for positive effects on motorcycle speed or lane position through curves. This reinforces the need for further experimentation to advance the field of the use of PCMs for motorcycle crashes.

On the basis of the limited evidence available, it is suggested that the following are promising treatments worth investigating in an on-road trial, either separately or in combination:

- Peripheral line marking (possibly herring lines)
- Where You Look Is Where You Go treatments.

The exact details for any of these two treatment types need to be discussed in a workshop with practitioners and other relevant experts, so that an optimal design or set of designs can be examined for their effects on real-world motorcycling. Variables to be measured will focus on indices of speed and lane position through curves, with outcomes compared to appropriate control sites.

When performing these studies, consideration also needs to be given to the likely long-term effectiveness of the treatments, the effectiveness at different sign-posted speed limits and operational speeds, whether there are any other road safety treatments upstream of the proposed treatment installation locations, and whether there are any optical illusions or unexpected changes in the road alignment. Any possible effects on other road users also need to be taken into account. The treatments will also need to be consistent with any guidelines for infrastructure that are applicable to TMR and/or Australian roads, and will need to be designed so that other hazards are not inadvertently introduced into the road or roadside environment.

2.5 Additional Motorcyclist-focused PCM Evaluations (Identified After the Trial Commenced)

After a PCM design was finalised and its trial commenced, the research team became aware of three additional recent investigations of perceptual treatments specifically focused on motorcyclist safety along curves. Two of these additional investigations were independently conducted almost concurrently with this project and their results have become available before the end of this project but after the trial of the PCM had already initiated. Another additional investigation was conducted overseas in Austria and partially completed before this project commenced, but the project report describing that evaluation was not readily available in literature. Additionally, that report was mostly written in German language. Each of these three additional trials are reported at the end of this literature review for the sake of accuracy and completeness. Although none of those trials could be considered during the design stage for the PCM treatment trialled in this project, their outcomes have been thoroughly considered in the discussion of the results obtained in this project. The following sections provide an overview of each of those three additional evaluations.

2.5.1 Peripheral Line Marking Treatment Trialled in Victoria

A recent trial of a peripheral line marking has been conducted in Victoria concurrently to this project (Abdelmesseh et al., 2021). The trialled PCM design was very similar to the design that has been eventually proposed in this current project. Indeed, the initial draft design of the PCM for this project was exchanged with the research team leading the trial in Victoria. A picture of the PCM trialled that has been evaluated in Victoria is shown in Figure 2.24.

Figure 2.24: Peripheral line marking treatment trialled in Victoria

Source: Abdelmesseh et al., 2021.

2.5.2 Gating Line Marking Treatment Trialled in Scotland

A gating-type line marking treatment named as Perceptual Rider Information for Maximising Expertise and Enjoyment (PRIME) has been recently trialled in Scotland (Stedmon et al., 2021). This type of treatment, which is shown in Figure 2.25, aims to induce motorcyclists to position themselves within a desired portion of the lane width when they enter the curve (hence, the definition ‘gating’). The gating line marking design was based on a similar design previously trialled in New Zealand by Hirsch et al. (2018), where the lead researcher for this trial in Scotland was also involved.

Figure 2.25: Gating-type line marking treatment trialled in Scotland

Source: Stedmon et al., 2021.

2.5.3 Peripheral Line Marking Treatments Trialled in Austria

Two designs of peripheral line marking treatments have been recently trialled in Austria (Winkelbauer et al., 2017). An additional long-term evaluation of the treatments was also conducted at some of the trial sites in 2021 (Winkelbauer et al., 2021). Both designs were specifically developed to prevent motorcyclists from crossing over the centreline when negotiating dangerous left-hand bends (equivalent to right-hand bends in left-lane driving countries such as Australia) along popular motorcycle routes in mountainous areas. The main difference between those two designs is in the type of shapes painted along the centreline, which were either rectangular blocks or hollow ellipses. In both cases, the width of those painted shapes incrementally increased when travelling from the curve entry to the apex. Example of the installations of each of these two treatment types at some of the trial sites are shown in Figure 2.26.

Figure 2.26: Peripheral line marking treatments trialled in Austria

Block design **Ellipses design**

Source: Winkelbauer et al., 2017.

3. Design of the Perceptual Treatment

A motorcyclist-focused PCM was designed as part of this project, which aims to induce motorcyclists to moderate their travel speed as well as choose a safe trajectory when negotiating a curve.
This section describes the overall process leading to the final design that was used in the trial, starting from a review and ranking of existing PCM designs identified in the literature and ending with a description of the rationale for the final design selected for the trial. The identification of the final design involved feedback obtained from road authorities and practitioners during a dedicated workshop and a subsequent review process.

The design of the motorcyclist PCM trialled in this study was obtained through an iterative process involving the following three major steps:

1. Initial identification of potential candidate designs
2. Shortlist preferred designs based on feedback received during a dedicated workshop with the project Working Group
3. Identification of a final design based on additional feedback received from the project Working Group and members of the Road Safety Task Force, as well as from the project Manager at Queensland Transport and Main Roads (TMR).

The following sections describe each of these three major steps leading to the identification of the design for the PCM that was trialled in this study.

Note that the predicted application of the PCM was to prevent intentional crossing of the centreline by motorcyclists rather than lane departures due to unintentionally drifting towards the outer side of the curve. Therefore, the PCM was specifically designed for treating curves in the direction of travel of the right-hand bend, where intentional cutting through the curve chord would cause to cross the centreline.

3.1 Identification of Suitable Perceptual Designs

Various potential candidate designs for a PCM were initially identified and discussed with road authorities and practitioners from the project Working Group during a dedicated one-day workshop. These candidate designs were mostly based on the existing designs of PCMs identified throughout the literature review that was conducted at the beginning of this project (see Section 2). Additionally, some novel concept designs developed by the research team were discussed during the workshop. A description of all those initial candidate designs as well as a summary of their pros and cons are provided in the interim project report in Appendix A. Additionally, details of the feedback received on each design are available in the workshop description in Appendix B.

The PCM treatment types and treatment applications can be broadly categorised as below:

- **Speed correction**: treatments that primarily affect a motorcyclist's speed selection on entry to and while traversing a curve.
- **Line navigation**: treatments that primarily affect a motorcyclist's chosen line through a curve by providing line-tracking guidance to direct motorcyclists through a preferred line.
- **Line correction**: treatments that primarily affect a motorcyclist's chosen line through a curve by providing general line-tracking guidance and directing motorcyclists away from safety risk-associated areas (e.g., near the centre line).
- **Combination**: treatments that affect multiple factors, such as both speed correction and line navigation.

- **General guidance**: treatments that provide motorcyclists with general guidance around a curve. An example is CAMs, also known as chevrons.
- **Threshold treatment**: treatments placed at the threshold of a series of curves to affect the speed selection and/or general riding behaviour of motorcyclists along a short length of roadway (NOTE: threshold treatments were raised during the project workshop and subsequently deemed to fall outside of the project scope).

Several features were indicated as not desired by the workshop participants and so the corresponding treatments that made use of any of them were discarded without further consideration in this trial. The list of undesired treatment features alongside with the perceived associated potential issue(s) is summarised in Table 3.1.

Table 3.1: Undesired treatment features and perceived associated potential issue(s)

Undesired design feature	Associated issue(s)
Use of multiple colours	• Maintenance issues • Potential to incite undesired speed behaviour, such as racing
Chequered flag patterns	Potential to incite undesired speed behaviour, such as racing
Traversing across the entire lane width	Potential to be perceived as a hazard by motorcyclists, especially if based on regular paint instead of high-grip paint (could encounter strong resistance from the motorcycling community)
Impose a strict trajectory	Potential for a 'one size fits all' approach to line navigation to interfere with a motorcyclist preferred curve trajectory, which can vary based on riding experience
Applied to left side of lane only	Potential to force motorcyclists to drift towards the centreline due to the perception of a narrowing lane
Complex designs (e.g., 3D painted lines, adaptive spacing)	Implementation difficulty and high maintenance costs
Complex /intricately detailed installation	Potential maintenance issue, as the original design may not be replicated during maintenance (e.g., replacing missing guideposts at an incorrect location for a variable-spacing design)
Technologically complex treatments	More expensive and difficult to install and/or maintain compared to simple treatments

The three PCM design options that received the largest support from the stakeholders participating to the workshop were (in the provided priority order):

1. Peripheral transverse line markings (with variations on the width of the line markings and/or spacing between line markings).
2. Peripheral transverse line markings applied in conjunction with reflector guideposts.
3. Lane markings applied in conjunction with post-mounted delineators or warning signs.

An example of each of the three preferred design options is shown in Figure 3.1.

Figure 3.1: Perceptual design options that received the largest support from stakeholders during the workshop

Option I	Option II	Option III
		
Peripheral transverse line markings*	***Peripheral transverse line markings**** **&** ***Reflector guide posts***	***Peripheral line markings*** **&** ***Warning signs***

* Yellow colour not required

3.2 Shortlisted Draft Designs

Based on the feedback obtained from relevant stakeholders during the project workshop, peripheral line marking was identified as the preferred design approach for a PCM to be trialled in this project. Two options of peripheral line marking that make use of rectangular painted blocks were shortlisted, as shown in Figure 3.2. Both designs make use of a peripheral transverse line marking on either edge of the lane and are applied throughout the entire curve. These two design options differed from each other in the width of the centreline blocks. In the first design option, centreline blocks of constant width run throughout the curve, whereas in the second option the centreline blocks change in width through the curve. Therefore, the second proposed shortlisted option was referred to as a 'modified peripheral transverse line marking'.

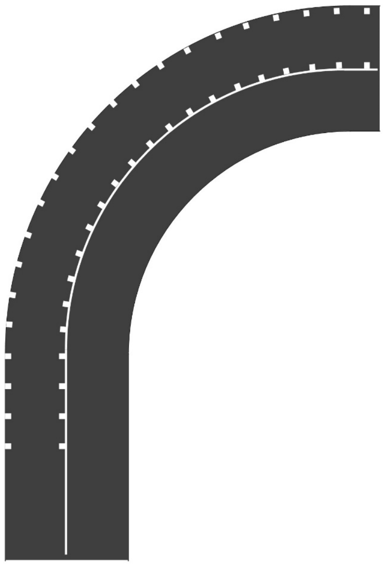
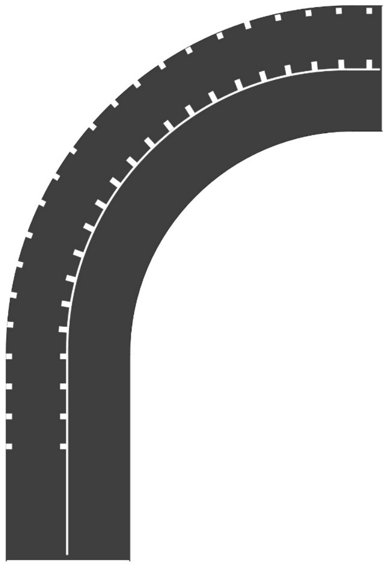
Both proposed options of the peripheral line marking aim to implicitly suggest a preferred trajectory for motorcyclists by narrowing the path to an ideal corridor. Nonetheless, the treatment is not expected to forcibly prevent a rider from negotiating the curve throughout alternative trajectories if they decide to do so or if they are not able to correct a different trajectory they may have already initiated. Occasionally, motorcyclists may need to overcorrect a badly chosen trajectory when negotiating a curve. In those cases, the proposed PCM design is not expected to limit their perception to be able to perform an emergency manoeuvre, if needed. Practically, motorcyclists would still have the option to ride over the peripheral line marking in the same way as they can currently do with a standard line marking if they had to cross over the centreline due to a badly chosen trajectory.

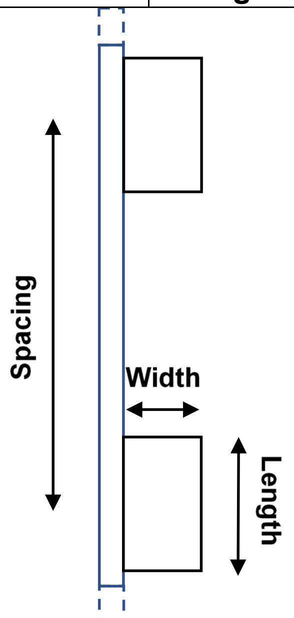
In the standard version of the peripheral line marking, all blocks on the inner side of the lane (i.e., on the centreline for a right-hand bend) are constantly 1.5 times wider than the outer blocks (i.e., along the edgeline for a right-hand bend). For the modified peripheral line marking, the width of the inner blocks increases linearly from a baseline value of 450 mm at the entry of the curve up to a maximum value of 600 mm at the apex of the curve. The inner block width then linearly reduces back to 450 mm between the apex and the curve exit. Such linear variation is expected to be implicitly perceived by riders albeit not consciously noticed. Additionally, these linear variations in the block width are expected to be relatively easy to implement.

Beside the presence of the blocks on both sides of the lane, an important aspect of each of the proposed peripheral line marking designs is the difference in width between blocks located opposite to each other. At the entry of the curve, the edgeline blocks are narrower than the opposing centreline blocks by a ratio of 2:3. This relative width differential between opposing edgeline and centreline blocks is expected to instinctively induce riders to shift their lane position towards the edge line rather than stay centred in the lane when approaching the entry of the curve.

Note also that a concept design using variable block spacing was initially considered but it was rejected on the grounds that the optimal degree to which line spacing should vary is unknown and therefore may not be effectively implemented.

Figure 3.2: Shortlisted treatment types to be considered for the trial

Peripheral transverse line marking			Modified peripheral transverse line marking		
					
Block Specifications					
	Edge Line	**Centre Line**		**Edge Line**	**Centre Line**
Spacing (mm)	3,500	3,500	**Spacing (mm)**	3,500	3,500
Width (mm)	300	450	**Width (mm)**	300	Linearly variable 450 (entry/exit) 600 (apex)
Length (mm)	500	500	**Length (mm)**	500	500



Note: Treatment to be trialled on right-hand curves

The proposed design and the dimensions for the standard peripheral line marking were loosely based on the latest version of a similar treatment that was trialled in New Zealand (Hirsch, Scott, Mackie, Stedmon & Moore, 2018). However, there are some important differences between both versions of the proposed design and the previous design trialled in New Zealand, as outlined below.

- In the trial conducted in New Zealand, the peripheral line marking was placed only on the approach to the curve and a painted wide centreline treatment was used throughout the rest of the curve. In the design proposed for this trial, the peripheral line marking is the sole treatment, and it is applied throughout the entire curve.
- The proposed treatment is to be applied to right-hand curves, as opposed to left-hand curves in the New Zealand trial. Therefore, the inside of the curve in this trial will be the centreline (instead of the edge line in the New Zealand trial).
- Similar to the New Zealand design, the painted blocks on opposing side of the travel lane are characterised by a different width. However, in both versions of the proposed design the inner blocks are larger than the opposing outer blocks, whereas in the New Zealand design the outer blocks were twice as wide as the blocks on the inside of the curve. The reason for this difference is that the proposed designs aim to reduce the possibility of intentional crossing over the centreline due to cutting through the cord while negotiating a right-hand curve (i.e., drifting towards the inner side of the curve). Conversely, the aim of the design trialled in New Zealand was to prevent unintentional drifting towards the outer side of the curve while negotiating a left-hand curve.

3.3 Selected PCM Design

The **modified** version of the peripheral line marking was selected as the final design for the trial. This design, which makes use of increasing block widths in the “head-on zone” near the centreline around right-hand curves was considered the best design option to trial based on the following reasons and considerations.

- TMR expressed a preference for trialling a single type of treatment in multiple road environments characterised by different speeds and curvatures (this option was also proposed in the feedback received by some of the stakeholders that were involved in the review of the shortlisted designs).
- A trial of the modified design would allow us to investigate whether the proposed modifications could improve the existing standard peripheral design by comparing the results of this trial with the results of previous trials of the standard design that were conducted in New Zealand (Hirsch et al., 2018) and in Victoria (Mulvihill et al., 2008), respectively.

The two main design features of the selected modified peripheral line marking, and their expected effect, are summarised in Table 3.2.

Table 3.2: Modified peripheral line marking - Main design features and expected effect

Design Feature	Expected Effect
Peripheral blocks	Create a perception of a narrow lane as well as a mild channelisation effect, which are both expected to induce motorcyclists to control their speed and stay withing the virtually reduced boundaries when negotiation the curve.
Variable centreline blocks	The width of the centreline blocks changes gradually and smoothly throughout the curve so that road users should intuitively adapt to such subtle changes, therefore leading to a potentially greater compliance and acceptance of the treatment
Widening centreline blocks through the curve apex and Narrowing centreline blocks downstream of the curve apex	Accentuate the expected effect of the standard peripheral line marking design of inducing motorcyclists to drift towards the outside of the curve at the entry and still allowing them to gradually move towards the centreline while maintaining a safe distance from oncoming vehicles through the negotiation of the rest of the curve

Note that in the modified version, the gradual increase in width of the centreline blocks accentuates the initial differential in width between opposing centreline and edgeline blocks when moving forward towards the curve apex. Since motorcyclists look forward of their current position, such increased differential will be detected when they are located upstream of where it actually occurs. Therefore, the mentioned effect to shift towards the curve outer edge due to an increased differential in the width of opposing blocks is expected to gradually increase while motorcyclists are approaching the curve entry. Conversely this effect is then expected to be gradually reducing when motorcyclists are riding through the curve, due to their anticipated perception of the progressive width reduction of the centreline blocks that occurs downstream of the curve apex. Overall, it is expected that after being initially induced to shift toward the outer edge on the approach and entry of the curve, motorcyclists will then start to gradually shift back to the centre of the lane while progressing through the curve and eventually will leave the curve at a safe distance from the centreline.

4. Trial of the Perceptual Treatment

A before-after trial was undertaken to evaluate the safety performance of the designed PCM. This section describes how the trial was conducted, including the selection of the trial curves, the data collection process, and the implementation of the PCM design at the treated sites.

4.1 Analysis Approach

The safety performance of the PCM design was evaluated through a trial. The PCM was installed at two different curves and a separate dedicated control curve was paired to each treated site. The evaluation was conducted comparing the motorcyclist behaviour when riding through the two treated curves before and after the treatment. Data collected at the two additional control sites were used to identify and discount for the potential effect of external factors (e.g., weather, traffic conditions) on any of the before-after changes in the motorcyclist's behaviour identified at the treated sites. Note that this approach assumes that any such controlled factors that may have influenced the motorcyclist riding behaviour would have acted simultaneously at both the treatment and control sites. Additionally, control sites allowed for discounting of the effect of existing PCMs that were present at both the treated and control sites such as the presence of roadside guide posts and CAMs. However, a potential perceptual effect on motorcyclists caused by other standard safety treatments such as roadside guardrails was not controlled.

The evaluation of the potential safety benefits of the trialled PCM focused on the following two aspects of the motorcyclist's behaviour: (i) travel speed (at the apex of the curve), and (ii) the motorcycle lane position (both at the entry and the apex of the curve).

For each of the two treated curves as well as for the two control curves, the profiles of the motorcycle travel speed as well as the lane position were compared before and after the treatment implementation. The overall distribution as well as the mean and 85thpercentile values were considered in the analysis. To exclude the effect of potential external factors, the before-after difference of those values at each treated site was discounted by any corresponding difference at the respective control sites. Note that no statistical significance could be drawn throughout this analysis due to the small size of the trial sample sites.

Motorcycles were classified into three main categories (cruisers, tourism/enduro, sport bikes). The speed and lane position analyses were undertaken separately for each of those categories as well as for an aggregation of all of them. Additionally, a speed analysis was also conducted on light and heavy vehicles with the intent of identifying whether the PCM treatment may have also had an effect on these categories of road users. Finally, a threshold analysis was conducted to identify the percentage of events falling within a series of given ranges for both the travel speed and motorcycle lane position.

Additional concurrent factors other than the implemented PCM may contribute to affect the motorcyclists' riding behaviour when negotiating a curve. Such factors include the condition of the road surface (dry/wet), and the presence of other vehicles travelling either in the same or the opposite direction. To rule out the potential effect of these common factors, detected vehicle events were pre-filtered based on the following criteria before conducting the analysis:

- Motorcyclist riding in a free flow condition through the curve (i.e., no other vehicle immediately leading or following the motorcycle)
- No oncoming vehicle(s) when negotiating the curve
- Dry road surface.

To avoid introducing any bias to the measured motorist behaviour, no informational road signage mentioning the ongoing testing of a novel line marking was provided during the entire duration of the trial. However, a media statement that briefly described the ongoing trial of the PCM along Mt Mee Rd was independently released by the Queensland Government immediately before the post-treatment data collection commenced. This public media statement was reported by a local newspaper[1] and circulated through a discussion thread in a local motorcyclist community page[2] on the social media Facebook.

4.2 Trial Sites

4.2.1 Site Selection Process

The overall process for the selection of the trial sites was based on the following three major steps:

1. Identification of a suitable route
2. Identification of suitable candidate sites
3. Pairing of treatment/control sites.

Route selection

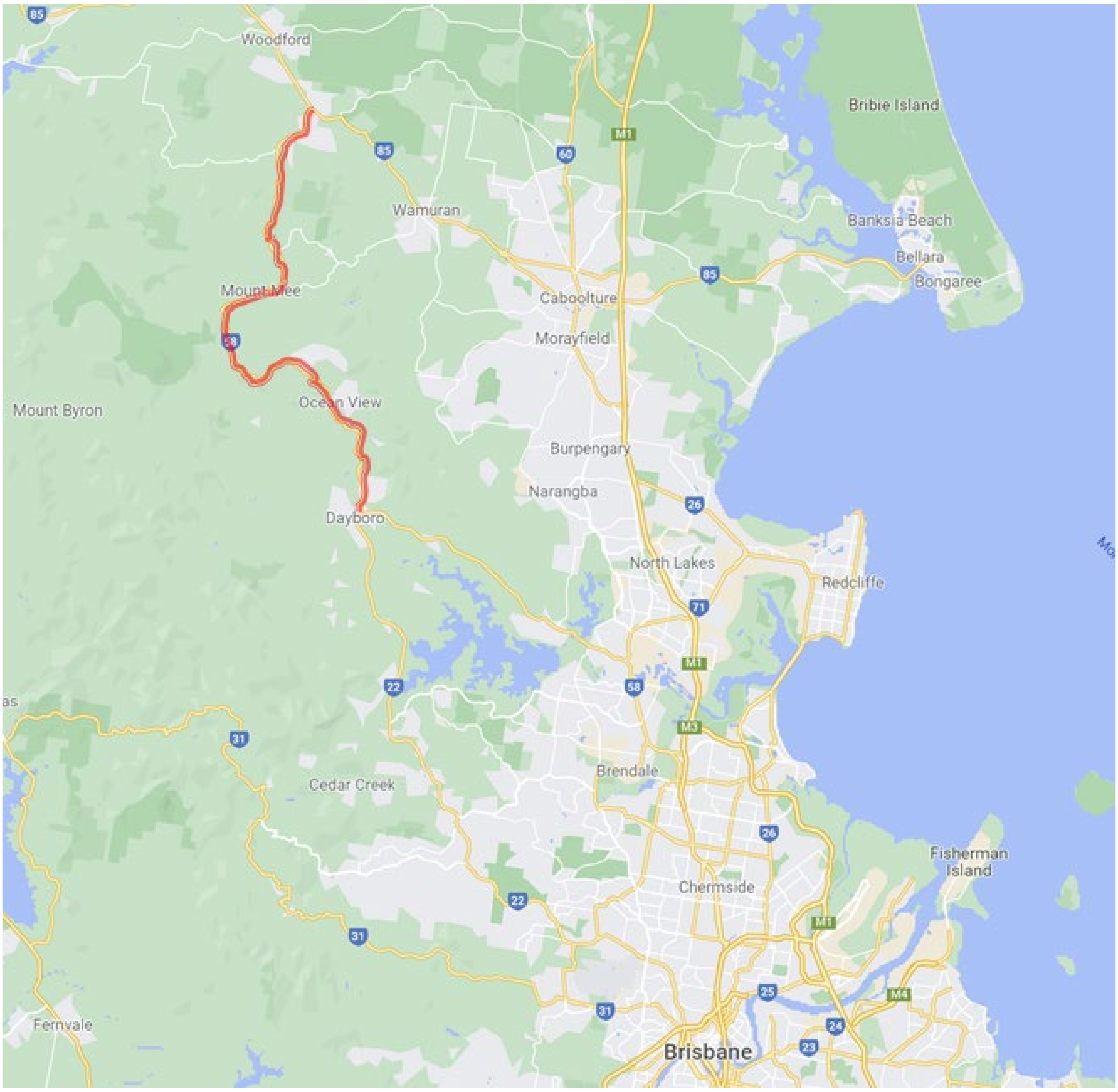
Three candidate suitable routes were initially shortlisted based on the following major criteria (with an overview of their related implementation):

- **Popular motorcycling routes**
  Motorcycles routes were initially identified based on routes suggested in the Australia Motorcycle Atlas (Hema Maps, 2015) and further confirmed by additional traffic data and insight knowledge available to TMR.
- **History of motorcycle-related fatal and serious injury (FSI) crashes**
  The PCM trial is targeted towards improving motorcyclist behaviour that could lead to motorcycle lane departure crashes, especially around curves, such as single motorcycle run off road crashes and motorcycle-involved head-on crashes. As such, route selection was based on the identification of routes where motorcycle lane departure crashes, especially those around curves, is an issue. The crash data used for the route identification were provided by TMR and included police reported crashes in the Moreton Bay area between 2009 and 2018. Relevant crashes were identified using the reported crash severity and Definitions for Coding Accidents (DCA) codes. Potential routes were identified within areas characterised by a high concentration of fatal and hospital severity motorcycle crashes that involved run off road crashes on straights (DCA codes 701-705) and on curves (DCA codes 801-805), and head-on crashes (DCA code 201). Details of the crash data for each of the three identified candidate routes can be found in the intermediate project report in Appendix A.
  Note that a detailed investigation regarding the specific reasons of each crash was not conducted. Such an in-depth crash investigation would have required time and resources outside of the project budget.
- **Within reasonable travel distance from Brisbane**
  The PCM trial was hosted in Queensland by TMR, through their central offices in Brisbane. Therefore, to optimise logistical aspects and take advantage of their knowledge of the local areas, candidate trial locations were identified within reasonable travel distance from the Brisbane CBD.

[1] Newspaper article on Moreton Daily titled '*Safety trial launched on Mt Mee road*' [09 NOV 2021]: https://www.moretondaily.com.au/news/safety-trial-launched-on-mt-mee-road (Accessed: 10 November 2021)
[2] Facebook post reporting the media release of an ongoing safety trial being conducted on Mt. Mee: https://www.facebook.com/groups/288712888143735/posts/1624336244581386/ (Accessed: 10 November 2021)

The route selected for this trial was Mt Mee Rd, which is shown in the map in Figure 4.1. Mt Mee Rd is a semi-mountainous road located about 45 km north-west of Brisbane. It is a popular destination for recreational motorcyclists, and it is characterised by three motorcycle-related crashes, which were mainly clustered around three closely located areas along that route. Its popularity among motorcyclists was further confirmed by the presence of a Facebook group[3] specifically dedicated to share information about road and weather conditions along this route. The other two routes initially identified were excluded due to either not being on a TMR-controlled road or being characterised by a steep gradient and therefore unlikely to be representative of the majority of locations in Australia and New Zealand where the trialled PCM could potentially be used. Details of those discarded routes are provided in the intermediate project report in Appendix A.

Figure 4.1: Route selected for the trial of the PCM - Mt Mee Rd



Source: Google Maps 2022.

[3] The ‘Mt Mee and Nth Ranges Motorcycle Road Conditions’ Facebook group dedicated to sharing information on riding conditions along Mt. Mee Rd. Accessible via https://www.facebook.com/groups/288712888143735 (Accessed: 10 November 10 2021).

Identification of candidate sites

The curve selection process was undertaken by means of a desktop analysis and, when possible, by a site visit, which incorporated a motorcycle road safety audit. Note that the curve selection process was not an exhaustive effort to classify all curves along the route but, instead, was meant to identify a large enough sample of curves from which compatible treatment and control sites could be selected. Only curves which would allow safe access by a contractor in charge of installing the data collection devices were considered.

The assessment of each curve was limited to the specific direction of travel treated by the PCM (i.e., right-hand curve). The following curve-specific criteria, which relate to the individual properties of each curve, were used during the initial selection of suitable candidate sites:

- **High-risk locations** - Treatment and control curves should incorporate curves where motorcyclist lane positioning could increase the risk of a fatal or serious injury crash, such as by positioning the rider close to oncoming traffic or close to the unsealed roadside shoulder.
- **Consistency** - Motorcycle site audit outcomes should confirm that treatment and control curves are well-suited for matching.
- **Pavement condition** – It is preferred to trial PCMs on curves characterised by a road surface that is representative of average good conditions in the environment where the treatment may be installed in the future.
- **Confounding factors** - Road user behaviour at treatment and control curves should not be affected by outside influences that could bias the evaluation, such as major intersections, adjacent land use (e.g., parking, high-use properties such as schools and cafes), transition between different speed limit zones, and townships.

Note that pavement condition was included as one of the curve-specific selection criteria as it may have an effect on the riding behaviour along curves. Surface irregularities and defects, such as corrugations, deep cracks, potholes, rutting and bitumen bleeding, can induce a sense of danger in riders and therefore induce them to reduce speed or adopt a more defensive riding behaviour. Conversely, a newly laid highly smooth and regular road surface may induce riders to feel more confident and adopt an aggressive riding behaviour. Given that the scope of this project was to investigate the effect that a PCM may have on the motorcyclist’s choice of speed and trajectory when negotiating a curve, any of the two aforementioned extreme conditions of the road surface should be avoided as they may either amplify or negate the effect of the countermeasure. Therefore, it was preferred to trial PCMs on sites characterised by a road surface that is representative of average good quality in the environment where the treatment may be installed in the future.

Sixteen candidate curves that matched the selection criteria were initially identified. Details of the attributes associated with each of those curves can be found in Appendix A. Pictures of the sites are provided in Appendix C.

Pairing of treatment/control sites

The process of matching the pairs of treatment and control sites required for the trial evaluation was based on matching curve-specific criteria as well as global criteria that related to properties of the routes along which the curves reside. Note that this matching process was based on the degree of overall qualitative agreement between the curves, rather than a specific weighting towards certain specific curve attributes.

An initial compatibility assessment was undertaken based on curve-specific criteria to identify groups of curves that would be compatible for use as treatment and control sites. Treatment and control curves were matched based on their geometric properties (e.g., curve radius, grade, superelevation), speed (e.g., speed limit, curve advisory speed), line marking and signage (e.g., curve type advisory, motorcyclist specific messaging). Above all, the following two specific curve attributes were deemed vital for compatibility between paired curves:

- presence of guideposts and CAMs, which themselves act as PCMs
- curve radius, which directly affects the speed at which a curve can be traversed.

The second stage of the compatibility assessment then involved selecting those potential initially matched treatment and control curve pairs that satisfy the following global criteria:

- **Traffic volume** – Paired treatment and control curves should experience similar traffic volumes with a substantial number of motorcycles traversing the curves.
- **Neutrality** - Road user behaviour at paired treatment and control curves should not be affected by each other. An example of non-compliance to neutrality would be a selection of treatment and control curves in the same direction and close enough that motorcyclist lane positioning in the latter curve is affected by the former curve (i.e., consecutive curves forming a chicane).

The aim of this second stage of the assessment was to identify potential groups of curves that could be selected for the trial evaluation. A total of nine candidate pairs of treatment/control sites were identified. The pairs as well as the specific matching criteria for each of those identified pairs can be found in the Interim Report in Appendix A.

4.2.2 Selected Sites

A summary of the curve-specific features for the selected pairs of treated/control sites is provided in Table 4.1. The map locations of each of the trial sites are shown in Figure 4.2 and the overall geometry of the trial curves through satellite images is shown in Figure 4.3. Additionally, the road and the roadside environment from the road user perspective are presented through the photographs in Figure 4.4.

One of the driving factors for the two selected pairs of trial sites was the desire to evaluate the performance of the PCM design in two distinct environments: a tight curve characterised by relatively slow travel speeds (Pair 1) and a shallow and fast curve (Pair 2). Both these different curve environments create a risk for motorcyclists to run off road or cross the centreline. Motorcyclists may approach curves characterised with a sharp curvature too fast or negotiate them through unsuitable trajectories, which would force them to suddenly brake or attempt to abruptly correct their trajectory or a combination of both. Even in shallow and fast curves, motorcyclists are still at risk of running out of their travel lane due to a combination of high speeds and the long trajectory needed to negotiate this type of curve. Therefore, the hosting road agency for this project, TMR, expressed a specific interest to identify whether the selected PCM may be able to mitigate a potential known risk of run-off -road crashes for curves characterised by a larger radius in the trial area.

Table 4.1: Pairs of treated/control sites selected for the trial

	Site Pair #1	Site Pair #2
Curve Type	Treatment	Control
Curve Name	T_1	C_1
Latitude Longitude	-27.024167, 152.779520	-27.025766, 152.778100
Direction*	North	North
Radius**	46 m (tight curvature)	31 m (tight curvature)
Curve type	Single radius	Slight compound
Grade*#^	Downhill	Uphill
Superelevation^	Positive (moderate)	Positive (steep)
Surface quality^	Good	Good
Side road / access point	None	Driveway (L)
Road safety barrier*	None (L) None (R)	W-beam (L) None (R)
Motorcycle rub rail*	None (L) None (R)	Yes (L) None (R)

	Site Pair #1	Site Pair #2
Guideposts*	Yes (L) Yes (R)	On barrier (L) Yes (R)
CAMs	Yes (N) None (S)	Yes (N) None (S)
Edge line*	None (L) None (R)	None (L) None (R)
Centre line	Double barrier	Double barrier
Speed limit	60 km/h (moderate speed)	60 km/h (moderate speed)
Curve warning sign (northbound)	Right curve [50 km/h advisory]	Right curve tightens [30 km/h advisory]
Curve warning sign (southbound)	Left curve 40 km/h	Left curve 30 km/h
Other signs	None	Narrowing Lane

L = Left side of road (outside edge), R = Right side of road (inside edge), N = Northbound, S = Southbound

**Relative to right-hand curve direction*

** *Radius provided by TMR (Locations 1-4)*

Grade was assessed using ride/drive through video footage and Queensland Government QTopo data (http://qtopo.dnrm.qld.gov.au/Mobile/)

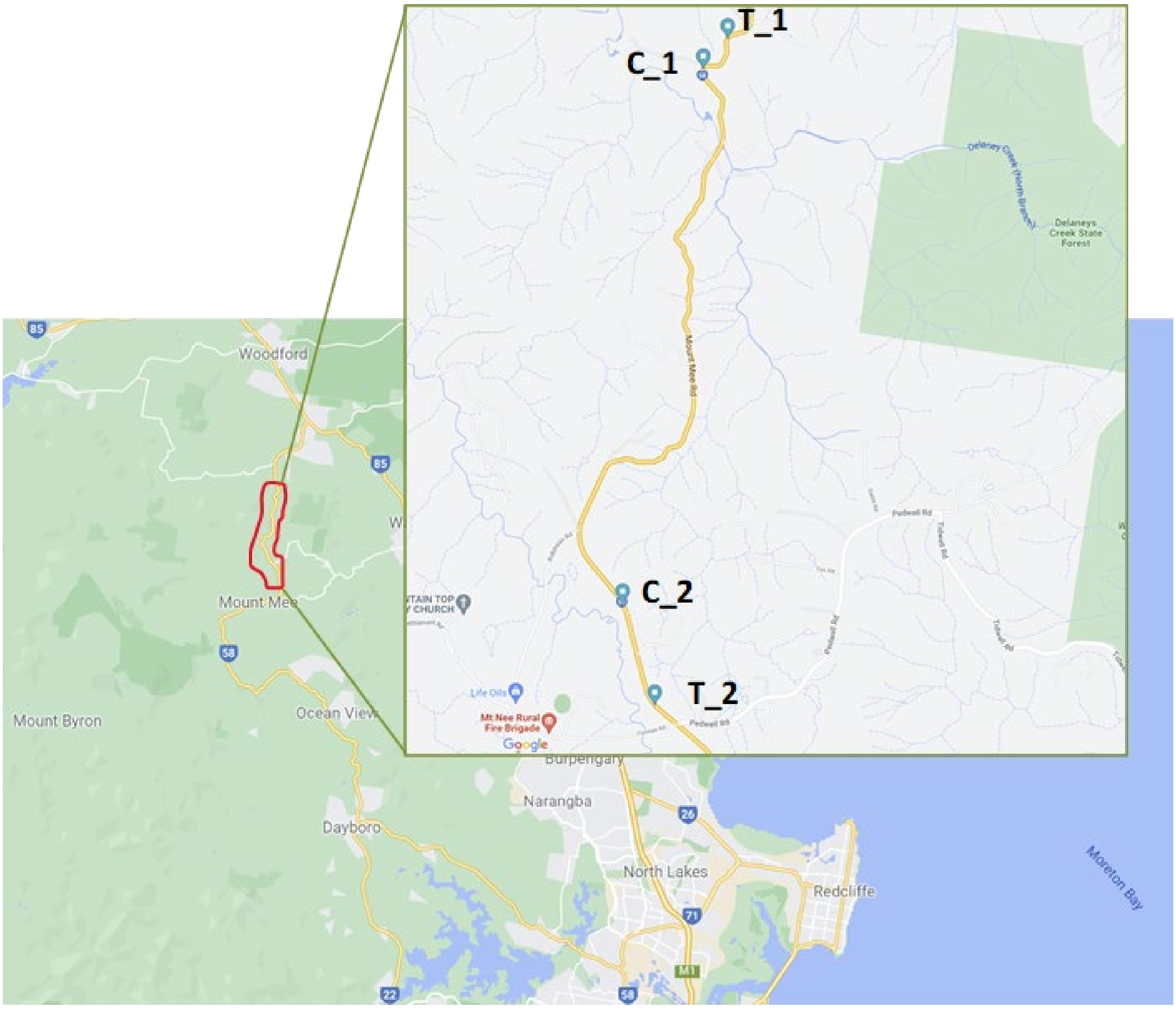
^ *Qualitative approximation*

Existing guide posts were present at many of the selected trial sites. Since guide posts in themselves can be considered as a PCM, it was necessary to control for their effect during the trial. Both selected treated sites had existing guide posts installed on the roadside in the direction of travel along of the right curve. Roadside guide posts were also present at the corresponding control sites that are matched to those treated sites. Therefore, it was possible to separate the potential effect of those delineators from the effect of the trialled PCM line marking. Similarly, the presence of CAMs at both the treatment and control curves for the site Pair 1 made it possible to control the potential effect of this existing PCM in the evaluation. Nonetheless, this control approach could not allow identification of any potential synergy between roadside guide posts and the trialled treatment (i.e., whether the treatment may become more effective when coupled with roadside guide posts compared to being installed on its own).

Note that the presence of roadside guardrails, which may occasionally have a perceptual effect on road users, could not be controlled as it was present only at one of the treatment curves (outer side of the curve at site C_1) but not at the paired control curve.

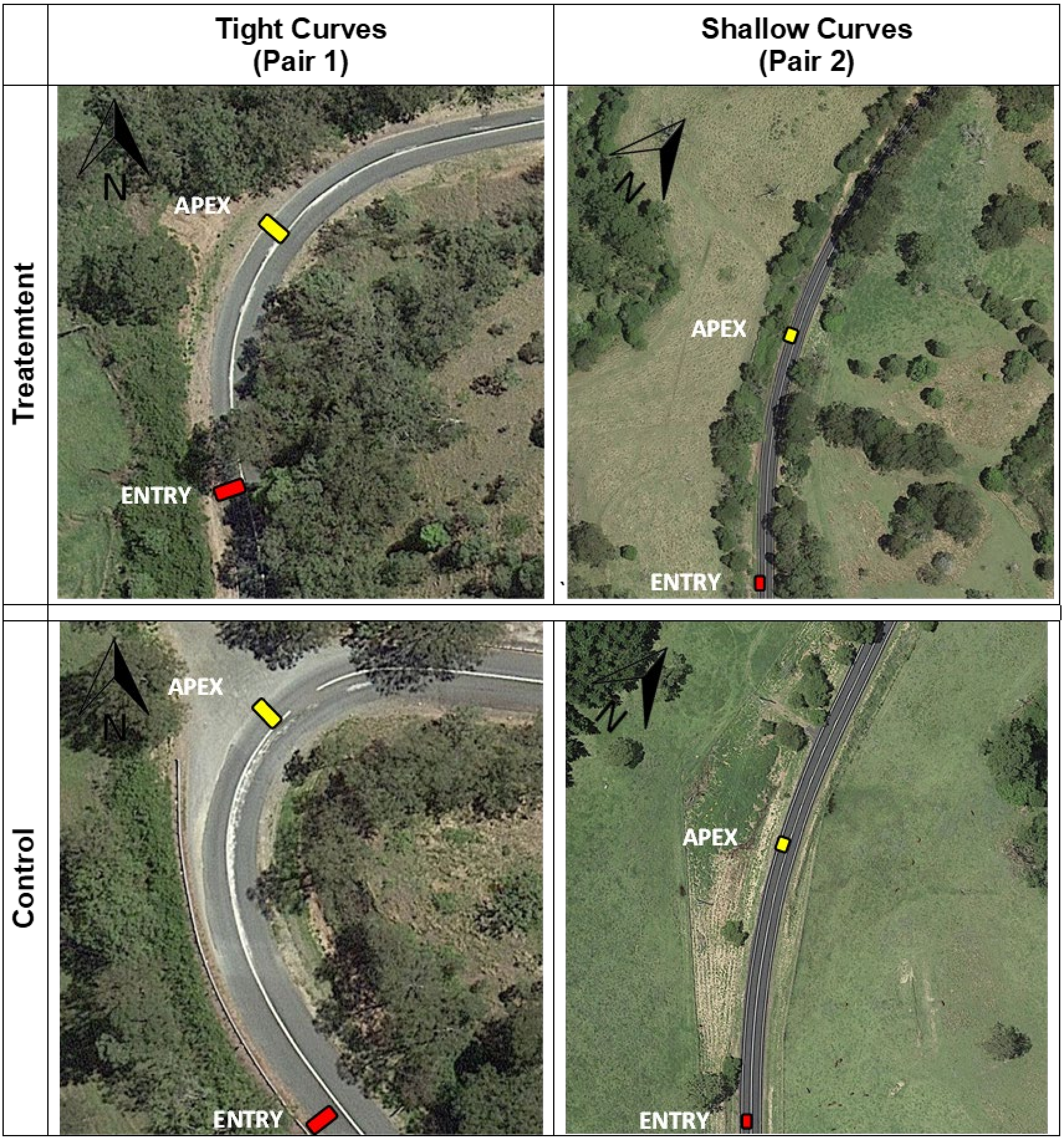
Note that the determination of the control and treatment for site Pair 1 was imposed by the fact that the two curves are sequentially one after the other and they both bend to the right-hand side along the same direction of travel. For the vehicle to pass through the control curve before travelling through the treatment curve, it was therefore necessary to assign as a control the first of the two right-hand curves in that direction of travel. The determination of the control and treatment curves for site Pair 2 could be assigned either way, given that for those two curves the right-hand curvature occurred along opposite directions of travel.

Figure 4.2: Map locations of each of the paired treatment-control trial sites



Source: Google Maps 2022.

Figure 4.3: Geometry of each of the paired treatment-control trial sites



Source: Google Maps 2022.

Figure 4.4: Road and roadside environment in each of the paired treatment-control trial sites

Source: Google Maps 2022.

4.3 Data Collection

4.3.1 Collection Periods

The time periods when data were collected before and after the treatment as well as the dates of the PCM implementation at each treated curve are presented in Table 4.2. The selected periods were chosen to enable the trial to be conducted under the following general conditions:

- normal traffic (i.e., no traffic disruption due to presence of work zones or temporary traffic restrictions, outside of extended holiday periods including school holidays, no travel restrictions due to Covid-19)
- outside of the wet season.

Data were collected over a period longer than the target evaluation interval both before and after the treatment installation in order to allow for a safety margin in case of issues (e.g., weather events) arising during those collection periods. Note that the post-treatment data collection commenced just over two weeks after the implementation of the PCM at the two treatment sites. A longer habituation period of four weeks was initially planned. However, a series of logistical and technical issues delayed the pre-treatment data collection and required its further extension, thus imposing the need for a shorter habituation period to avoid conducting the post-treatment data collection too far into the wet season. Nonetheless, two weeks of habituation were deemed sufficient to allow motorists to familiarise themselves with the implemented PCM treatment. Therefore, the provided habituation period should ensure with a good level of confidence that results of this trial are representative of the effect of the treatment in the medium to long term.

Table 4.2: Trial data collection periods and date of treatment implementation

Before(1)		PCM Installation dates	After(2)	
Start	**End**		**Start**	**End**
28/08/2021	24/09/2021	26/10/2021 [T_1] 27/10/2021 [T_2]	12/11/2021	09/12/2021

(1) *Video footage lost at site C_1 due to vandalism to one of the video cameras [28/08/2021 – 09/09/2021]*
(2) *Video footage lost at site T_2 due to technical issues at different dates/locations*

4.3.2 Measurements

Three major types of data were measured during the trial: (i) vehicle classification and (ii) lane position (for motorcycles only), and (iii) travel speed. A summary of the curve positions where each measurement was taken as well as the measurement units is provided in Table 4.3. Two separate and independent types of devices were used to collect the data used for this analysis. Radar-based devices measured the vehicle travel speed and video cameras recorded vehicles driving through the curves, allowing determination of position in the lane. Note that the video cameras were present on-site only during the pre-treatment and post-treatment survey periods (i.e., they were removed at the end of the before survey and then re-installed at the beginning of the after period). Nonetheless, the supporting poles as well as the solar panels and the radar were left on-site throughout the entire duration of the trial.

Table 4.3: Summary of the measurements taken at each site during the trial

	Speed	Vehicle Classification	Lane Position
Curve Location	Apex	Apex	Apex/Entry
Vehicle Types	Any	Any	Motorcycles ONLY
Travel Direction	Any	Any	Right bend ONLY
Units	km/h	• Motorcycles – Cruisers – Tourism/Enduro – Sport bikes • Light vehicles (1) • Heavy vehicles	In lane: 1 to 6 (see schematics below) Out of lane: 7 (crossed centre line)

(1) *Light vehicles include cars (e.g., sedans, station wagons, SUVs, 4WDs), small utility vehicles and small people movers*

Both vehicle classification and motorcycle lane position were measured through a manual analysis of the video footage collected using video cameras strategically installed on the roadside at each of the control and treatment sites. Two separate cameras were used to monitor the traffic at either the entry or the apex of each of the four curves involved in this trial, both before and after the installation of the PCM treatment.

All motor vehicles were classified along either travel direction. Motorcycles were classified based on the following three specific subcategories: cruisers, tourism/enduro, sport bikes. The remaining motor vehicles were grouped in two broad categories: heavy vehicles or light vehicles. Light vehicles included Austroads vehicle classes 1 and 2, while heavy vehicles included Austroads vehicle classes 3 to 12.

Given the specific focus of the trialled treatment on motorcyclists who are negotiating right-hand curves, lane position was measured only for motorcycles that were travelling along the right bend of the curves. Lane position, which was measured both at the entry and the apex of those curves, was based on the location of the motorcycle wheels on a virtual grid of six equally spaced segments across the lane. Those segments were sequentially numbered from 1 to 6, with the first segment starting from the edge of the road and the last segment on the centreline. A separate score equal to 7 was assigned to those motorcycles which crossed the centreline. An example of the application of this reference grid to measure the lane position at the apex of one of the trial curves is shown in Figure 4.5.

As previously mentioned, the main focus of the trialled PCM is to prevent voluntary lane crossing when negotiating right-hand bends, which starts with entering the curve tight at then culminates in crossing the centreline when reaching in proximity of the apex. Due to limited resources, only two locations along each trial curve could be monitored. Given the mechanism mentioned above, the entry and the apex locations were therefore chosen. Note that motorcyclists running wide on right bends would run off road when leaving the curve (as opposite to running towards or crossing the centreline for left-hand bends). Although lane position at the exit of the curve was not monitored, the observed motorcycle shift at the apex yet provided some indirect confidence whether motorcyclists were eventually leaving the curve tight as opposed to wide.

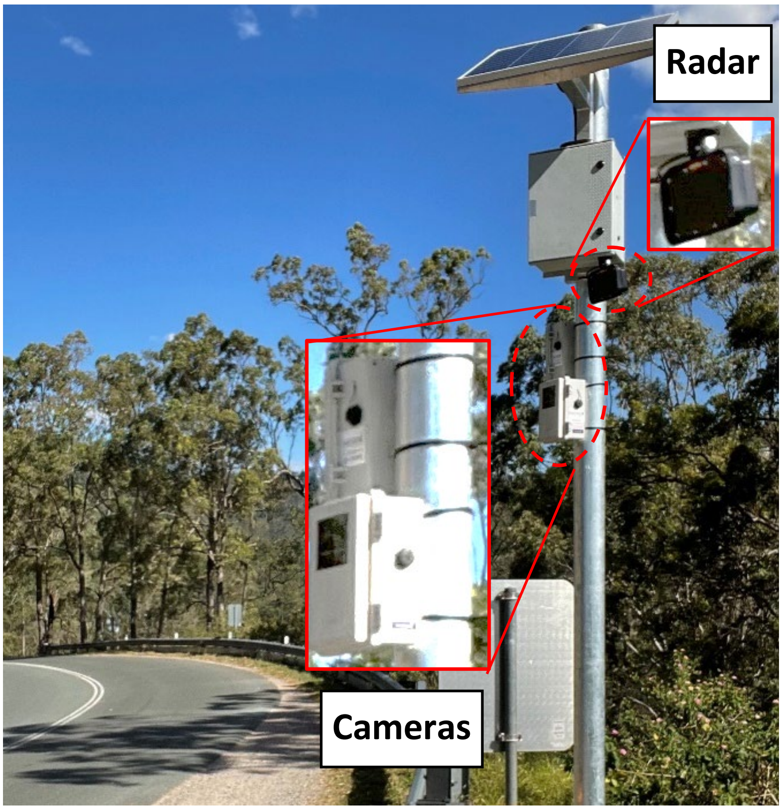
The analysis of all the video footage was performed by professional video analysts under contract with Matrix Traffic and Transport Data, an ISO 9001-certified contractor specialised in collecting and analysing video footage for traffic surveying. The quality of the video analysis was verified through a randomised comparison between the reported results and the provided video footage. For some of the days that were included in this evaluation, three motorcycle detections from the video analysis were randomly selected and compared against an independent re-assessment performed by one of the researchers. To maximise repeatability throughout all the assessments, this validation activity was entirely performed by the same researcher.
The radar devices used to measure the speed of vehicles when travelling at the apex of the right-hand curves were installed and operated by SAGE Automation, a professional technology company specialised in the use of this type of sensor for traffic-related and safety applications. The radar sensor implemented by SAGE was an AGD 318 (AGD, 2022), which is a professional traffic radar that was developed starting from enforcement-grade technology. This radar sensor is certified to have a maximum speed tolerance of ±0.3 km/h.

Figure 4.5: Example of reference grid used for measuring the motorcycle lane position at the apex of the trial sites (Site C_1)

The travel speed was measured when vehicles were transiting through the apex of the curve. Radar-based equipment specifically assembled for this purpose was installed on top of poles placed on the roadside at each of the four trial curves. To properly track vehicles negotiating a curved trajectory, the setup of the radar sensor had to be optimised for one of the two travel directions. Given that the trialled treatment was specifically focused on right-hand curves, the radar sensor was then optimised to measure the speed of vehicles when negotiating the curve on the right-hand travel direction. Depending on the availability of space along the roadside, the equipment was located either upstream or downstream of the curve apex along the target travel direction (i.e., vehicles along the target travel direction were either receding or approaching the radar unit). Additionally, site-specific adjustments were made to the settings of the radar units installed at each of the trial curve, including optimising the sensitivity of the radar sensor to improve the detection of narrow vehicles such as motorcycles.

An example of the installed roadside radar devices and the video camera is provided in Figure 4.6. Each radar device was mounted on top of a dedicated pole which was temporarily installed on the roadside. The video camera devices were also mounted on the same pole at most of the sites, with the exception of two cameras, which had to be mounted on a tree and an existing sign pole on the roadside. Both radar and video devices were operated with batteries. Each video camera had an interchangeable battery, which was regularly replaced to guarantee a continuous collection of data during the trial. The pole-mounted radar devices used a high-capacity battery, which was automatically recharged through a dedicated solar panel attached on top of the device. Details of the locations of each radar device and video camera are provided in Appendix D.

Figure 4.6: Example of the radar device and video cameras installed along the roadside at a trial site



Note that the timestamps of events either detected by the radar devices or manually identified through the video analysis were within an unavoidable level of tolerance. This was due to factors such as minor offsets between the clock of the radar and the camera devices as well as potential differences in the exact position where vehicles were identified by the radar or reported in the manual video analysis. It was therefore necessary to synchronise the timestamp of each radar detection to the corresponding event captured by the video cameras. This process involved an initial manual identification of the time gap between the clock of each camera at the apex and the corresponding radar device at sampled points in time at the beginning, middle and end of each collection period. A linear function of the evolution of this time gap through the collection period was then created and used to convert the radar timestamps to the clock of the corresponding video camera at the apex.

Table 4.4: Proportion of radar matches against the identified video events

	Before		After	
	Treatment	Control	Treatment	Control
Tight Curves (Pair 1)	97.3%	87.9%	91.3%	81.3%
Shallow Curves (Pair 2)	99.3%	99.6%	72.3%	58.8%

The proportion of video events for which a radar match could be identified is summarised in Table 4.4 for each trial site and period of the data collection. Generally, radar match ratios were above 80%. However, lower radar match ratios occurred for data collected during the post-treatment period at the pair of shallow curves (treatment site: 72.3%; control site: 58.8%). In those instances for which a radar match could not be found, the reason was a failure of the radar device to detect the vehicle or a larger than usual tolerance between the reported radar and video events, or a combination of both. Additionally, the radar devices occasionally failed to track all the vehicles travelling in a platoon of units that closely followed each other. This occurred especially in the case of a group of closely following motorcycles. Nonetheless, the missed speed measurements for those following motorcycles would not affect the investigation conducted in this study as only the leading motorcycle was considered in the evaluation and the remaining motorcyclists could not be considered to be travelling at a free speed.

4.3.3 Analysed Periods

The availability of video footage was a condition necessary to proceed with the evaluation, as motorcycles were identified through an analysis of the video footage. For some intervals during the data collection period, video footage could not be collected due to either technical issues (e.g., discharged battery, memory reaching capacity, condensation) or acts of vandalism. Therefore, for those days when video footage was not available at one or both monitored curve locations (i.e., entry or apex) no analysis could be carried out at the corresponding locations with missing footage. Nonetheless, the analysis was still carried out at the other monitored location for that curve whenever footage was available for that location.

Additionally, the availability of video footage at the paired control curve was a condition necessary to include the corresponding treatment curve in the analysis. Therefore, if footage was missing at the entry or the apex of the control site for a day, then that day was excluded in the analysis as it was not be possible to have a control for that period. Also in this case, if footage was available at only one of the two monitored curve locations at both the paired treatment and control curves then the analysis still included that location while excluding the other monitored location.

4.4 Implemented PCM

The appearance of the implemented PCM design at each of the two designated trial treatment curves is shown in Figures 4.7 and 4.8. The pictures provide an indication of how the implemented treatment looked both at daytime and night-time. However, note that the evaluation of the treatment effectiveness was limited to daytime only in this trial. Technical details on how the treatment was implemented and suggestions for streamlining future implementations are provided in Appendix E.

Note that the PCM was implemented only at the specific treatment sites as opposed to being implemented on a series of sequential curves. Extending the treatment implementation to curves immediately upstream of a designated treated site could have acted as pre-warning as well as allowing riders to familiarise themselves with the treatment but it was preferred to limit its implementation to the critical trial curve based on the following motivations:

- **Treatment-control interference** - At one of the trial paired sites, the control curve was located immediately upstream of the designated treated curve, therefore making an extension of the upstream treatment not practically feasible due to an unavoidable interference between the treatment and control curves.

- **Expected application** - If the trialled treatment proves effective, it is likely that road authorities would limit its implementation only to those specific curves that are deemed to be dangerous; thus, it was important that the treatment was trialled under this probable implementation condition.
- **Expected compliance** - Automatically extending the PCM treatment upstream of the critical target curve would likely result in its additional application to non-critical curves for which the treatment is not needed. This would potentially decrease motorcyclists' overall compliance with, and trust in, the treatment in the medium to long term, as they may perceive it is as irritating at non-critical treated curves and therefore generalise such perception to any treated site.

Water-based paint was used for the line marking implemented in this trial. The choice of this type of paint was based on a trade-off between TMR's preference for a trial implementation and friction performance. The rationale for the adoption of water-based paint is that it would be easier to be removed at the end of the trial if TMR decided to do so. Potentially, a longer lasting type of paint would be an ideal solution in the future if this type of marking if proven successful during the trial. As for friction performance, although water-based paint is expected to cause some reduction in the micro friction (i.e., the friction due to the surface of each grain), the macro friction (i.e., the friction due to the gaps between the grains) should remain unaffected by the application of this type of paint. As the reduction of friction is limited to the micro friction, motorcyclists are expected to travel safely over the painted area under normal conditions, although they may experience some instability under extreme riding conditions (i.e., racing style behaviour). Indeed, a perceived impression of a friction reduction on the painted areas, albeit still safe to ride over, could provide additional motivation for motorcyclists to follow the trajectory that is implicitly suggested by the treatment as well as act as a deterrent for extreme riding behaviour. Additionally, a marginal reduction of friction caused by water-based paint is not expected to create relevant safety issues to cyclists.

Figure 4.7: Peripheral line marking PCM implemented at the treated curve T_1 – Daytime and night-time appearance

Figure 4.8: Peripheral line marking PCM implemented at the treated curve T_2 – Daytime and night-time appearance

	Day	Night
Entry		
Apex		

5. Results

This chapter presents the results of the before-after analysis on motorcycle speed and lane positions that were measured at each of the trial curves.

In general, the travel speed of motorcycles through the apex of both treated curves tended to decrease after the PCM was implemented. After adjusting for the change at the paired control sites, the mean travel speed of motorcycles decreased by 1.8 km/h at the tight curve and 3.3 km/h at the shallow curve (similarly also for the 85thpercentile speed). Nonetheless, an exception to this trend was observed for sports motorcycles at the tight curve where a slight increase in travel speed was observed after the treatment installation. Additionally, moderate reduction in travel speed after the PCM installation was also found for light and heavy vehicles.

When travelling through the apex of each treated curve, motorcyclists tended to position themselves farther away from the centreline compared to before the treatment. The proportion of motorcyclists travelling within the most left 2/3 of the lane at the treated tight curve increased from 6.8% (pre-treatment) to 46.6% (post-treatment), and from 27.5% to 51.3% at the treated shallow curve. Most importantly, the proportion of motorcyclists riding within 600 mm of the centreline at the apex of the treated tight curve decreased from 55.3% before the treatment to 4.5% after the implementation of the PCM, and from 29.1% to 6.2% at the treated shallow curve. As changes in lane positioning at each paired control site were either negligible or marginal, the changes observed at the corresponding treatment sites could be associated with the installation of the PCM treatment with a reasonable level of confidence.

5.1 Vehicle detections

The matrix in Figure 5.1 provides a summary of the days which were included in the analysis of each pair of the treated/control trial sites, as indicated in the columns titled as *Included*. In general, a total of 20 days were analysed during both the pre-treatment and post-treatment periods. However, the pre-treatment analysis for the pair of tight curves had to be limited to 14 days.

Figure 5.1: Analysed pre-treatment and post-treatment periods for each pair of trial sites

BEFORE

	Tight Curves (Pair #1) T Entry	T Apex	C Entry	C Apex	Analysed?	Shallow Curves (Pair #2) T Entry	T Apex	C Entry	C Apex	Analysed?
Sat-28/08/21					N					N
Sun-29/08/21					N					N
Mon-30/08/21					N					N
Tue-31/08/21					N					N
Wed-01/09/21					N					N
Thu-02/09/21					N					N
Fri-03/09/21					N					N
Sat-04/09/21					N					N
Sun-05/09/21					N					Y
Mon-06/09/21					N					Y
Tue-07/09/21					N					Y
Wed-08/09/21					N					Y
Thu-09/09/21					N					Y
Fri-10/09/21					Y					Y
Sat-11/09/21					Y					Y
Sun-12/09/21					Y					Y
Mon-13/09/21					N					Y
Tue-14/09/21					Y					Y
Wed-15/09/21					Y					Y
Thu-16/09/21					Y					Y
Fri-17/09/21					Y					Y
Sat-18/09/21					Y					Y
Sun-19/09/21					Y					Y
Mon-20/09/21					Y					Y
Tue-21/09/21					Y					Y
Wed-22/09/21					Y					Y
Thu-23/09/21					Y					Y
Fri-24/09/21					Y					Y
No. days analysed					**14**					**20**

AFTER

	Tight Curves (Pair #1) T Entry	T Apex	C Entry	C Apex	Analysed?	Shallow Curves (Pair #2) T Entry	T Apex	C Entry	C Apex	Analysed?
Fri-12/11/21					Y					Y
Sat-13/11/21					Y					Y
Sun-14/11/21					Y					Y
Mon-15/11/21					N					N
Tue-16/11/21					N					N
Wed-17/11/21					N					N
Thu-18/11/21					Y					N
Fri-19/11/21					Y					Y
Sat-20/11/21					Y					Y
Sun-21/11/21					Y					Y
Mon-22/11/21					N					N
Tue-23/11/21					N					N
Wed-24/11/21					N					N
Thu-25/11/21					N					N
Fri-26/11/21					Y					Y
Sat-27/11/21					Y					Y
Sun-28/11/21					Y					Y
Mon-29/11/21					Y					Y
Tue-30/11/21					N					Y
Wed-01/12/21					Y					Y
Thu-02/12/21					Y					Y
Fri-03/12/21					Y					Y
Sat-04/12/21					Y					Y
Sun-05/12/21					Y					Y
Mon-06/12/21					Y					Y
Tue-07/12/21					Y					Y
Wed-08/12/21					Y					Y
Thu-09/12/21					Y					Y
No. days analysed					**20**					**20**

LEGEND

- Video available (full day)
- Video available but NOT at Control
- Video available (part of day)
- Video NOT available

Dates in bold indicate weekends (Saturday/Sunday)

Table 5.1 provides a broad classification of all the vehicles initially detected along the direction of the right-hand curve through the video analysis of the selected trial intervals as well as the group of vehicles which were eventually included in the analysis upon matching the trial selection criteria (dry road surface, free-flowing motion, and no oncoming traffic). Note that only a portion of all the vehicles that were initially detected through the video analysis could be included in the analysis. A more detailed classification of motorcycles into the three major subcategories considered in this analysis is also provided in that table.

Additionally, the plots in Figure 5.2 provide a visual summary of the proportions for each of the major types of detected vehicle that were included in the analysis for the pre-treatment and post-treatment periods. A more detailed classification of the detected motorcycles into the three major subcategories that were used in the analysis is also provided in the same figure. The pre-treatment and post-treatment distributions by each day of the week of those detected motorcycles that were included in the analysis are shown in Figure 5.3 for each of the trial sites.

Table 5.1: Classification of vehicles travelling along the right-hand direction at each trial site - All detected vehicles and vehicles matching the analysis criteria

	Motorcycle Categories	Treatment				Control			
		ALL Detected vehicles		Vehicles matching filter criteria*		ALL Detected vehicles		Vehicles matching filter criteria*	
		Before	After	Before	After	Before	After	Before	After
Tight Curves (Pair #1)	**All Motorcycles**	1,741	2,259	756	912	1,626	2,163	711	934
	• Cruiser	364	438	156	188	373	420	145	175
	• Touring	1,084	1,591	462	623	1,005	1,434	446	605
	• Sports	293	230	138	101	248	309	120	154
	Light Vehicles	5,343	7,553	3,599	4,498	5,267	7,463	3,559	4,868
	Heavy Vehicles	294	417	241	288	315	423	245	302
Shallow Curves (Pair #2)	**All Motorcycles**	1,438	1,934	852	992	991	1,731	651	871
	• Cruiser	316	399	173	195	194	333	140	163
	• Touring	926	1,362	552	704	695	1,212	450	603
	• Sports	196	173	127	93	102	186	61	105
	Light Vehicles	3,905	5,007	3,210	3,482	3,800	5,284	3,134	3,435
	Heavy Vehicles	262	285	230	199	257	295	225	192

**** Filter conditions***
a) Free flowing
b) Free oncoming lane (no oncoming vehicles)
c) Dry surface

Figure 5.2: Classification of the detected vehicles (events meeting analysis conditions)

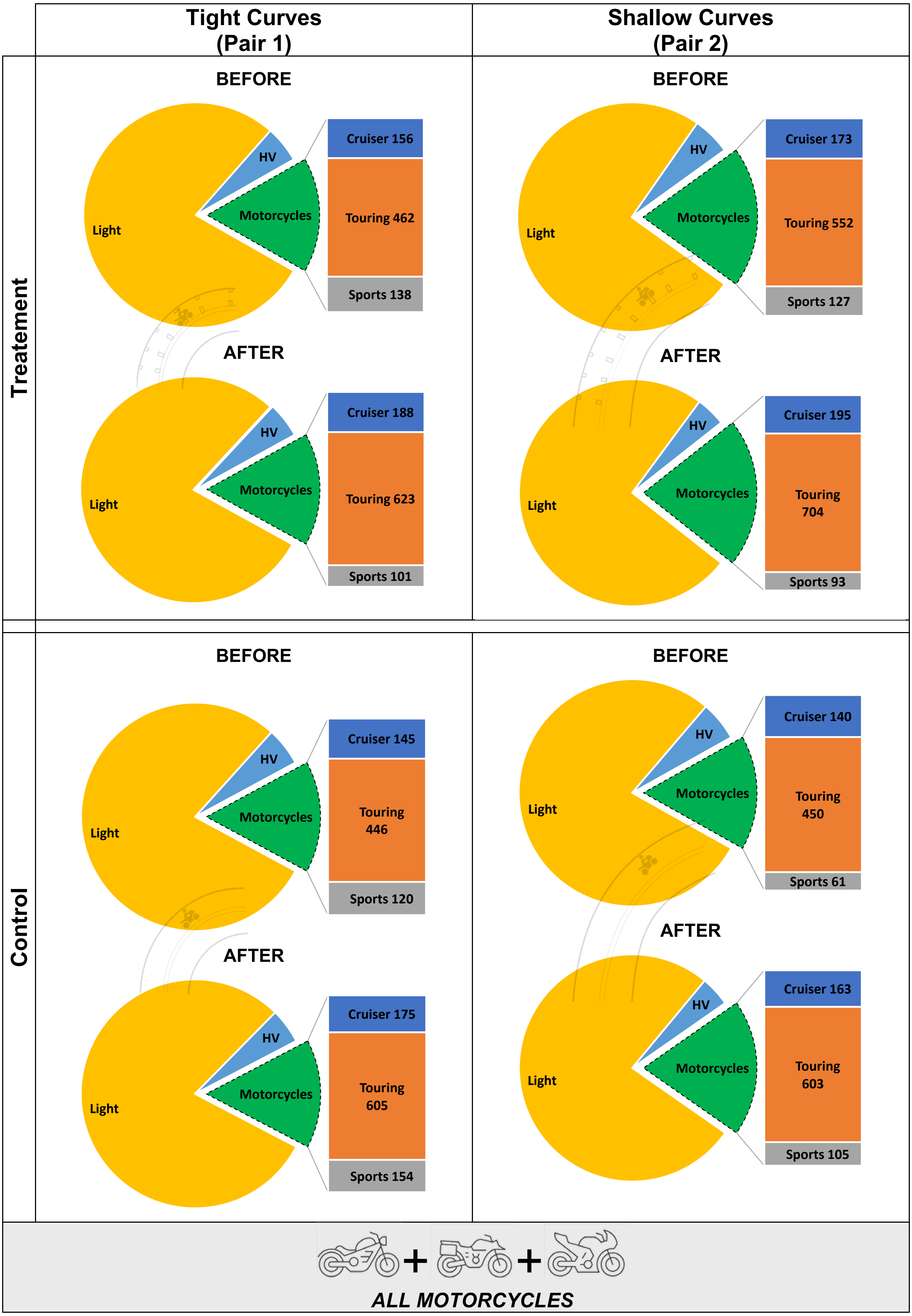
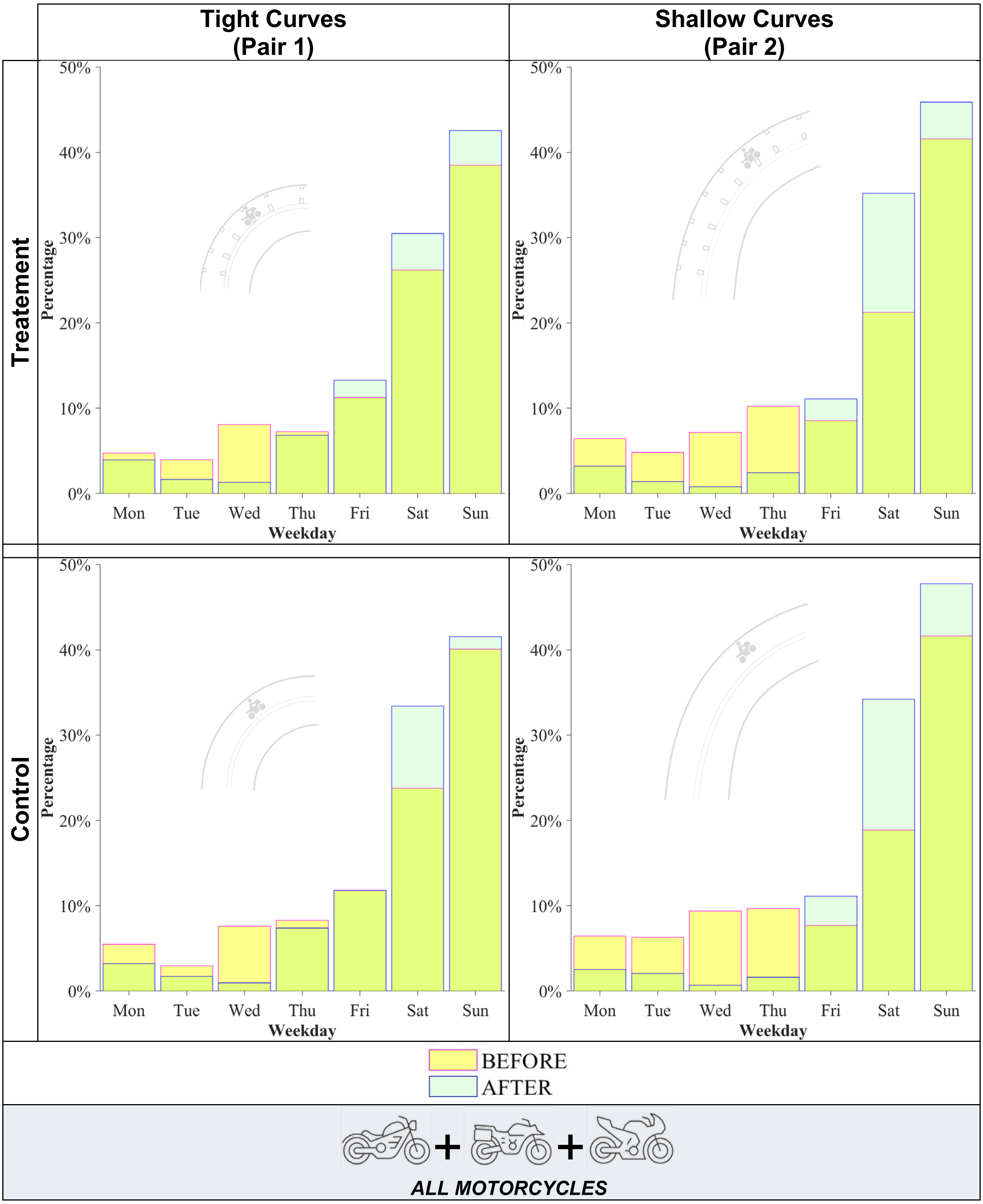


Figure 5.3: Distribution of detected motorcycles by each day of the week (events meeting analysis conditions)



5.2 Speed

5.2.1 Distribution

The speed distributions of the detected motorcycles at each of the four trial curves are shown in Figure 5.4. A breakdown of the distributions into each of the three major categories of motorcycles for the tight and shallow trial curves are shown in Figures 5.5 and 5.6, respectively. Additionally, plots of the distributions of the travel speed for light vehicles and heavy vehicles are provided in Appendix F. In each plot, separate and overlapping histograms indicate the distribution of vehicle speeds before and after the PCM installation. This allows for an intuitive visual comparison of changes in travel speed between the before and after periods at each of the trial sites.

Figure 5.4: Distribution of travel speed at the apex of the right-hand curve in each trial site - All motorcycles

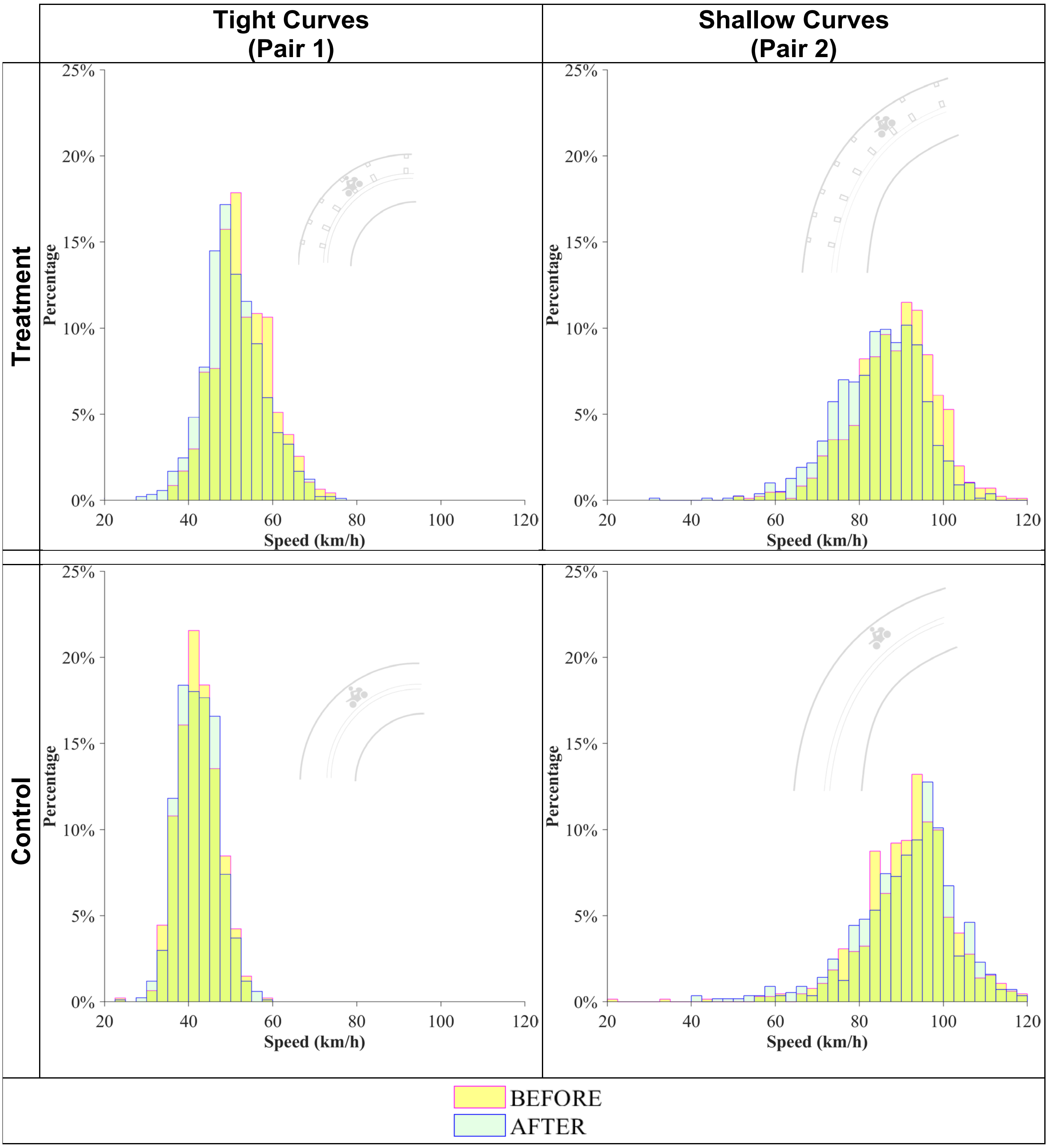


Figure 5.5: Distribution of travel speed at the apex of the right-hand tight curves (Site Pair 1) – Breakdown by major motorcycle categories

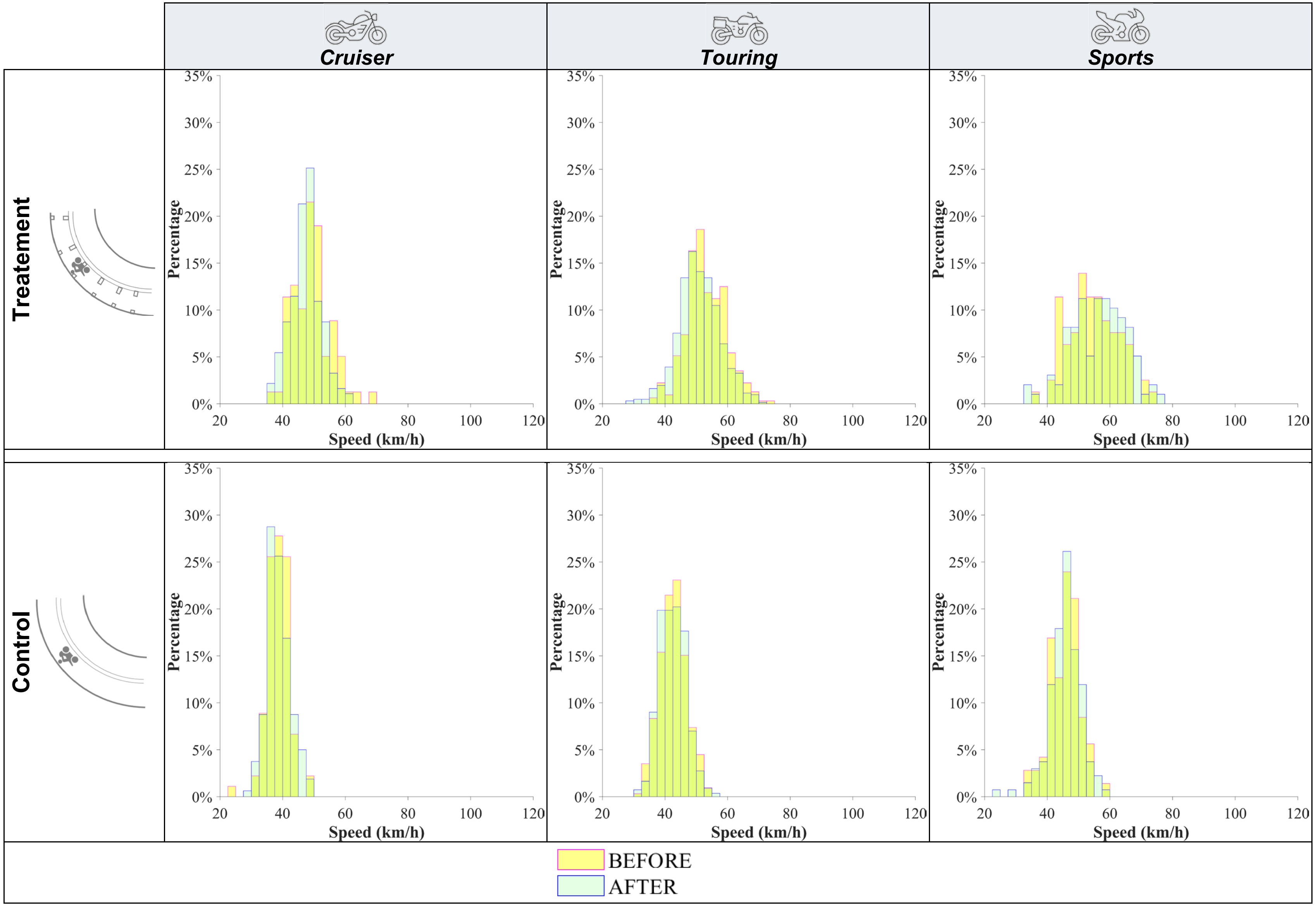
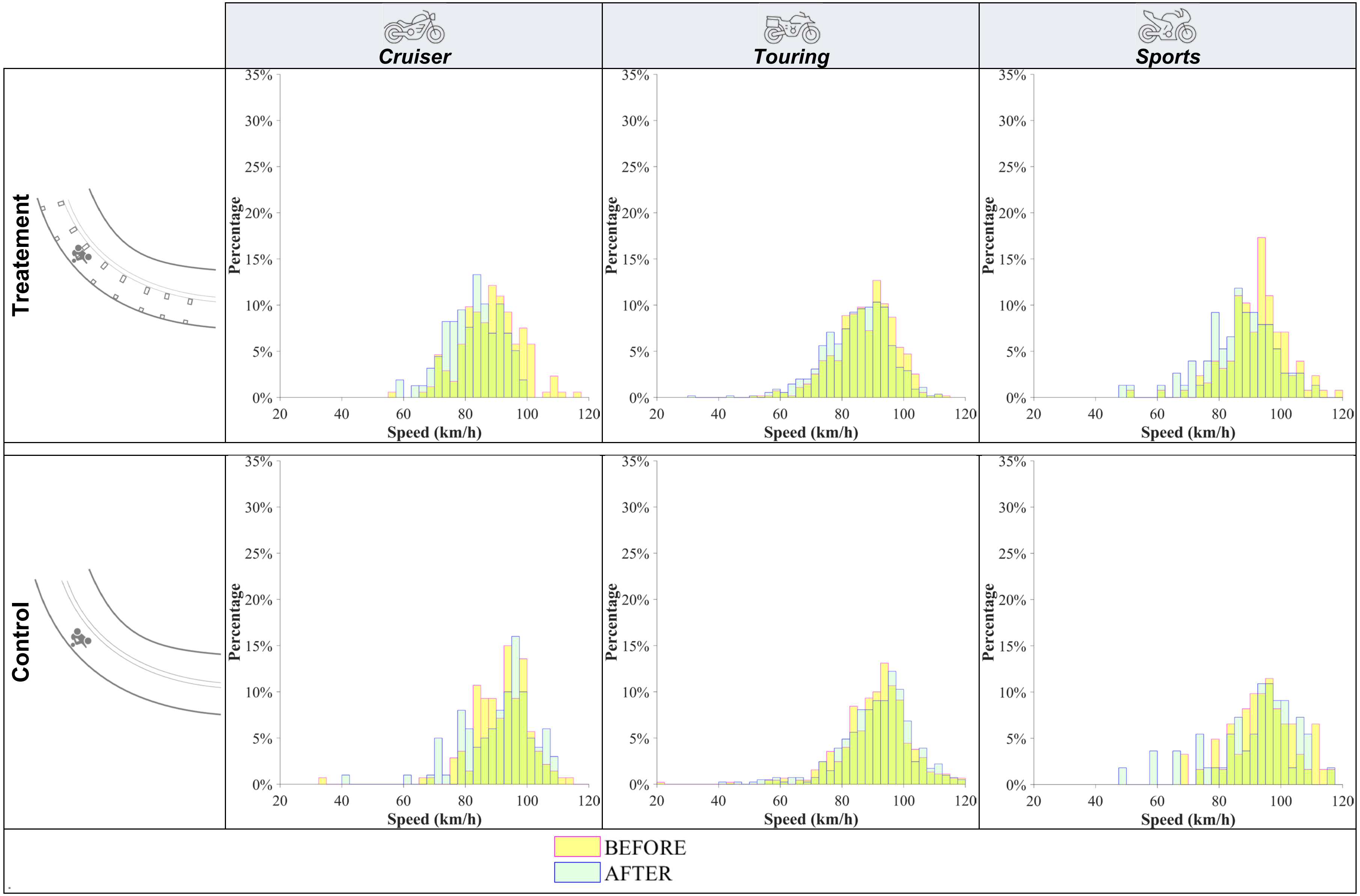


Figure 5.6: Distribution of travel speed at the apex of the right-hand shallow curves (Site Pair 2) – Breakdown by major motorcycle categories



5.2.2 Descriptive Statistics

A summary of the mean and the 85thpercentile travel speeds of all the detected vehicle types at the apex of each trial curve is presented in Tables 5.2 and 5.3, respectively. Speed values and their corresponding before-after variation are provided for all the detected motorcycles as well as for their breakdown in the three major categories used to classify them in this study. Additionally, travel speeds for light and heavy vehicles are also presented in the tables. The controlled before-after variation, which discounts the variation measured at the treatment site by the corresponding variation at the matched control site, provides an indication of the actual effect expected to be caused by the installed PCM treatment for each of the detected vehicle types.

Generally, both the mean and 85thpercentile motorcycle travel speeds at the apex tended to decrease marginally at each of the two treated curves. When considering all the detected motorcycles, the mean speed and shallow curves reduced by 1.8 km/h at the at the tight treated curve and 3.8 km/h at the shallow treated curve; and similarly, the 85thpercentile speed at the tight and shallow curves reduced by 1.2 km/h and 3.5 km/h, respectively. Such trend was also observed for any of the specific motorcycle categories except for sport motorcycles at the tight curve (i.e., Site T_1), where the travel speed at the apex slightly increased after the treatment was installed. Conversely, travel speeds at the control sites tended to remain unchanged or slightly increased for most of the motorcycle categories with the only exception of sports motorcycles, for which the mean travel speed increased in the after period at the apex of the tight control curve. Generally, this different trend in the before-after variation of the travel speed at the treatment and paired control sites effectively resulted in a decrease of speed due to the treatment after accounting for the control (i.e., negative values of the ‘controlled variation’).

In general, a moderate reduction in the controlled mean travel speed was also found for both light and heavy vehicles after the PCM installation. However, after the PCM installation a slight increase in the controlled 85thpercentile speed was observed for heavy vehicles travelling at the apex of the shallow curves.

Table 5.2: Mean motorcycle travel speed at the apex of each trial curve

	Motorcycle Categories	Treatment			Control			Controlled Variation
		Before	After	Variation	Before	After	Variation	
Tight Curve (Pair #1)	**All Motorcycles**	52.6	50.8	-1.8	42.1	42.2	0.0	-1.8
	• Cruiser	49.1	47.4	-1.8	38.4	38.6	0.2	-2.0
	• Touring	53.0	50.9	-2.1	42.4	42.4	0.0	-2.1
	• Sports	54.2	56.4	2.3	45.6	45.6	0.0	2.3
	Light Vehicles	47.3	45.7	-1.6	37.4	37.1	-0.3	-1.3
	Heavy Vehicles	45.2	41.5	-3.7	35.8	35.0	-0.8	-2.9
Shallow Curve (Pair #2)	**All Motorcycles**	88.4	84.6	-3.8	91.9	91.4	-0.5	-3.3
	• Cruiser	88.2	82.6	-5.5	92.2	90.9	-1.3	-4.2
	• Touring	87.5	84.8	-2.7	91.3	91.5	0.2	-2.9
	• Sports	92.5	87.0	-5.5	95.8	91.6	-4.2	-1.2
	Light Vehicles	81.1	80.4	-0.7	84.5	85.3	0.9	-1.5
	Heavy Vehicles	76.3	75.0	-1.3	81.0	80.0	-1.0	-0.3

Table 5.3: 85th percentile motorcycle travel speed at the apex of each trial curve

	Motorcycle Categories	Treatment			Control			Controlled Variation
		Before	After	Variation	Before	After	Variation	
Tight Curves (Pair #1)	**All Motorcycles**	59.5	58.3	-1.2	47.3	47.1	-0.2	-1.0
	• Cruiser	55.3	52.4	-2.9	41.7	42.6	0.8	-3.7
	• Touring	59.6	57.8	-1.8	47.0	46.9	-0.1	-1.7
	• Sports	63.4	65.5	2.1	50.0	50.4	0.4	1.7
	Light Vehicles	51.9	50.4	-1.5	41.1	40.8	-0.3	-1.2
	Heavy Vehicles	49.8	45.8	-4.0	39.1	37.8	-1.3	-2.7
Shallow Curves (Pair #2)	**All Motorcycles**	97.9	92.3	-3.5	100.0	102.0	1.0	-4.5
	• Cruiser	97.0	94.6	-5.6	101.0	102.0	2.0	-7.6
	• Touring	101.0	97.9	-2.4	106.4	105.0	1.0	-3.4
	• Sports	90.8	90.1	-3.1	94.3	95.2	-1.4	-1.7
	Light Vehicles	87.7	86.7	-0.7	91.6	88.3	0.9	-1.6
	Heavy Vehicles	97.9	92.3	-1.0	100.0	102.0	-3.3	2.3

Additionally, a visual and concise summary of the statistical metrics used to quantify the travel speed of motorcycles at the apex is provided in the plots of Figures 5.7 through 5.10. A combination of box plots and line charts was used. Box plots provide a visual indication of the quartiles (25th, 50th and 75th percentiles) as well as the value of the minimum, maximum and the outliers for each distribution. The box horizontal edges indicate the quartiles, the extremes of the whiskers indicate the minimum and maximum values, and the 'plus' symbols indicate the outliers. Two separate line plots are also overlayed on the box plots to provide a visual representation of the mean and the 85th percentile of the speed distribution, respectively. A side-by-side arrangement of the plots before and after the PCM installation allows to intuitively visualise how vehicle travel speed changed after the treatment was implemented.

Figure 5.7: Boxplots of travel speeds at the apex of the right-hand curve in each trial site (including trendlines of mean and 85th percentile values) - All motorcycles

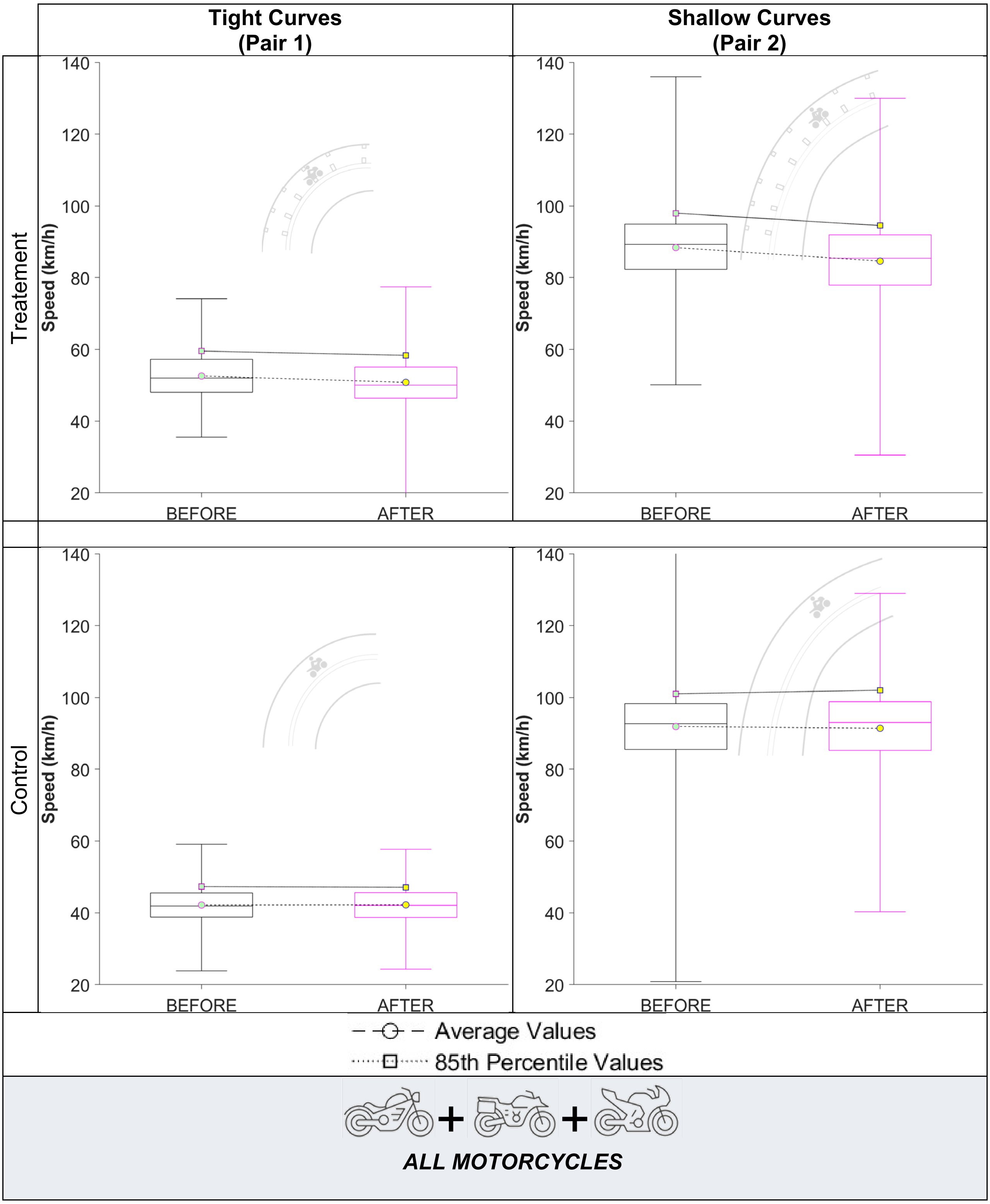


Figure 5.8: Boxplots of the travel speeds at the apex of the right-hand curve in each trial site (including trendlines of mean and 85th percentile values) – Cruiser motorcycles only

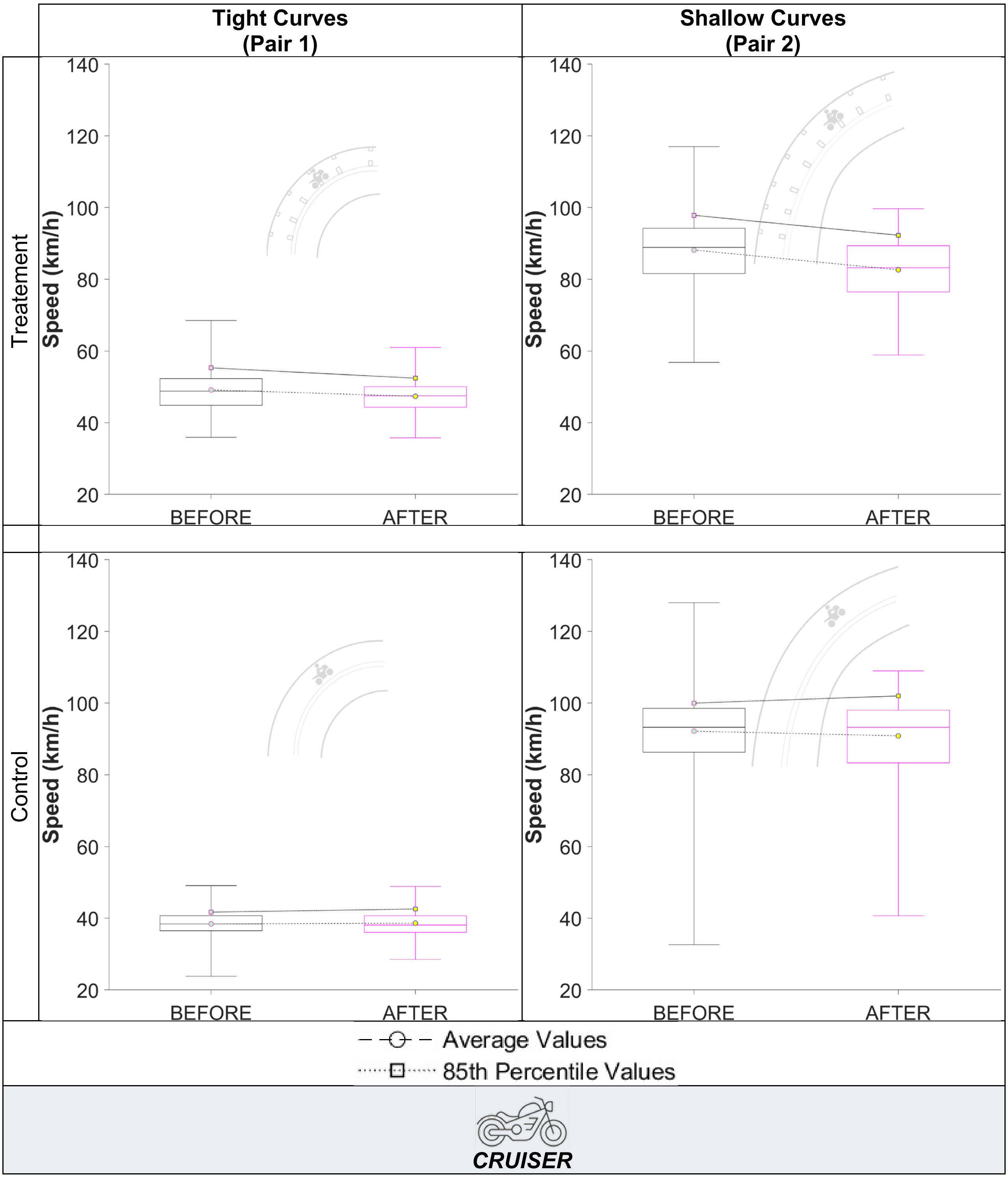


Figure 5.9: Boxplots of the travel speeds at the apex of the right-hand curve in each trial site (including trendlines of mean and 85th percentile values) - Touring motorcycles only

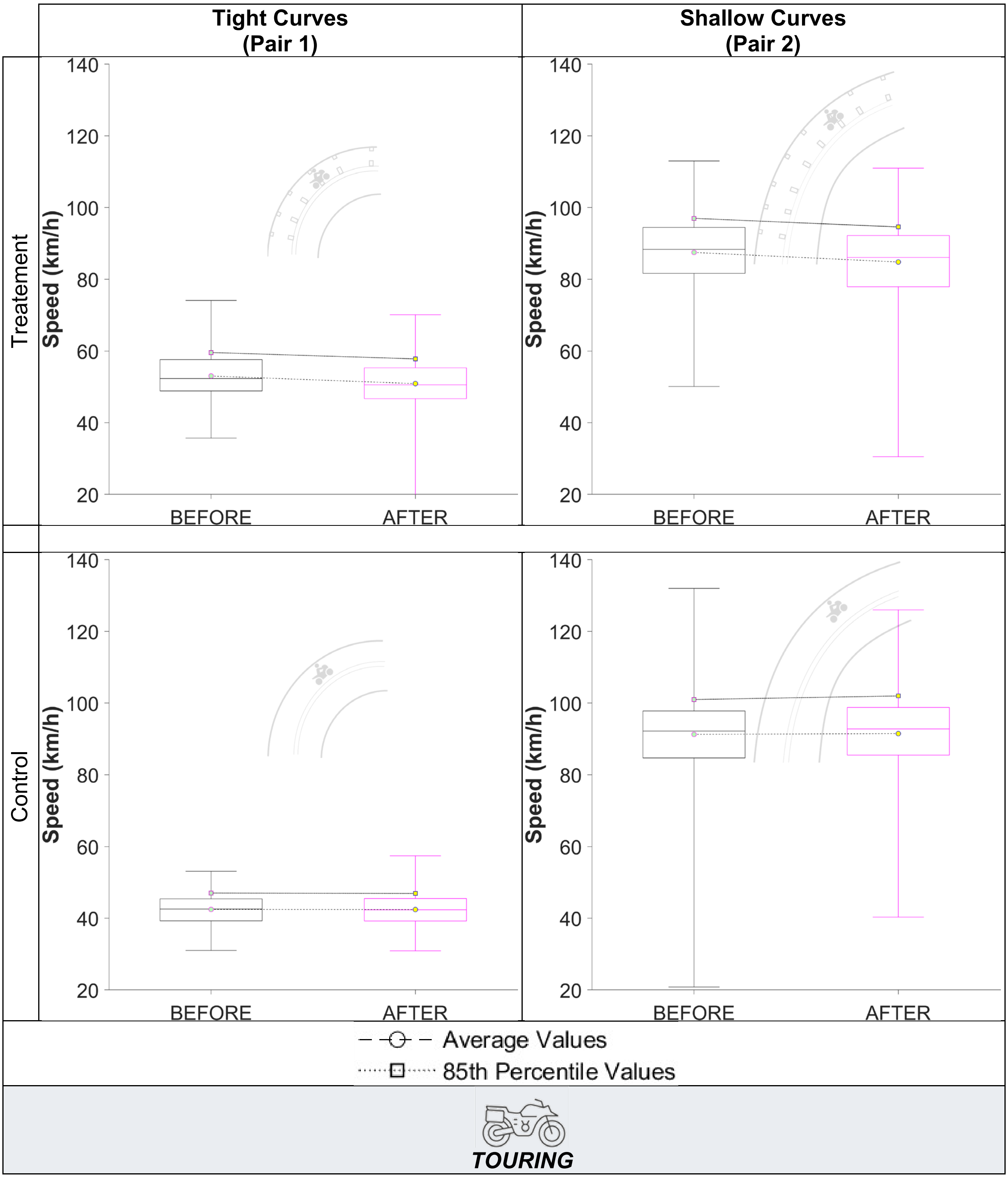
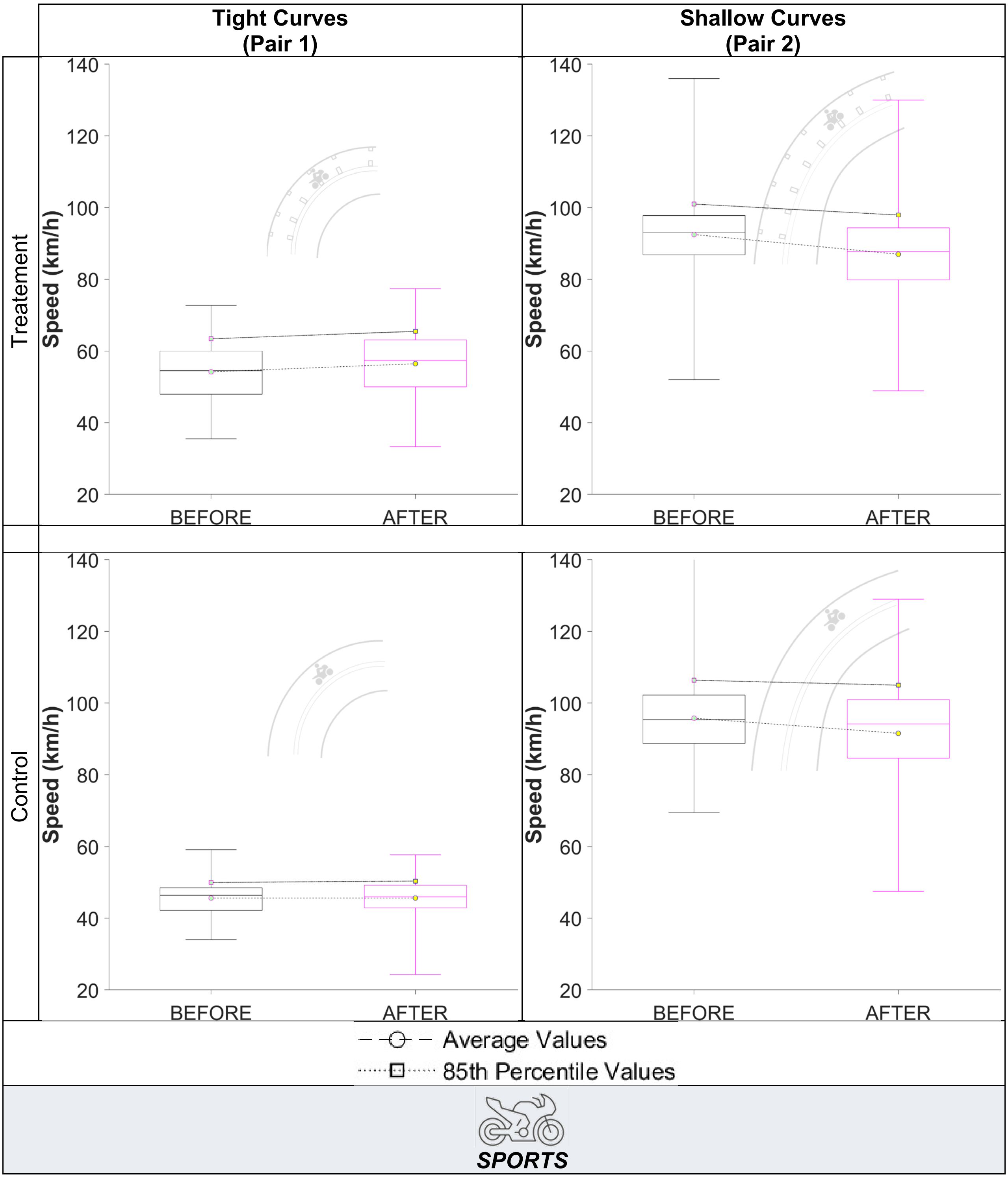


Figure 5.10: Boxplots of the travel speeds at the apex of the right-hand curve in each trial site (including trendlines of mean and 85th percentile values) - Sports motorcycles only



5.2.3 Cumulative Distribution

The plots in Figure 5.11 show a before-after comparison of the cumulative distribution of the travel speeds of all the analysed motorcycles, as measured at the apex of each right-hand curve in the trial. The cumulative distribution curves provide the corresponding percentage of motorcycles that were riding at a speed equal or below a given speed value. The curves of the travel speeds collected at both treated sites after the installation of the PCM shifted towards left, while the curves of the travel speed collected at their corresponding control sites in the periods before and after the installation of PCM at the treated sites tended to match. This shift of the curves at the treated sites indicates that the proportion of motorcyclists who tended to ride through the curve apex at a speed equal or below a given speed level after the installation of the PCM treatment was larger than what was observed before the installation. Since no shift occurred between the pre-treatment and post-treatment curves for the paired control sites, then the change observed at the corresponding treatment sites could be associated with the installation of the PCM treatment.

In Table 5.4 a quantitative comparison is presented of the proportion of motorcyclists riding at or below a series of common speed thresholds within the speed limit as well as above the speed limit, both before and after the installation of the PCM treatment at each of the trial sites (including the paired control curves). In general, the proportion of motorcyclists riding below the speed limit tended to increase after the PCM treatment was implemented. In particular, the proportion of motorcyclists riding at or below 50 km/h at the treated tight curve (posted limit = 60 km/h) increased from 37.0% to 50.2%, while the proportion riding at or below 90 km/h at the treated shallow curve (posted limit = 100 km/h) increased from 53.1% to 67.9%. Noticeably, this effect was almost negligible at each paired control site. After accounting for the change at the corresponding paired control site, the expected equivalent increase in those proportions of motorcyclists riding at or below 10 km/h compared to the posted speed limit was 13.6 percentage points at the tight curve and 14.5 percentage points at the shallow curve.

Additionally, the proportion of motorcyclists who travelled above the posted speed limit tended to decrease at the apex of either of the two treated curves in the trial. After accounting for the change at the corresponding paired control site, the proportion of motorcyclists speeding decreased by 3 percentage points at the tight curve (posted speed limit of 60 km/h) and by 6.5 percentage points at the shallow curve (posted speed limit of 100 km/h). Note that no motorcyclists were found riding above the speed limit at the control for the tight curve during the entire duration of the trial. This was likely caused by the presence of a lower advisory speed limit of 30 km/h at the control curve compared to an advisory speed limit of 50 km/h at the paired treated curve.

Figure 5.11: Cumulative distribution of the motorcycle travel speed at the apex of right-hand curves - All analysed motorcycles

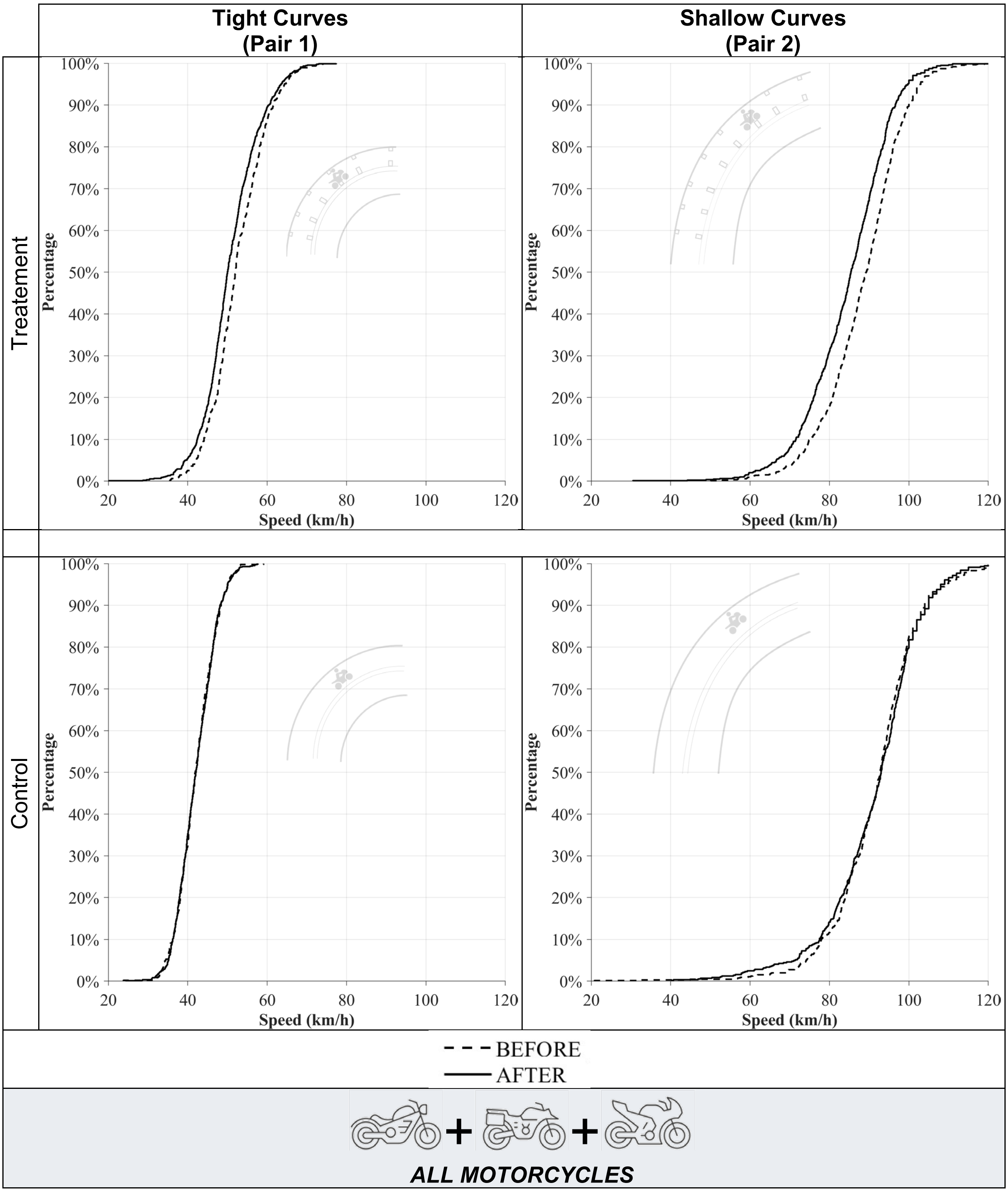


Table 5.4: Proportion of motorcycles riding below various speed thresholds or over the speed limit before and after the PCM installation

Curve Type	Site Type	Period	Percentage of motorcycles			
			<=40 km/h (%)	*<=50 + km/h (%)*	*<=60 * km/h (%)*	*> 60 km/h (%)*
Tight Curves (Pair #1)	**Treatment**	**Before**	2.6	37.0	86.6	13.4
		After	5.5	50.2	89.6	10.4
		Variation	2.9	13.2	3.0	-3.0
	Control	**Before**	33.2	95.1	100	-
		After	35.3	94.7	100	-
		Variation	2.1	-0.4	0.0	-
		Controlled Variation	0.8	13.6	3	-3
			<=80 km/h (%)	*<=90 km/h (%)*	*<100 * km/h (%)*	*> 100 km/h (%)*
Shallow Curves (Pair #2)	**Treatment**	**Before**	18	53.1	91.1	8.9
		After	31.2	67.9	95.9	4.1
		Variation	13.2	14.8	4.8	-4.8
	Control	**Before**	11.7	39.2	83.4	16.6
		After	14.2	39.5	81.7	18.3
		Variation	2.5	0.3	-1.7	1.7
		Controlled Variation	10.7	14.5	6.5	-6.5

+ Advisory speed at Treatment curve (a lower advisory speed of 30 km/h applies at Control curve)
** Speed limit*

5.3 Lane Position

5.3.1 Distribution

The distribution of the lane position at the entry and the apex of each trial curve for all the detected motorcycles is shown in Figures 5.12 and 5.13, respectively. Additionally, a breakdown of the distributions into each of the three major categories used to classify the detected motorcycles at the entry of the tight and shallow curves is provided in Figures 5.14 and 5.15, respectively, and similarly in Figure 5.16 and 5.17 for the apex of those curves. In each plot, separate and overlapping histograms indicate the distribution of vehicle lane position before and after the PCM installation. The evident skew towards the left for the distributions at the apex of both types of treated curves during the after period indicates a shift of motorcycle lane position away from the centreline compared to the before period. However, a marginal can be observed at the entry of those curves, therefore indicating a marginal shift of lane position after the treatment installation at the entry of the curves.

Figure 5.12: Distribution of motorcycle lane position at the entry of the right-hand curve in each trial site - All motorcycles

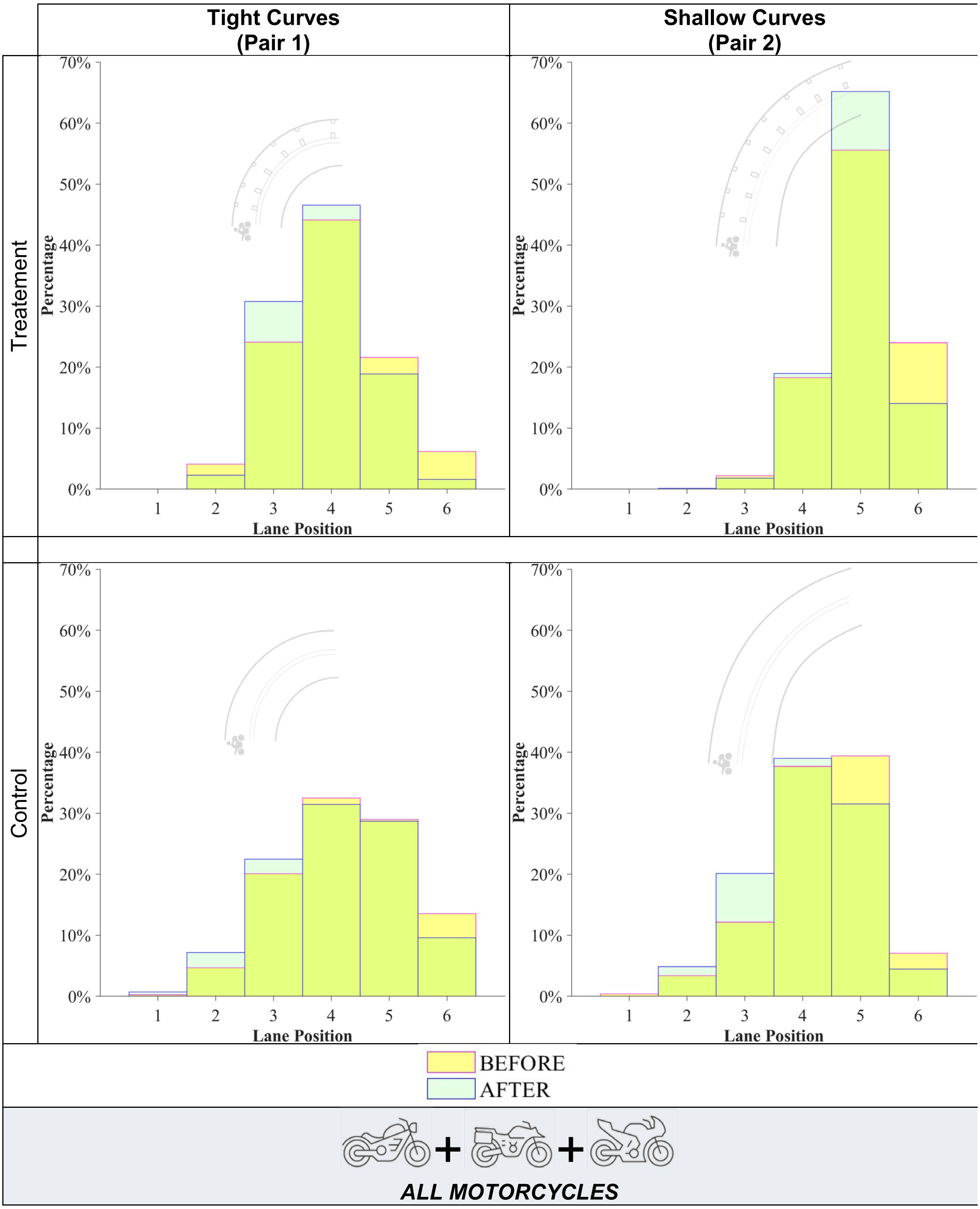


Figure 5.13: Distribution of motorcycle lane position at the apex of the right-hand curve in each trial site - All motorcycles

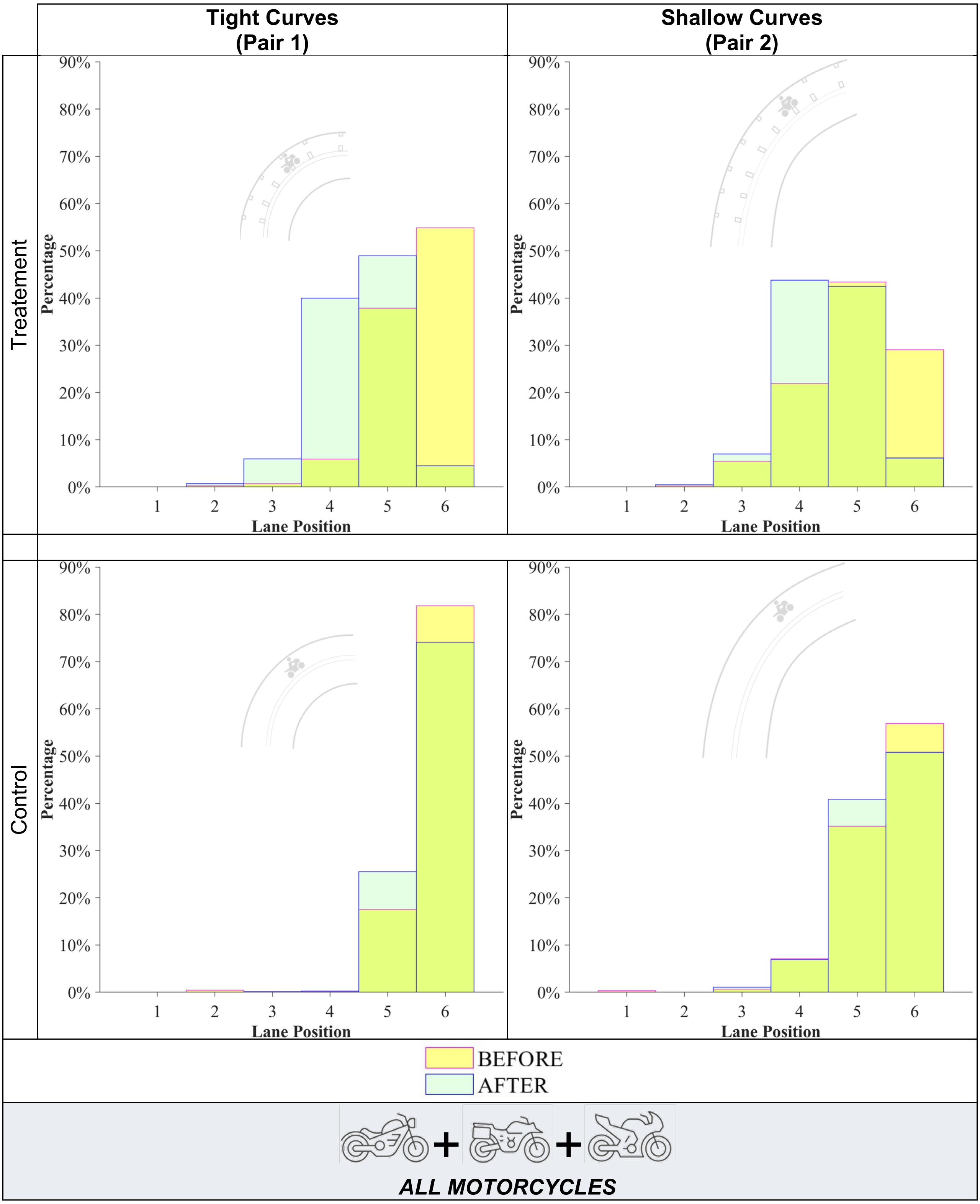


Figure 5.14: Distribution of motorcycle lane position at the entry of the right-hand tight curves (Site Pair 1) – Breakdown by motorcycle categories

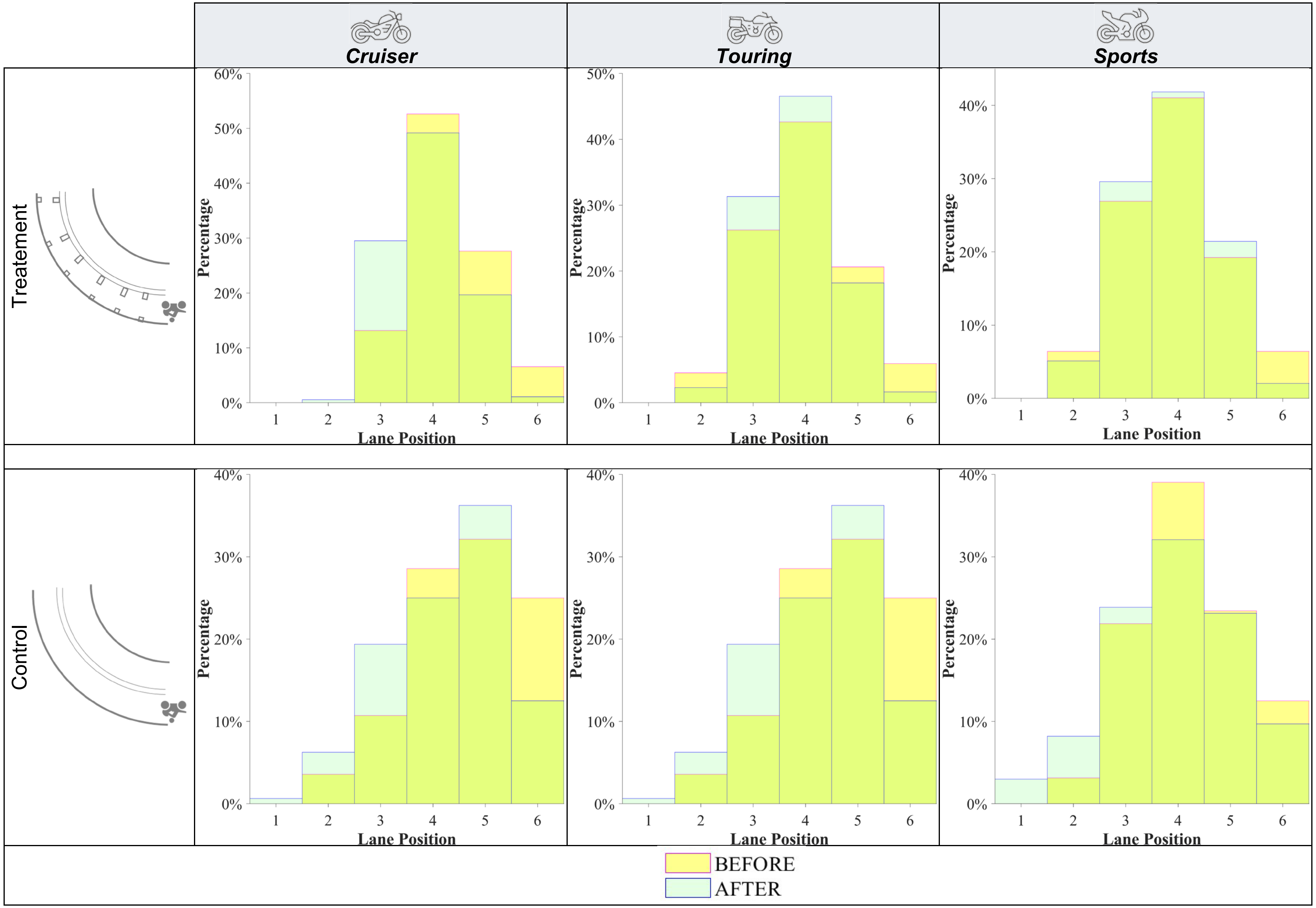


Figure 5.15: Distribution of motorcycle lane position at the entry of the right-hand shallow curves (Site Pair 2) – Breakdown by motorcycle categories

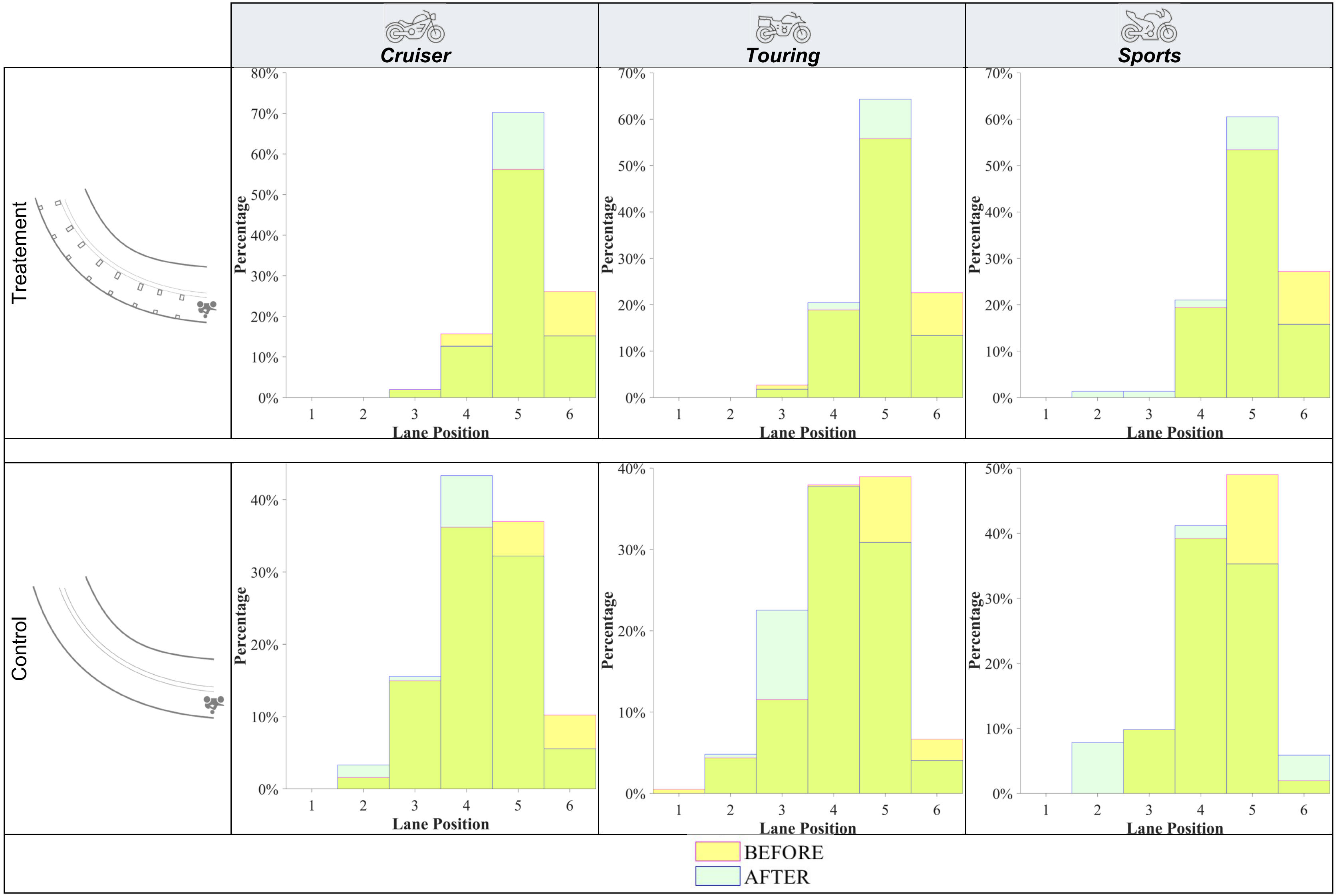


Figure 5.16: Distribution of motorcycle lane position at the apex of the right-hand tight curves (Site Pair 1) – Breakdown by motorcycle categories

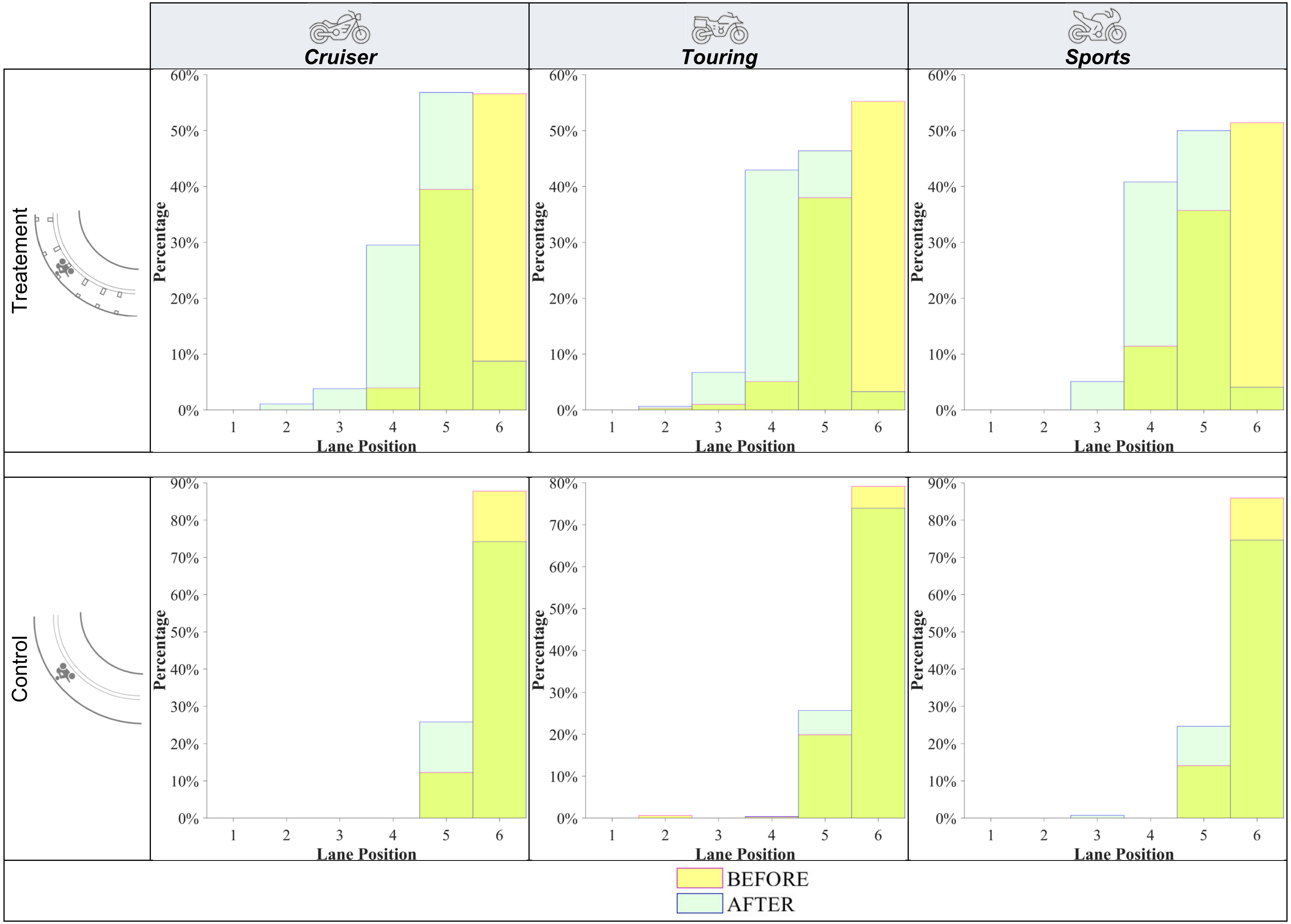
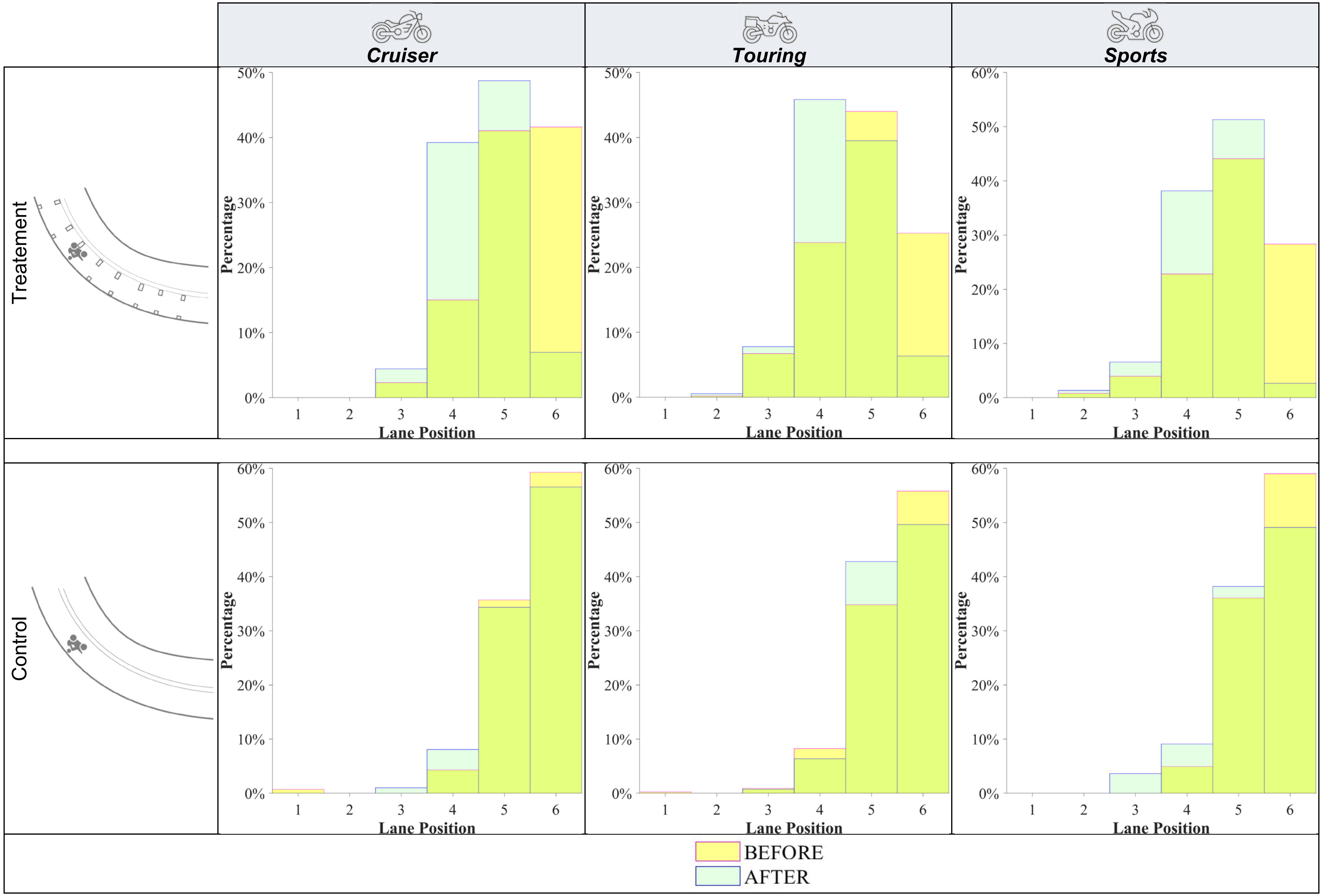


Figure 5.17: Distribution of motorcycle lane position at the apex of the right-hand shallow curves (Site Pair 2) – Breakdown by motorcycle categories



5.3.2 Cumulative Distribution

The plots in Figures 5.18 and 5.19 provide a before-after comparison of the cumulative distribution of the lane position for all the analysed motorcycles, as measured at the entry and the apex of each right-hand curve in the trial, respectively.

When considering the motorcycle lane position at the apex of trial curves, after the installation of the PCM the cumulative curves clearly shifted towards left for both treated sites. Still, the corresponding curves for the matched control sites tended to have a minimal shift between the before and after periods. This shift of the curves at the treated sites indicates that the proportion of motorcyclists who tended to ride through the curve apex at a distance from the edge line equal or below a given position level after the installation of the PCM treatment was larger than what was observed before the installation. Since no shift occurred between the pre-treatment and post-treatment curves for the paired control sites, then the change observed at the apex of the corresponding treatment sites could be associated with the installation of the PCM treatment.

Conversely, a marginal shift occurred between the before and after curves for both the treatment and the matched control site when considering the motorcycle lane position at the entry of any of the two types of curves considered in the trial. Therefore, the before-after change in the motorcycle lane position at the entry of both the treated sites could be considered as negligible.

A quantitative pre-post treatment comparison of the proportion of motorcyclists riding at or below each of the left-most first five lane positions as well as at or above the right-most lane position is provided in Table 5.5 for each of the trial sites, including the paired control curves. The before-after variations of these proportions were considerable at the apex of each treated curve, while smaller changes occurred at the entry of the curves. At the treated tight curve (Site T_1), the proportion of motorcyclists riding within the left-most 2/3 portion of the lane at the apex increased from 6.8% during the before period to 46.6% in the period after the treatment installation. Similarly, that proportion at the apex increased from 27.5% to 51.3% at the shallow treated curve (Site T_2). This resulted in a variation of 39.8% (40% after accounting for the variation at the paired control site) for the tight curve and 23.8% (same also after accounting for the variation at the paired control site) shallow curve. At the same time, the proportion of motorcyclists riding in the segment of the lane closest to the centreline (i.e., greater than position 5) after the installation of the treatment decreased from 55.3% to 4.5% at the apex of the tight curve and from 29.1 to 6.2% at the apex of the shallow curve. This resulted in a variation of -50.8 percentage points for the tight curve and -22.9 percentage points for the shallow curve (-43.1 and -17.2 after accounting for the variation at the corresponding paired control sites).

Figure 5.18: Cumulative distribution of the motorcycle lane position at the entry of right-hand curves - All analysed motorcycles

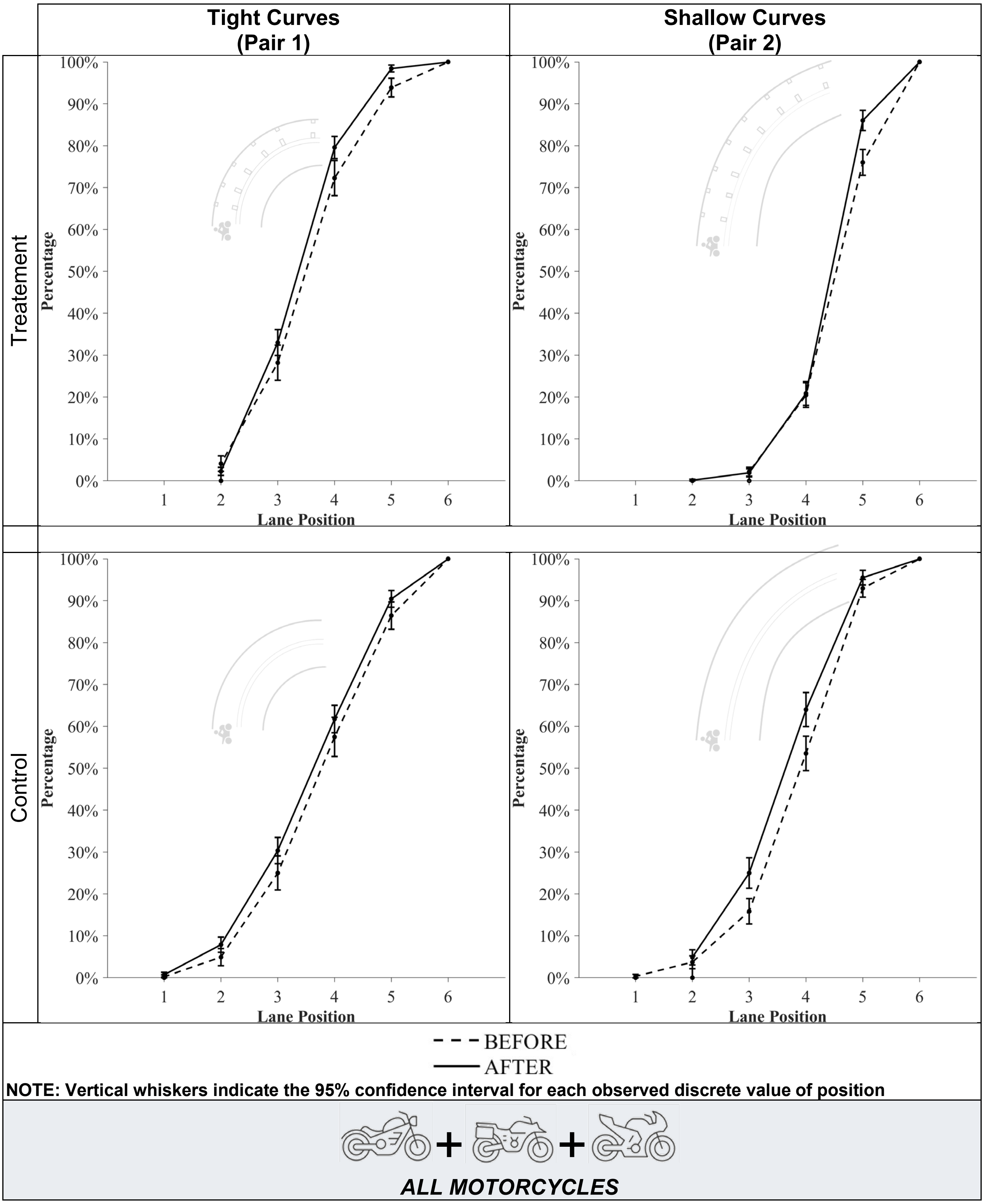


Figure 5.19: Cumulative distribution of the motorcycle lane position at the apex of right-hand curves - All analysed motorcycles

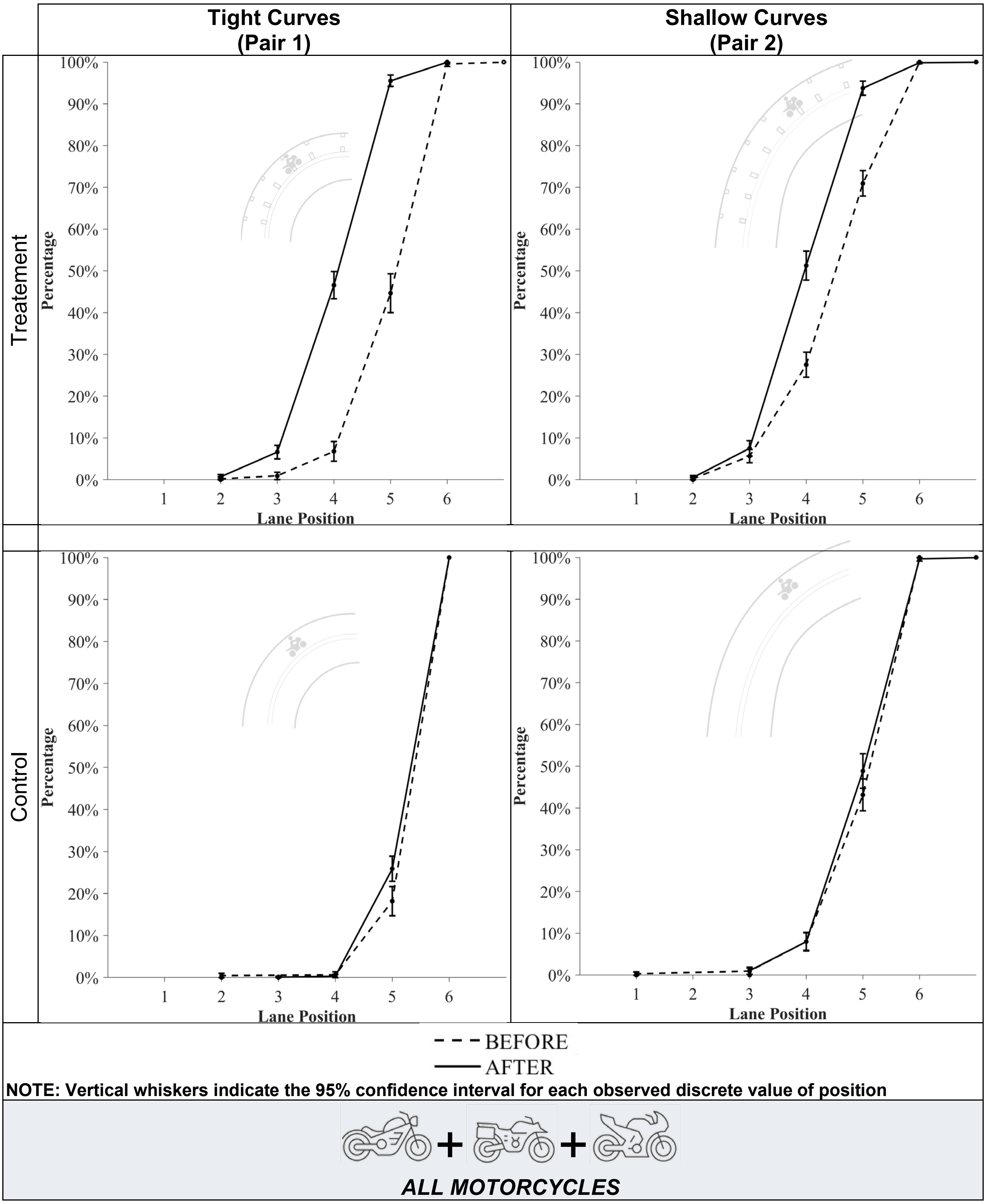


Table 5.5: Proportion of motorcyclists riding within or below each of the six lane positions before and after the installation of the PCM

			Percentage of all motorcycles											
			Entry						Apex					
			<=1	<=2	<=3	<=4	<=5	>=6	<=1	<=2	<=3	<=4	<=5	>=6+
Tight Curves (Pair #1)	**Treatment**	**Before**	0.0	4.1	28.2	72.3	93.9	6.1	0.0	0.2	0.9	6.8	44.7	55.3
		After	0.0	2.2	33.0	79.6	98.4	1.6	0.0	0.7	6.6	46.6	95.5	4.5
		Variation	0.0	-1.9	4.8	7.3	4.5	-4.5	0.0	0.5	5.7	39.8	50.8	-50.8
	Control	**Before**	0.2	4.9	25.0	57.5	86.4	13.6	0.0	0.4	0.4	0.6	18.2	81.8
		After	0.7	7.9	30.3	61.8	90.4	9.6	0.0	0.0	0.1	0.4	25.9	74.1
		Variation	0.5	3.0	5.3	4.3	4.0	-4.0	0.0	-0.4	-0.3	-0.2	7.7	-7.7
		Controlled Variation	-0.5	-4.9	-0.5	3.0	0.5	-0.5	-	0.9	6.0	40.0	43.1	-43.1
Shallow Curves (Pair #2)	**Treatment**	**Before**	0.0	0.0	2.2	20.5	76.0	24.0	0.0	0.2	5.6	27.5	70.9	29.1
		After	0.0	0.1	1.9	20.9	86.0	14.0	0.0	0.5	7.5	51.3	93.8	6.2
		Variation	0.0	0.1	-0.3	0.4	10.0	-10.0	0.0	0.3	1.9	23.8	22.9	-22.9
	Control	**Before**	0.4	3.7	15.8	53.5	93.0	7.0	0.3	0.3	0.9	8.0	43.1	56.9
		After	0.0	4.9	25.0	64.0	95.5	4.5	0.0	0.0	1.1	8.0	48.8	51.2
		Variation	-0.4	1.2	9.2	10.5	2.5	-2.5	-0.3	-0.3	0.2	0.0	5.7	-5.7
		Controlled Variation	0.4	-1.1	-9.5	-10.1	7.5	-7.5	0.3	0.6	1.7	23.8	17.2	-17.2

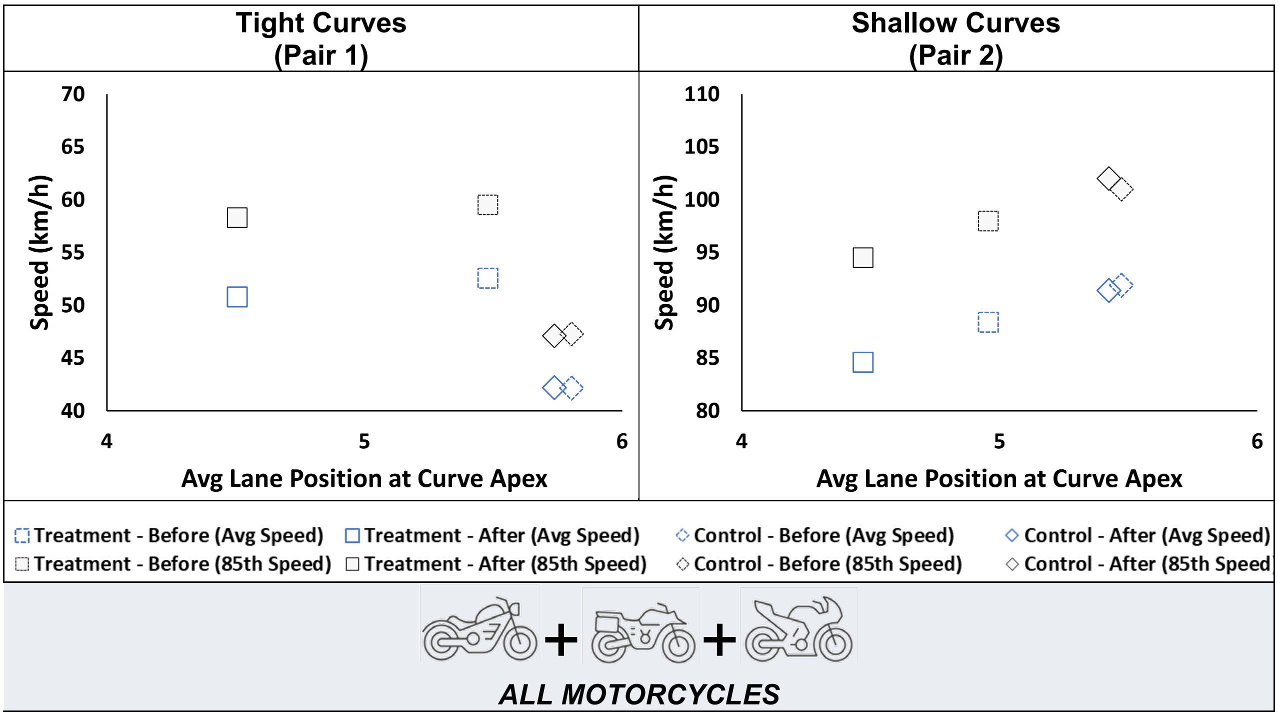
+ *Only two events detected with motorcycles crossing the centreline (Lane position = 7)*

5.4 Speed and Lane Position Relationship at the Curve Apex

The scatter plot in Figure 5.20 provides a visual representation of the relationship between motorcycle speed and lane position at the apex of each trial site before and after the PCM implementation. A comparison of this relationship between the treatment and control sites is provided separately for the two pairs of tight and shallow curves.

Before the installation of the PCM treatment, the average motorcycle lane position at each of the treatment sites was already slightly further away from the centreline compared to what was observed at the corresponding paired control curve. After the installation of the PCM treatment, the average motorcycle lane position shifted considerably further away from the centreline at each of the two treated curves while it remained almost unchanged at the corresponding control sites.
Additionally, motorcyclists tended to travel through the apex of the tight treatment curve at a slightly higher speed than at the paired control curve, whereas they tended to travel through the apex of the shallow curve at a lower speed than the corresponding control curve. This trend was observed both before and after the installation of the PCM treatment. However, the travel speed at the apex tended to drop at both of the treated sites after the installation of the treatment.

Figure 5.20: Comparison of speed-lane position relationship at the apex of the treatment and control curves before and after the PCM implementation (All motorcycles)



6. Discussion

A discussion of the results is provided in this chapter, including the outcomes of the present motorcycle-focused PCM trial as well as a comparison against the outcomes reported in other recent PCM trials. Further discussion is also provided regarding major implications that can be derived from the trial results, including potential safety benefits and side effects of the PCM treatment which were not assessed during this trial.

Overall, the trialled PCM design appears to be capable of influencing motorcyclists to safely position themselves away from the centreline when they are riding through the apex of right-hand curves. The PCM design can also have some calming effect on motorcyclists' speed choice when riding through the apex of the treated right-hand curves. These results are consistent with what has been reported in recent trials of other perceptual designs that are specifically targeting motorcyclists.

The analysis of the lane position measurements that were collected during this trial indicated that the proposed PCM design can have a considerable effect in influencing motorcyclists to safely position themselves within the travel lane when they are riding through the apex of right-hand curves. Additionally, it appears that the implemented PCM can have some calming effect on motorcyclists' speed choice when riding through the apex of the treated right-hand curves.

The following sections present a rational analysis of various aspects of the results obtained in this trial and a comparison against results reported in recent trials of similar PCM designs. Further discussion is also provided regarding major implications that can be derived from the trial results, including potential safety benefits that could be provided by the PCM treatment but were not investigated during this trial, as well as potential side effects. Finally, some concerns that were raised by representatives of a motorcyclist association during the trial are presented and addressed.

6.1 Observed Effects of the PCM Treatment

6.1.1 Influence of the PCM on Travel Speed

Speed reduction

The trialled PCM treatment can induce motorcyclist to reduce their speed when travelling through the apex of the treated curves. Generally, both the mean and 85thpercentile travel speeds at the curve apex tended to decrease at each of the two treated curves, with a much more marginal reduction occurring at their paired control curves. After accounting for the variation at the control sites, the mean speed reduced by 1.8 km/h at the tight curve and 3.8 km/h at the shallow curve. Similarly, the 85thpercentile speed at the tight and shallow curves reduced by 1.2 km/h and 3.5 km/h, respectively. This trend was also observed for the different broad motorcycle categories considered in this analysis, with the exception of sport motorcycles, for which travel speed increased at the treated tight curve after the installation of the PCM.

Note that the increase in travel speed for sport bikes was observed only at the tight curve, where all motorcyclists tended to travel at relatively low speeds below 60 km/h. It is unlikely that a better grip of the tyres typically used in sport-bikes had played a major role in their speeding behaviour at those relative low travel speeds. Nonetheless, better handling of the motorcycle could have played a role. However, even in that case sport bikes would have not been particularly favoured when it comes to negotiating tight curve. Potentially, the riding corridor suggested by the PCM may have allowed super-sport riders to navigate through the curve adopting smoother trajectories than what they would otherwise follow and, therefore, potentially induce them to feel confident to maintain a higher speed when travelling through (i.e., reduce the amount of braking when entering the curve). However, the PCM provides a conspicuous warning about the curve immediately ahead, which is expected to induce riders to be cautious and potentially slow down.

The PCM treatment appears to induce a marginal speed reduction at both the trialled tight and shallow curves also for drivers of light vehicles and partially also heavy vehicles, as indicated by the observed reductions in their controlled mean travel speed, which varied between 0.3 km/h and 2.9 km/h depending on the type of vehicle and site. The peripheral blocks may potentially cause a similar effect to the dragon’s teeth marking (i.e., lane narrowing and side friction). However, the blocks of the trialled PCM protrude into the lane more than the small triangles typically used for the dragon’s teeth treatment, therefore requiring drivers to travel over them as opposite to being able to drive in the lane space between opposite dragon’s teeth. In general, it should be noted that no statistical significance could be derived for any of the analysed motorcycle and vehicle types given that the PCM was trialled only at one site for both the tight and shallow curves.

Increase of motorcyclists travelling at lower speeds

In addition to the decrease in the average and 85thpercentile travel speeds observed during the trial, the trialled PCM treatment was associated with an increase in the proportion of motorcyclists who chose to ride below the posted speed limit. This shift in the speed distribution was particularly evident for a speed threshold of 10 km/h below the posted speed limit at each of the treated curves (i.e., travelling at or below 50 km/h at the tight curve and 90 km/h at the shallow curve). As this effect was almost negligible at each paired control site, then the change observed at the corresponding treatment sites for those speed thresholds can be attributed to the installation of the PCM treatment with a reasonable level of confidence. After accounting for the change at the paired control site, the before-after increase in the proportion of motorcyclists who rode in the most left 2/3 of the lane at the apex was 40% at the tight curve and 23.8% at the shallow curve.

Additionally, the reduction in the proportion of motorcyclists who travelled through the apex of the treated curves over the speed limit indicates that the trialled PCM treatment can effectively inform motorcyclists about the need to safely adjust their travel speed when negotiating the treated curves. After accounting for the change at the corresponding paired control site, the proportion of motorcyclists who were speeding decreased by 3 percentage points at the tight curve (posted speed limit of 60 km/h) and by 6.5 percentage points at the shallow curve (posted speed limit of 100 km/h). Note that there was a smaller drop in the proportion of motorcyclists who chose to ride at or below the posted limit at the tight curve compared to the shallow curve. This small drop at the tight curve is likely motivated by a lower willingness of road users to further reduce their speed below low posted speed limits.

Comparison against recent trials

The moderate reduction of motorcycle travel speeds which was observed in this trial is consistent with findings of other recent trials conducted on various designs of PCMs specifically focused on motorcyclists (Abdelmesseh et al., 2021; Stedmon et al., 2021; Hirsch et al.,2018). Nonetheless it should be noted that there have been other trials for which inconclusive effects on travel speed were reported, either in the short term (Winkelbauer et al., 2017) or as a substantial decay of an initial positive speed effect within the medium term (Mulvihill et al., 2008). Additionally, in a recent trial conducted in the state of Victoria (Abdelmesseh et al., 2021) a moderate speed increase was reported at the apex of a curve treated with a perceptual peripheral design treatment based on the same concepts as the PCM that was evaluated in this study.

Interestingly, in the modified transverse line marking design trialled in Victoria, the painted blocks were spaced further away from each other compared to the PCM design trialled in this study (i.e., 5 m for the tight curve and 10 m for the shallow curve in the DOT design as opposed to 3.5 m for any type of curve in the PCM design trialled in this study). Given this opposite speed behaviour at the curve apex observed in the two trials, it might be possible that variations of some specific design details, such as the block spacing, may considerably affect motorcyclist speed behaviour.

The objective of the trialled PCM treatment is to induce motorcyclists to safely negotiate critical curves. This is achieved primarily through the adoption of safe trajectories. While the adoption of lower speeds would certainly allow for an increased safety margin to correct a trajectory, this is not strictly required to achieve the desired goal as far as the speed chosen by motorcyclists is adequate for the type of curve, traffic and road conditions. Therefore, substantial speed reductions are not a goal for the proposed PCM treatment. Indeed, large speed reductions could be reasonable obtained only in the particular case of an aggressive trajectory where the motorcyclist purposely cuts through the curve cord and is then corrected to a suggested safe trajectory. Such types of aggressive trajectories are relatively rare and have been only observed in three instances during the pre-treatment period of this trial. Thus, the small average reduction in travel speed between the pre-treatment and post-treatment periods in this trial.

6.1.2 Influence of the PCM on Lane Position

The trialled PCM treatment appears to be capable of effectively inducing motorcyclists to shift their position away from the dangerous zone close to the centreline when travelling through the apex of right-hand curves. The proportion of motorcyclist riding in the monitored lane segment closest to the centreline after the installation of the treatment decreased from 55.3% to 4.5% at the apex of the tight curve and from 29.1 to 6.2% at the apex of the shallow curve. After accounting for the change at the paired control site, the before-after variation for this measure was -43.1 percentage points for the tight curve and -17.2 percentage points for the shallow curve.

Besides reducing the number of motorcyclists who position themselves in the dangerous zone where a potential for head on crashes with oncoming vehicles exists, the trialled PCM treatment also appears to induce them to conservatively position within the lane so that they can have an additional safety margin. Indeed, after the installation of the PCM treatment there was a considerable increase in the proportion of motorcyclists who chose to ride within the left most 2/3 of the lane while they were negotiating the apex of the treated curves. The proportion of motorcyclists riding within the left most 2/3 of the lane increased from 6.8% to 46.6% at the treated tight curve, and from 27.5% to 51.3% at the treated shallow curve. As the changes were almost negligible at each paired control site, the change observed at the corresponding treatment sites could be attributed to the installation of the PCM treatment with a reasonable level of confidence. After accounting for the change at the paired control site, the before-after variation in the proportion of motorcyclists who rode in the left most 2/3 of the lane at the apex was 40% at the tight curve and 23.8% at the shallow curve.

Interestingly, any changes in motorcyclist lane positioning observed at the entry of the curve were minimal. After the treatment, motorcyclists continued positioning themselves in the centre of the lane when approaching the curves as they did before the installation of the PCM treatment.

Comparison against recent trials

The effect of the trialled PCM treatment to shift motorcyclist lane position away from the centreline at the apex of the treated curve is comparable to what has been reported in other trials of various perceptual peripheral line marking treatments (Abdelmesseh et al., 2021; Winkelbauer et al., 2017; Hirsch et al., 2018; Mulvihill et al., 2008).

As previously mentioned, the perceptual design trialled in Victoria (Abdelmesseh et al., 2021) was very similar to the PCM evaluated in this study. The minimum (baseline) width of the centreline painted blocks trialled in Victoria (Abdelmesseh et al., 2021) was smaller (300 mm) than in the PCM trialled in this study (450 mm). Despite this difference, comparable outcomes between the two trials in terms of shifting motorcyclist position away from the centreline suggests that the proposed PCM design may provide similar safety benefits also with a narrower baseline width for the centreline blocks. This appears to be further confirmed also by the comparable low proportion of motorcyclists who were observed to ride within 600 m from the centreline in both trials.

Additionally, a safe shift away from the centreline was reported also for vehicles other than motorcycles in the design trialled in Victoria. Therefore, it is reasonable to expect that a similar positive influence on driver lane position likely occurred also in the similar PCM design evaluated in this trial.

Marginal changes in motorcyclist lane positioning were observed at the entry of the curve during the trial in Victoria. Similar marginal effects appear to have occurred also in other trials of perceptual peripheral line marking designs. On the other hand, positive effects on influencing motorcyclist lane position at the curve entry were reported for gating perceptual designs (Stedmon et al., 2021; Hirsch et al.,2018), which are specifically aimed at influencing motorcyclist lane position at the approach and entry of the curve (hence, their definition as a ‘gating’ treatment). Therefore, a hybrid design that combines an initial gating approach and a subsequent peripheral line marking may potentially influence the motorcyclist lane position both at the entry and the apex of the curve.

6.2 Further Considerations Regarding the Trialled PCM Treatment

6.2.1 Potential Bias Due to Presence of Cameras and Radars

Due to logistical reasons, the radar and video camera devices used in this trial had to be mounted on poles located on the roadside. Their presence on the side of the road during the trial could have biased the behaviour of some road users when travelling through the curves in case they may have mistakenly perceived them as enforcement devices. Nonetheless, the camera protective case and small size case looked very different from the typical safety enclosures used in modern speed cameras. It is likely that most road users correctly perceived them as monitoring devices instead. In this latter case, any potential bias that may have been caused by the equipment conspicuity, is expected to have been limited. The compatibility of the results observed in this trial with those outcomes reported in other previous or concurrent trials appears to confirm that no bias occurred.

As previously mentioned, some cameras were vandalised at the beginning of the before period during the trial. Although the specific reasons behind this act of vandalism are not known, likely the cameras were perceived as surveillance cameras used to monitor extreme riding behaviour. The fact that this vandalism was limited to the beginning of the trial only appears to indicate that that vandals quickly realised that cameras were not to be used neither for enforcement nor identity monitoring purposes.

6.2.2 Treatment Effect on the Motorcyclist Trajectory

The suggested safe approach to negotiate a right-hand curve in most current riding training programs involves entering the curve on the left portion of the lane, then gradually shifting towards the centre of the lane while travelling through the bend, and finally exiting close to the centreline.

The trialled PCM has shown potential to induce riders to negotiate curves with trajectories that are more consistent with his suggested approach, compared to their observed behaviour before the curves were treated. Indeed, after the PCM treatment was implemented, motorcyclists tended to safely shift away from the centreline when transitioning through the curve apex. Conversely, before the treatment was implemented, the majority of motorcyclists tended to position themselves too close the centreline when they reached the curve apex, which likely required them to either slow down or cross the centreline in order to negotiate the remaining portion of the curve. Despite the positive effect of the PCM treatment at the curve apex, it appears that the trialled PCM treatment did not improve the initial lane position of motorcyclists at the entry of the treated right-hand curves, where they kept riding mostly on the centre of the lane both before and after the treatment was installed. One potential reason for this behaviour may be the poor conditions of edges of the roads at the trial sites (broken/uneven), which likely further increased their expectation of being a dangerous section of the lane to ride over. A future alteration of the current design of the edge-line blocks could potentially help motorcyclists use those blocks as a reference to safely enter the curve in the left half of the travel lane.

It should be noted that the observation of motorcyclist lane position in this trial was limited to two specific locations along the curve, namely the entry and the apex. Therefore, a detailed reconstruction of the trajectory throughout the curve could not be created. Nonetheless, it can be reasonably expected that motorcyclists that were positioning in the centre of the lane at the apex of the curve would safely keep drifting closer to the centreline once they travel past the apex as they would then be able to see any approaching oncoming vehicles. Also note that motorcyclists running wide on right bends would run off road when leaving the curve (as opposite to running towards or crossing the centreline for left-hand bends). Although the lane position of motorcycles at the exit of the curve was not monitored in this trial, their observed shift toward the centre of the lane at the apex provided some indirect confidence that riders were eventually leaving the curve tight as opposed to wide. Additionally, the motorcyclist lane position trend observed at the apex of the treated curves is similar to what was reported in a recent trial of a very similar design in Victoria (Abdelmesseh et al., 2021), during which detailed motorcyclist trajectories measured with advanced vehicle tracking technology confirmed the expected safe approach to negotiate a right-hand curve described above. Given the similarity in the motorcyclist lane position observed at the apex between the two trials and the comparable treatment design, it could then be assumed that those detailed trajectories would likely apply also for those events observed in this trial.

6.2.3 Long-term Effect of the Treatment

The PCM was trialled in the short term only (between 2 and 6 weeks after the initial installation). The observed positive effects on travel speed and lane position may be mainly due to a ‘novelty’ effect and may dissipate in the medium to long term. Indeed, in one of the first trials of a perceptual peripheral line marking treatment conducted in Victoria, it was reported that the speed reduction initially observed in motorcyclists during the short term almost completely vanished five months after the treatment installation (Mulvihill et al., 2008). It is possible that in the trial conducted in Victoria some of the design details, such as the choice to use yellow paint for the peripheral blocks or the choices made for block spacing and dimensions, may have contributed to the long-term decay of the initial speed calming effect. Therefore, long-term speed effects might be achieved with other type of perceptual treatments with different design characteristics.

On the other hand, long-term effects on motorcyclist lane positioning were still observed three years after the treatment in another more recent Austrian trial of two peripheral line marking treatments with a design concept very similar to that of the PCM treatment trialled in this study (Winkelbauer et al., 2021). Additionally, in that follow-up evaluation, an increase in the proportion of motorcyclists riding in the desired safe section of the lane was reported. Given the similarity in the design choices between the PCM treatment trialled in this study and the block design from the Austrian trial, it may then be assumed that the effects on the motorcyclist lane position behaviour observed in this trial would likely be retained in the long term.

6.2.4 Treatment Effectiveness at Night-time

Neither this trial nor any of the recent previous trials reported in literature have evaluated the effect of peripheral line marking at night-time. This common deficiency in these trials is likely due to the various technical challenges associated with operating video cameras at night-time (e.g., no solar power to compensate a prolonged battery drain and the need to use expensive infra-red cameras). It is therefore unknown whether the line marking may have a stronger or a weaker effect under those conditions. Likely, the PCM treatment would not only make the curve more visible at night thanks to the high visibility of the white blocks but would also induce motorcyclists to shift away from the centreline at a higher rate than what is observed during the day. None of this could be assessed in this study as data were collected only during daytime (6am to 6pm). Further investigation is needed to test these hypotheses.

6.2.5 Potential Effect of a Media Release Ahead of the Post-treatment Evaluation

A public media statement was released just before the start of the collection of data that were used to evaluate the post-treatment behaviour of road users. The media statement revealed to the public the existence of the ongoing trial as well as some of the objectives of the investigation. This information appeared to be shared and briefly discussed through a couple of dedicated posts on the social media site Facebook by the local community of motorcyclists who are familiar with the trial route. It is not possible to assess whether and to what extent this information may have affected the way road users interacted with the treatment during the second phase of the trial. Nonetheless, the limited extent and duration of the social media discussion following the media statement (two posts with about a dozen comments each across two days) suggests that the local motorcyclist community quickly overlooked the treatment and so any effects on the outcomes were hopefully minimal.

6.2.6 Potential Seasonal Effect

The post-treatment period occurred during the beginning of the wet season in Queensland. Although the analysis was conducted only using data from events observed when the road surface was dry and paired control sites were specifically used to rule out external factors, the wet season may have partially influenced motorcyclists towards a more cautious riding approach compared to their normal behaviour during the dry season.

6.2.7 Additional Potential Benefits (Not Investigated in this Trial)

The presence of the painted blocks along the outer edge of the curve in the PCM design is expected to discourage motorcyclists from riding too close to the edge of the curve, where typically gravel/dirt tends to accumulate, and the surface is more prone to developing cracks or broken edges. As the vast majority of motorcyclists tended to approach the entry of the right curves in the mid-section of the travel lane, this potential benefit could not be validated in this trial. Nonetheless, approaching the entry of a curve on the left most portion of the lane may likely occur at other sites and any such deterrent function of the PCM treatment could further improve safety. This aspect requires additional investigation.

Aside from inducing motorcyclists to safely negotiate right-hand curves by keeping a safe distance from the centreline and moderating travel speed at the apex, the proposed PCM design may also likely provide the following additional safety benefits to all motorists:

- Increased awareness of the curve presence and improving its conspicuity
- Complementing and reinforcing existing line marking and acting in lieu of missing edge line marking

Given the high conspicuity of the white painted blocks, the trialled PCM can likely increase curve visibility and awareness at the approach as well as provide helpful supporting references to locate both left and right boundaries of the travel lane when travelling through the curve. This effect may be particularly helpful during night-time and in low-light conditions, when the increased visibility and the edge boundary reference provided by the PCM treatment is expected to complement and support other existing countermeasures that are specifically designed to help motorists stay within the travel lane in such conditions, such as reflective guide posts and chevron signs.

6.2.8 Potential Side Effects

Although no specific side effects were identified during this trial, it may still be possible that some side effects may arise from the use of the proposed PCM treatment at different sites or in the long term. Two potential side effects that may arise are inducing drivers to drift through long shallow curves and the creation of visual clutter.

Potential to induce drivers to drift through long shallow curves

This trial focused specifically on investigating the effects of the PCM treatment on motorcyclists. While an analysis was conducted of the effect of the treatment on the speed behaviour of drivers, the potential effect that the treatment may have on driver lane positioning when negotiating the curve was not investigated in this trial. A potential side effect of the PCM treatment could be that of inducing drivers to drift to the edge while negotiating long shallow curves.

Wide vehicles will have to travel over the PCM painted blocks. A long exposure travelling over the gradually widening centreline blocks while approaching the apex of shallow curves may induce drivers of those vehicles to drift on the edge of the lane. This effect may be further accentuated by the road superelevation that is typically used for high-speed shallow curves, which would allow vehicles to shift safely towards the edge line as a consequence of a perceived increased vehicle stability when negotiating this type of curve. Future investigations should consider this potential side effect of the treatment on wide vehicles.

Potential to create visual clutter

The presence of additional pavement marking other than the standard edge and centre lines may overload motorists with visual information, especially in combination with other existing visual treatments such as advisory speed warning curve signs and CAMS. This cognitive overload may potentially distract motorists and take their attention away from the main task of negotiating the curve, therefore making it harder to negotiate a curve compared to the case without additional perceptive marking. Although nothing that was observed in the trial suggested this to be the case, it was not something that was specifically investigated.

Potential impact on cyclists

This analysis did not investigate any potential effects that the PCM may have on cyclists. Nonetheless, it is expected that the use of standard paint may induce cyclists to avoid riding on the painted blocks positioned along the edge of the curve therefore resulting in shifting their position towards the centre of the lane. The use of high-friction paint or thermoplastic foils instead of standard paint would likely give cyclists confidence to safely ride over the painted blocks. \

Potential interference on vehicle safety technologies

The PCM may affect the functionality of active vehicle safety technologies that rely on the detection of line marking, such as Lane Keeping Systems (LKS). As no investigation on this regard was conducted during this trial, at this stage it is unknow whether the PCM may potentially trigger any false LKS warning messages or activations when a vehicle is driving close to the edge of the painted blocks.

6.2.9 Concerns Raised During the Trial

During the post-treatment period, representatives of the QLD Motorcyclist Council Inc., a motorcyclist association based in Queensland, brought to the attention of the TMR Project manager some concerns regarding the trialled PCM treatment. These concerns from QLD Motorcyclist were raised upon being briefed about this trial during one of their regular monthly meetings with TMR. After the trial ended, TMR updated them on the study results during other following regular meetings. No further feedback or concerns were received by TMR during those following meetings.

The following sections provide a description of each of the perceived side effects of the installed PCM treatment that concerned the motorcyclist association along with a discussion to address them.

Slipperiness of painted line marking

It was argued that painted line marking could reduce the friction of the road surface, especially in wet conditions. Thus, riding over the painted line marking when negotiating a curve could cause a loss of control of the motorcycle.

For the purpose of limiting installation (and potentially de-installation) costs and reducing the amount of existing uncertainty surrounding the field implementation of a novel line marking for the first time, standard paint was used for implementing the PCM design during this trial. It should be noted that, despite standard paint often being perceived by motorcyclist as slippery when wet, no instances of slipped motorcycles were reported during the trial period. Nonetheless, it is likely that the standard installation practice that would be used for this PCM treatment, should it be implemented on a permanent basis, will involve the use of high-friction paint or custom-cut thermoplastic film glued to the road surface. Either of these advanced line marking materials are commonly adopted by road authorities. Apart from a high level of friction, thermoplastic film would also provide additional advantages such as retro-reflectivity, the possibility of pre-cutting the desired blocks ahead of the installation, low maintenance, and excellent durability. Durability would be a particularly important aspect due to the location of the painted blocks on the travel path of vehicle wheel tracks. Indeed, in recent trials of peripheral line marking designs, the treatment was implemented using either *Beadlock* high-friction paint (Hirsch et al.,2018), 3M™ retro-reflective and high-friction foil (Stedmon et al., 2021), or high-friction thermoplastic film (Abdelmesseh et al., 2021; Winkelbauer et al., 2017). In particular, the use of thermoplastic film or foils may provide additional logistic benefits, including the possibility of being installed much faster than any painting, thanks to the possibility of being pre-cut, as well as the possibility of being driven on immediately after they are bonded to the road surface and longer durability compared to paint-based options.

An alternative solution, either in combination with thermoplastic marking or with standard line marking, is the use of hollow bar shapes, which could be perceived as less slippery than equivalent filled painted shapes. However, marking with hollow shapes may be less intuitive to understand and therefore be considered as annoying and confusing by motorcyclists as also reported in the Austrian trial (Winkelbauer et al., 2017) where it was evaluated as an alternative design.

Forcing motorcyclists to travel in the centre of the lane

A safety concern was raised about forcing motorcyclists to travel in the centre of the lane, which is perceived to be a slippery portion of the travel lane. Four-wheeled vehicles travel over the centre of the lane and this section of the road is exposed to potential oil leak from the vehicle engine or exhaust. Therefore, the centre of the lane is perceived to become rather slippery, especially in wet conditions.

Since the PCM treatment induces motorcyclists to avoid riding close to either the road edgeline or centreline, it is perceived that it would force them to travel onto the centre of the lane, whereas they would normally tend to ride either towards the centre or edge of the road.

Although the PCM treatment is designed to induce motorcyclists to avoid riding close to either the road edgeline or centreline where the peripheral blocks are painted, it still allows them to ride through most of the lane section that is left unpainted and not necessarily only in the centre of the lane. It should be noted that the optimal curve negotiation approach suggested in standard riding training programs involves entering the curve on the outside edge, gradually shifting to the centre of the lane when negotiating towards the apex of the curve and finally leaving the curve close to the centreline while still maintaining a safe distance from oncoming traffic. Therefore, riding in the centre of the lane would still be required when following this suggested curve negotiation approach. The trialled PCM treatment induced this desired optimal lane positioning when transition through the apex of the curve, while still allowing motorcyclists a large margin of freedom to choose their preferred lane position. Indeed, this flexibility in the choice of lane position taken by motorcyclists is confirmed by the distributions of the lane position both before and after the treatment was installed. Additionally, it was observed that the majority of motorcyclists, in any case, tended to enter the curve in the middle of the lane even before the treatment was installed. This trend was simply maintained after the treatment was implemented.

Imposing a travel path inconsistent with the standard approach to negotiate curves

As previously mentioned, a safe approach for negotiating a right-hand curve for motorcyclists is to start close to the outside edge, gradually shift to the centre of the road when proceeding towards the apex, and then exit close to the inside of the lane at a safe distance from the centreline. The presence of painted blocks was perceived as not supporting this approach as motorcyclists would tend to avoid riding on those peripheral sections of the lane. In particular, the PCM treatment was perceived as being potentially confusing or misleading to learner riders, who are taught to negotiate a curve using the mentioned approach.

Although the standard training approach to negotiate a right curve by starting on the outside of the curve and finishing close to the centreline is safer than other approaches, there is still some residual risk that a rider may intrude into the head-on zone close to the centreline. The presence of centreline blocks at the exit of the curve can act as a reference for riders to clearly identify this risky head-on zone, and therefore better plan their trajectory to avoid riding in that dangerous area while executing the manoeuvre. In general, the width of the painted blocks along the edge-line and centreline is limited to a fraction of the lane, therefore still allowing motorcyclists a reasonable margin to negotiate the curve using the suggested safer approach within the remaining unpainted portion of the lane.

In the trialled PCM design, the width of centreline blocks gradually increase when travelling between the entry and the apex and it gradually reverses back to the initial width when reaching the curve exit. Motorcyclists look forward from their current position when riding. It is then expected that they will detect this change in the width of centreline blocks when they are located upstream of where it actually occurs. Therefore, the perceptual effect due to the increase in the centreline block width is expected to be anticipated while motorcyclists are approaching the curve entry inducing them to shift to the left half of the lane. Similarly, the perceived reduction in width in the second part of the curve is expected to be anticipated when motorcyclists are riding through the curve apex. Also in this case, the anticipation effect should induce motorcyclists to gradually start shifting towards the centreline when they reach the apex and then further when progressing towards the exit of the curve.

6.2.10 Expected Safety Outcomes of the PCM

Overall, the positive effects on both lane positioning and travel speeds observed in this trial of the proposed PCM treatment are expected to improve motorcyclist safety at the treated curves and therefore reduce the risk of crashes as well as injury severity when a crash still occurs. This predicted safety outcome would replicate the considerable drop in crashes that was reported at the treated curves in a recent follow-up evaluation of the PCM trial in Austria (Winkelbauer et al., 2017), with an analysis comparing motorcycle-related crashes three years before and after the installation of various types of perceptual treatments.

6.2.11 Localised Installation of the PCM Treatment

Installation of the PCM should be avoided on curves where the risk of head-on crashes is limited. The trialled PCM is intended for treating curves which are deemed to be at high risk of head-on crashes in case motorcyclists decide to voluntary cross the centreline. The dangerousness of a curve could be based on factors such as limited line of sight, high frequency of heavy vehicles, curve geometry, narrow lanes, or a combination of these factors. When available, also any known systematic crash history or critical road safety-related issues could be taken into consideration. Additionally, given the specific focus of the PCM to motorcyclists, application of this treatment should be limited to popular motorcycles routes in regional and rural areas. Under this suggested application scenarios, it is expected that motorcyclists would associate this PCM to curves at risk of head-on crashes along popular motorcyclist routes. Consequently, motorcyclists would expect any of the other non-treated curves along the route to be characterised by varying levels of risk but not being as critical as for those curves treated with the PCM. A targeted implementation of this PCM is also expected to support both acceptance and compliance to this treatment thanks to a likely induced perception that the treatment is applied where required, therefore limiting the warning message as well as the associated potential visual burden that the PCM may cause to dangerous curves only.

6.2.12 Compatibility with the Safe System Approach to Road Safety

Based on the various benefits discussed in this chapter, the trialled PCM treatment can be considered compatible with the Safe System approach to road safety. Indeed, the PCM treatment addresses simultaneously three of the five main pillars adopted by the Safe System framework in road safety, as presented below.

- **Safe road users** – The trialled PCM design has proven to be capable of inducing motorcyclists to negotiate curves through trajectories that comply with optimal safe trajectories better than what they tended to do before the treatment was implemented (i.e., maintain a safe margin from the centreline when riding through the apex of right-hand curves). This improved behaviour may potentially extend to other untreated curves as motorcyclists might start to regularly adopt such trajectory approach when negotiating any curve along their trip. Potentially, the PCM treatment may also subconsciously increase general risk awareness in motorcyclists as well as other road users when negotiating curves. However, this particular aspect was not investigated in this study and therefore would require to be specifically explored in the future.
- **Safe speeds** – The trialled PCM design has proven capable of inducing motorcyclists as well as other road users to reduce their travel speed when negotiating right-hand curves (and potentially also left-hand curves, although not investigated in this trial). Reducing travel speed at the apex of the treated curves allows for a larger margin to react and make corrections to the initial trajectory in case of mistakes or in an emergency situation. Therefore, the PCM design could be an appropriate secondary treatment for speed management to support and complement the primary treatment provided by mandatory speed limits (e.g., for cases where would not be feasible to further reduce the current posted speed limit).
- **Safe roads** – The trialled PCM design contributes to making the curve boundaries more conspicuous in both daylight and night-time conditions. Additionally, it provides improved reference guidance when negotiating the curve, especially in the case of missing edge lines. Therefore, the PCM design is an appropriate low-cost secondary treatment to improve and complement existing primary treatments such as standard line marking and signage. It is also compatible with other types of road infrastructure interventions such as vehicle restraint systems.

7. Conclusions

This section provides conclusions and recommendations based on the evidence collected during this trial. Overall, the trialled PCM design appears to be capable of influencing motorcyclists to position themselves safely away from the centreline when they are riding through the apex of right-hand curves. The PCM design can also have some calming effect on motorcyclists' speed choice when riding through the apex of the treated right-hand curves. Additionally, this speed calming effect applies to some extent to drivers of light and heavy vehicles.

The trialled PCM design showed high potential of enhancing motorcyclist safety at critical rural curves. Additional research would be still required to confirm behavioural changes on the long-term as well as investigate potential side effects. Improvements to the current design may also be investigated in further research activities.

Based on the analysis of the trial results, the proposed PCM treatment appears to deliver both safety effects for which it was designed. The major and most desired effect is that of inducing most motorcyclists to maintain a safe distance from the centreline when travelling through the apex of a right-hand curve. The observed positioning towards the centre of the lane at the apex of the treated curve appears to indicate that riders negotiated the treated curves following trajectories which were more consistent with the standard rider training approach compared to before the PCM was installed.

The second but more marginal effect of the PCM treatment is to mitigate the travel speed of motorcyclists as well as other road users at the apex of the treated curves. Both effects have been observed at the tight as well as the shallow trial curves.

Additionally, the proposed PCM design may provide the following further safety benefits, which have not been investigated in this trial and therefore would need to be confirmed by future investigations:

- increased conspicuity of the treated curves at night-time and in low-light conditions
- providing a complementary reference to traditional features typically used by road users when negotiating a curve during the day but which may not be clearly visible at night
- discouraging motorcyclists from riding too close to the edge of the lane, which typically tends to be slippery due to accumulation of dirt and gravel.

No side effects were identified in the analysis of the data collected during this trial. Nonetheless, the following side effects may potentially arise as a consequence of the treatment installation, which might require specific future investigation:

- potential to induce drivers to drift towards the roadside when negotiating shallow curves due to long exposure travelling over the gradually widening centreline blocks while approaching the apex
- potential confusion due to a visual-clutter effect created by the presence of the PCM treatment in combination with other existing visual treatments such as CAMS and advisory speed warning signs
- potential to induce cyclists to drift towards the centre of the lane to avoid riding over the painted blocks located along the edge of the curve
- potential interference with vehicle safety technology based on detection of line marking.

The proposed PCM design can be quickly installed on existing roads with minimal work. It is an appropriate low-cost and low-maintenance secondary treatment to improve and complement existing primary treatments such as standard line marking and signage. Additionally, it is also compatible with other types of road infrastructure interventions such as vehicle restraint systems.

The overall positive outcomes from this trial, which are consistent with the results observed in most other recent trials on various designs of perceptual treatments targeting motorcyclists, indicate that the trialled PCM design has high potential to enhance motorcyclist safety at critical curves in regional and rural environments. In addition, the proposed PCM treatment is compatible with various pillars of the Safe System approach to road safety, which provides the high-level reference framework for reducing trauma due to road crashes. Nonetheless, additional research is required to expand the currently limited sample size of trialled sites, which is required to obtain statistically significant conclusions. Future trials are also required to confirm the long-term duration of the behavioural changes observed in this short-term trial as well as to investigate the potential safety benefits listed above. In particular, it is critical to ensure that PCMs do not have unintended consequences on other road users as well as vehicle safety technologies that rely on line marking. Therefore, further research should focus also on investigating any of the potential side effects listed above as well as any other additional unintended consequences that may arise. Finally, improvements to the current design of the proposed PCM treatment should also be considered in further research activities, including the use of high-friction paint or thermoplastic material. In particular, thermoplastic material may provide additional logistical benefits compared to paint due to the faster application times and higher durability. The use of high-friction material will may also contribute to increase the acceptance of this type of treatment by the motorcyclist community as well as help to prevent potential side effects on cyclists.

Installation of the PCM should be avoided on curves where the risk of head-on crashes is limited. The adoption of consistent warrants/criteria to identify critical curves that may require to be treated with the proposed PCM is expected to play a critical role. An otherwise indiscriminate large-scale extension of this PCM to non-critical curves may cause motorcyclists to start losing confidence in this treatment. Additionally, it could potentially also induce motorcyclists into generalising that any non-treated curve would be characterised a-priori by a low level of risk at any time. A consistent and targeted implementation of this PCM is also expected to support both acceptance and compliance to this treatment thanks to a perception by road users that the treatment is applied where required and any potential visual burden that the PCM may cause is limited.

Considering the various aspects discussed above, it is suggested to retain the PCM currently installed at the two sites that have been treated in this trial. However, the current blocks should be either repainted using high-friction paint or replaced with high-friction thermoplastic foils placed on top of the existing painted areas. Additionally, it is suggested to expand the installations at additional sites in order to expand the sample of treated sites needed to obtain the statistical confidence to confirm the preliminary results of this trial as well as to monitor for long-term effects or any unintended consequences that may arise from the adoption of this system.

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Appendix A Options and Recommendations Report

A.1 Introduction

Single-vehicle motorcycle crashes are known to occur often on curved sections of road. Enhancing the delineation of the curve is one of a number of countermeasures that can potentially reduce the likelihood of vehicles failing to maintain lane position on curves, running off the road or colliding head-on with other vehicles. Given the common involvement of excessive speed among serious motorcycle crashes, reducing travelling speed is likely to be another means by which motorcycle crash risk on curves can be addressed.

This project is concerned with using road-based treatments to influence the travelling speed and/or lane position of motorcyclists. A trial is being undertaken to assess whether infrastructure countermeasures can be used to alter motorcyclist behaviour on curved roads on a recreational riding route in Queensland, Australia. The emphasis of the project is on perceptual countermeasures, which can be used to affect a rider's perception of travel speed and can also direct the rider to choose the safest path through a curve.

This particular report summarises a series of processes undertaken to design the trial of perceptual countermeasures in Queensland. This report builds on a literature review already completed as part of the project, which identified a number of potential countermeasures to be considered for trial. These various potential countermeasures were then presented and discussed at a workshop. Project team members also analysed motorcycle crash data along recreational riding routes in Queensland, to identify candidate riding routes for the trial. The most suitable riding route was then visited to choose possible specific curves to be used as the treatment and control sites. The outcomes are summarised in this report.

A.2 Treatment Selection

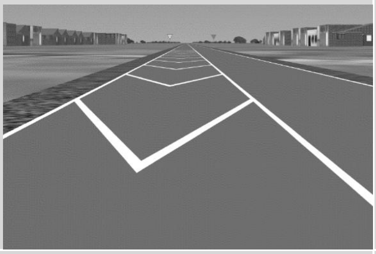
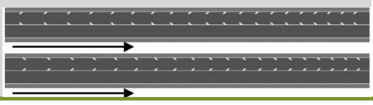
Several types of treatments and treatment applications were considered as part of the treatment selection process. These were developed through the literature review and the project workshop held in Brisbane on March 3, 2020. The perceptual countermeasure treatment types and treatment applications can be broadly categorised as below:

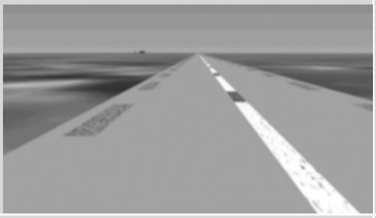
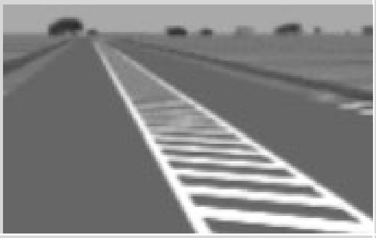
- **Speed correction**: treatments that primarily affect a motorcyclist's speed selection on entry to and while traversing a curve.
- **Line navigation**: treatments that primarily affect a motorcyclist's chosen line through a curve by providing line-tracking guidance to direct motorcyclists through a preferred line.
- **Line correction**: treatments that primarily affect a motorcyclist's chosen line through a curve by providing general line-tracking guidance and directing motorcyclists away from safety risk-associated areas (e.g., near the centre line).
- **Combination**: treatments that primarily affect multiple factors, such as both speed correction and line navigation.
- **General guidance**: treatments that provide motorcyclists with general guidance around a curve. An example is curve alignment markers (CAMs), also known as chevrons.
- **Threshold treatment**: treatments placed at the threshold of a series of curves to affect the speed selection and/or general riding behaviour of motorcyclists along a short length of roadway.
  NOTE: threshold treatments were raised during the project workshop and subsequently deemed to fall outside of the project scope.

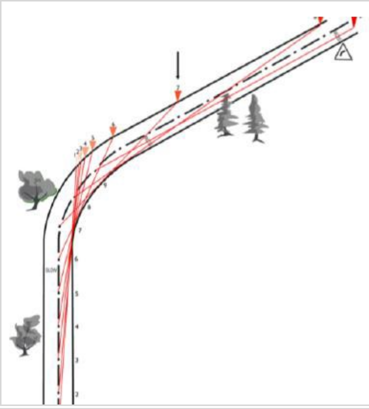
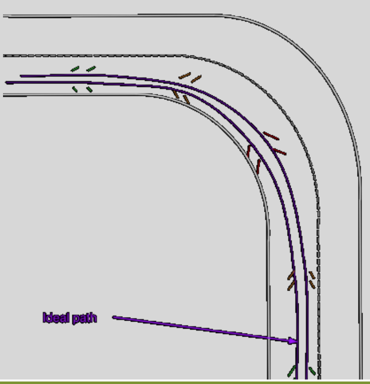
The list of treatments considered for trialling in this study is based on the results of the literature review. The list of treatments that were reviewed were used to populate a long list of potential treatments. This long list was presented to participants at the Austroads workshop. Attendees were given the opportunity to discuss the different treatments and vote on their preference for which treatment(s) to trial. The long list of treatments presented at the Austroads workshop is shown in Table A.1. Note that several of the treatments are similar to one another or consist of multiple treatments that are also individually presented.

After the workshop, a shortlist of potential treatments was created. The shortlist was populated while considering the outcomes of the workshop, the applicability of applying the treatments at the trial locations (see below for trial location selection details), and what treatments may already be present at the trial locations (e.g., guideposts are already present around most curves along the trial route).

Table A.1 Long list of countermeasures presented at the project workshop

Treatment	Treatment image	Category	Notes
Existing concepts (found in literature)			
Post-mounted delineators		General guidance	
Vehicle-activated warnings		Speed correction	
Rumble strips		Speed correction	Participants viewed this as a potential hazard for motorcyclists
Transverse line markings		Speed correction	Participants viewed this as a potential hazard for motorcyclists
Herringbone line markings	 	Speed correction	Participants viewed this as a potential hazard for motorcyclists
Peripheral transverse line markings (NOTE: Yellow colour not required)		Speed correction Line correction	Voted as **first preference** for trialling (with possible variations of line spacing and/or line width)
Peripheral herring line markings		Speed correction Line correction	

Treatment	Treatment image	Category	Notes
Warning signs and peripheral line markings		Speed correction Line correction	Voted as **third preference** for trialling
Low visual-contrast edge lines		Speed correction Line correction	Not preferred by participants as could "push" motorcyclists towards centre line
Hatched edge lines		Speed correction Line correction	
Painted chequered edge lines		Speed correction Line correction	Not preferred by participants as could "push" motorcyclists towards centreline and incite undesired speed behaviour
Hatched centre lines		Line correction	
Edge lines and reflector guide posts		General guidance	
Perceptual lane width narrowing		Speed correction Line correction	
Peripheral transverse line markings and reflector guide posts (NOTE: Yellow colour not required)		Speed correction Line correction	Voted as **second preference** for trialling
3-dimensional road markings		Speed correction General guidance	Not preferred by participants as a potential maintenance issue

Treatment	Treatment image	Category	Notes
Where you look is where you go (WYLIWYG)		Speed correction Line navigation	
Herring line guidance		Speed correction Line navigation	
Novel concepts (proposed by team members)			
Conceptual perceptual countermeasure 1*		Speed correction Line navigation	Not preferred by participants as pavement colouring could incite undesired speed behaviour
Conceptual perceptual countermeasure 2*		Speed correction Line navigation	
Conceptual perceptual countermeasure 3*		Speed correction Line navigation	Not preferred by participants as pavement colouring could incite undesired speed behaviour

** Conceptual perceptual countermeasures developed by the project team members and informed by the treatments identified through the literature review.*

From the long list of treatments, a shortlist of proposed treatments was created. Several treatment features were not desired by the workshop participants and so were excluded from the shortlist of proposed treatments. These were:

- Treatments that involve the use of different pavement colours. This was raised as a maintenance issue and for its potential to incite undesired speed behaviour, such as racing.
- Treatments that use chequered flag patterns. This was raised as having potential to incite undesired speed behaviour, such as racing.
- Treatments that traverse the entire lane width. This was raised as a perceived hazard for motorcyclists that could encounter strong resistance from the motorcycling community. This was also raised as a potential actual hazard if later maintenance was undertaken using regular paint instead of high-grip paint.
- Treatments that provide line navigation. This was raised as a potential hazard as a motorcyclist's chosen line through a curve can be varied and therefore a "one size fits all" approach to line navigation could influence a motorcyclist to ride away from their natural line.
- Treatments applied to the left side of a lane, which gives the perception of a narrowed lane. This was raised as a potential hazard as it may "push" motorcyclists towards the centreline.
- Treatments that involved complex designs, such as three-dimensional images. This was raised as a maintenance issue, as they would not be able to be properly maintained.
- Treatments that rely on complex or intricately detailed installation, such as guideposts that require installation at continually varying spacing. This was raised as a potential maintenance issue, as the original design may not be replicated during maintenance (e.g., replacing missing guideposts at non-original spacing).
- Technologically complex treatments. Participants raised the desire to trial simple treatments that are inexpensive to install and maintain. Technologically complex treatments, such as vehicle activated signs, were perceived not to fulfil this requirement.

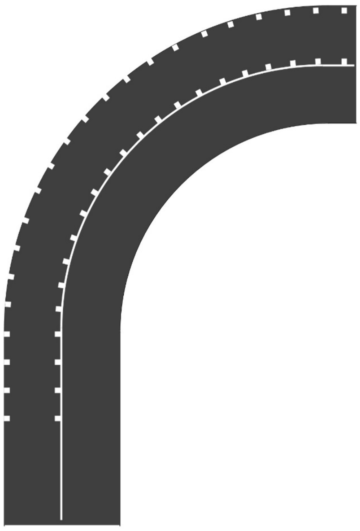
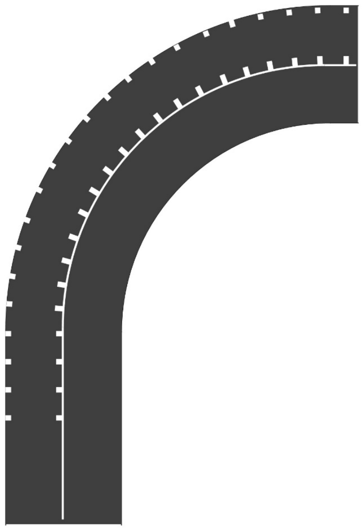
Most treatments were therefore excluded from the shortlist of potential treatments. Those that remained were peripheral transverse or herring line marking and roadside delineators. Roadside delineators were further excluded as Mt Mee Rd, the chosen location for the trial, has recently undergone roadside delineation improvements that mean most curves now have a high level of roadside delineation, such as double-spaced guideposts and CAMs.

Most workshop participants showed an interest in trialling peripheral transverse line markings. This interest was reflected in participant voting for the different treatment options. Participants further suggested to trial peripheral transverse line marking with different variations, such as variable line spacing and variable line widths. Variable line spacing was discussed post-workshop and was rejected on the grounds that the optimal degree to which line spacing should vary is unknown and therefore may not be effectively implemented. Variable line widths in the "head-on zone" (near the centreline around right-hand curves) were considered a viable option to trial. The workshop minutes as well as participants comments and ranking of each of the treatments discussed during the workshop are available in Appendix B.

The shortlist therefore included two treatment options, which are shown in Figure A.1. The first proposed treatment is peripheral transverse line marking on both edges of the lane that extend from the curve approach to the curve exit. The second proposed treatment is a variation of the first treatment, in which the peripheral transverse line markings increase in width around the curve on the inside edge of the lane, where the likelihood of a head-on collision due to a motorcyclist leaning over the centreline is greatest. This second proposed treatment is hereon referred to as a 'modified peripheral transverse line marking'. Note that the modified peripheral line marking aims to suggest a preferred trajectory by implicitly narrowing the path to an ideal corridor. Given the implicit nature of this corridor, it is not expected to forcibly prevent a rider to negotiate the curve throughout alternative trajectories if they want to do so or if they would not be able to correct a different trajectory they may have already initiated. Practically, riders would still have the option to ride safely over the peripheral line marking as they can currently do when they had to cross over the centreline due to a badly negotiated trajectory. The proposed dimensions for the standard peripheral line marking are loosely based on the latest version of such treatment that was trialled in New Zealand (Hirsch, Scott, Mackie, Stedmon & Moore, 2018). It should be noted that in the trial conducted in New Zealand, the peripheral line marking was placed only on the approach to the curve and a painted wide centreline treatment was used throughout the curve. Therefore, the addition of a wide centreline in that trial may have affected the rider’s behaviour. Additionally, in the New Zealand design, blocks on the inside of the curve were twice as wide than the blocks on the outside of the curve. Note that in this trial right-hand curves will be considered, as opposed to left-hand curves in the New Zealand trial. Therefore, the inside of the curve in this trial will be the centreline (instead of the edge line in the New Zealand trial). Consequently, the wider blocks in this trial will be located on the centreline.

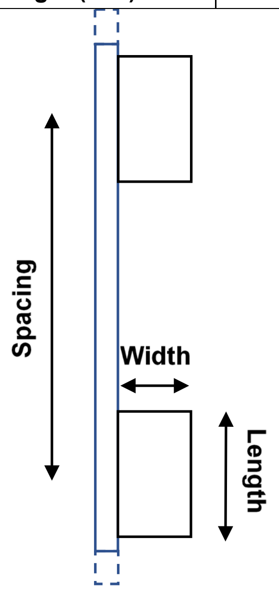
We propose to use blocks that are 1.5 times wider on the inside of the curve in our standard version of the peripheral line marking. Those specifications may be adjusted to fit any existing TMR installation requirements, if needed. As for the modified peripheral line marking, it is proposed to consider that the line width increase linearly by 150 mm from the baseline value (starting at the entry of the curve) to its maximum value at the apex of the curve. Such variation in the line width is expected to be a trade-off between the width increase being implicitly perceived by riders albeit not consciously noticed. Additionally, a linear increase in the line width is expected to be relatively easy to implement.

Figure A.1: Shortlisted treatment types to be considered for the trial

Peripheral transverse line marking	Modified peripheral transverse line marking
	

Block Specifications

	Edge Line	Centre Line		Edge Line	Centre Line
Spacing (mm)	3,500	3,500	**Spacing (mm)**	3,500	3,500
Width (mm)	300	450	**Width (mm)**	300	450 (entry/exit) to 600 (apex)
Length (mm)	500	500	**Length (mm)**	500	500



Note: Treatment to be trialled on right-hand curves

A.3 Trial Location

The brief for this project called for the implementation and evaluation of motorcyclist perceptual countermeasures (PCMs) at trial locations in Queensland. The trials are to be conducted on roads controlled by Transport and Main Roads (TMR) Queensland, who are hosting the PCM trial. As the PCM trial is being hosted by TMR through their central office in the Brisbane central business district (CBD), it was decided to undertake the PCM trial at locations within reasonable travel distance from the Brisbane CBD.

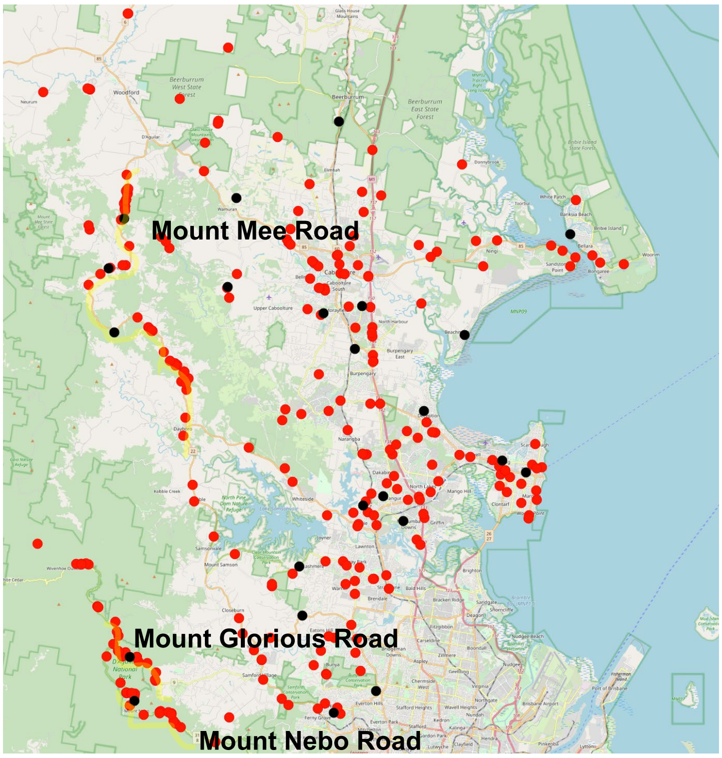
Route selection

Due to the targeted nature of the PCM trial, it was decided to undertake the PCM trial evaluation along popular motorcycling routes where fatal and serious injury (FSI) crashes of motorcyclists are a substantial issue. The PCM trial is targeted towards improving motorcyclist behaviour that could lead to motorcycle lane departure crashes, especially around curves, such as single motorcycle run off road crashes and motorcycle-involved head-on crashes. As such, route selection was based on the identification of routes where motorcycle lane departure crashes, especially those around curves, is an issue.

Route selection was performed using crash data provided by TMR. The crash data provided by TMR was for all police reported crashes in the Moreton Bay area between 2009 and 2018. Crash data analysis was refined using the police reported crash severity and definitions for classifying accidents (DCA) codes. Identification of potential routes was made by identifying areas of high numbers of fatal and hospital severity motorcycle crashes that involved run off road crashes on straights (DCA codes 701-705) and on curves (DCA codes 801-805), and head-on crashes (DCA code 201).

The crash data revealed three potential routes for the PCM trial, which are highlighted in yellow in Figure A.2. These three routes were Mount Mee Road, Mount Nebo Road and Mount Glorious Road. Mount Nebo was excluded as the road is not a state-controlled road and therefore TMR, the hosting road agency, is limited in its ability to undertake the PCM trial along this route. Mount Glorious Road was excluded as the segment along this road with substantial motorcycle FSI crash numbers has a very steep gradient of about 15%, which is unlikely to be representative of the majority of locations in Australia and New Zealand where the trialled PCM could potentially be used.

Figure A.2: Location of motorcycle-related fatal (black) and serious-injury (red) lane departure crashes in the Moreton Bay area (potential trial segments highlighted in yellow)



Due to the exclusion of the two other potential routes, Mount Mee Road was decided as the route along which the PCM trial would be undertaken. Of interest, crashes are clustered around three closely located areas of the route: near Delaney's Creek (south of D'Aguilar), near Mount Mee and near Oceanview (north of Dayboro). It was therefore decided to concentrate the site selection between D'Aguilar and Dayboro to incorporate all three cluster areas.

A.4 Site Selection

As the PCM trial evaluation is to be undertaken as a controlled before-after study, the following curve-specific and global selection criteria are used for selecting treatment and control evaluation sites and matching these sites to one another. Curve-specific criteria relate to the individual properties of each curve. Global criteria relate to properties of the routes along which the curves reside.

Curve-specific criteria:

- **High-risk locations** - Treatment and control curves should incorporate curves where motorcyclist lane positioning could increase the risk of a fatal or serious injury crash, such as by positioning the rider close to oncoming traffic or close to the unsealed roadside shoulder.
- **Matching curve properties** - Treatment and control curves should be closely matched based on their geometric properties (e.g., curve radius, grade, superelevation), speed (e.g., speed limit, curve advisory speed), line marking and signage (e.g., curve type advisory, motorcyclist specific messaging).
- **Consistency** - Motorcycle site audit outcomes should also indicate treatment and control curves are well-suited for matching.
- **Pavement condition** – It is preferred to trial perceptual countermeasures on curves characterised by a road surface that is representative of average good conditions of the environment where the treatment may be installed in the future.

Global criteria:

- **Traffic volume** - Treatment and control curves should experience similar traffic volumes with a substantial number of motorcycles traversing the curves.
- **Confounding factors** - Road user behaviour at treatment and control curves should not be affected by outside influences that could bias the evaluation, such as major intersections, adjacent land use (e.g., parking, high-use properties such as schools and cafes), speed limit changes and townships.
- **Neutrality** - Road user behaviour at treatment and control curves should not be affected be each other. An example of this neutrality would be a selection of treatment and control curves in the same direction and close enough that motorcyclist lane positioning in the latter curve is affected by the former curve.

Note that the matching of curves using curve-specific criteria and global criteria was based on the degree of overall qualitative agreement between the curves, rather than a specific weighting towards certain attributes.

Note that pavement condition was included as one of the curve-specific selection criteria as it may have an effect on the riding behaviour along curves. Surface irregularities and defects, such as corrugations, deep cracks, potholes, rooting and bitumen bleeding, can induce a sense of danger in riders and therefore induce them to reduce speed or adopt a more defensive riding behaviour. Conversely, a newly laid highly smooth and regular road surface may induce riders to feel more confident and induce them to adopt an aggressive riding behaviour. Given that the scope of this project is to investigate the effect that a perceptual countermeasure may have on the riders' choice of speed and trajectory when negotiating a curve, any of the two aforementioned extreme conditions of the road surface should be avoided as they may either amplify or negate the effect of the countermeasure. Therefore, it is preferred to trial perceptual countermeasures on sites characterised by a road surface that is representative of average good quality of the environment where the treatment may be installed in the future.

Note that during the initial selection of suitable sites, some curves that were of interest but which were characterised by sub-optimal pavement condition were still listed as potential candidates under the assumption that the road surface could be improved prior to conducting the trial. However, this option was later ruled out by TMR due to lack of a discretionary budget to cover additional expenses associated with improving the road surface. Those curves are identified as part of site 5.

Curve selection

The curve selection process was undertaken by means of a desktop analysis and a site visit, which incorporated a motorcycle road safety audit. During the site inspection, the route was ridden in both directions by two of the project researchers who are experienced motorcyclists, Dr. Tana Tan (auditor) and Dr. Chris Stokes. The inspection of the potential curves was undertaken by the following participants:

- Tana Tan and Chris Stokes (project team researchers)
- Paul Gottke and Spike Wilson (TMR)
- Rob Mothersole and Martin Jones (TMR North Coast)
- Jeremy Parsons (Matrix – data collection contractor).

Due to time restrictions, not all potential curves could be inspected in person during the site visits. The curve selection process was not an exhaustive effort to classify all curves along the route but, instead, was used to select a large enough sample of curves from which compatible treatment and control sites could be selected later. Only curves which would allow safe access by a contractor in charge of installing the data collection devices were considered.

While road user data will be collected for both directions of traffic flow where possible, the curve selection process was focussed on assessing the treatment mainly in one direction of travel. This was undertaken to reduce the potential bias of comparing rider behaviour at curves of different directions. Thus, it was then decided to prioritise right-hand curves. For right-hand curves PCMs would be more likely to reduce the likelihood of FSI crashes, based on the following two reasons:

- **Higher potential risk of head-on crashes** –when negotiating right-hand curves, riders tend to get close to the centreline in the middle of the manoeuvre process or they may experience a loss of control while “cutting” the curve apex. At that stage of the curve negotiation, they may not have enough time to react to unexpected oncoming traffic travelling in the opposite direction or quickly regain control of the motorcycle. Conversely, during left-hand turns riders tend to be close to the centreline at the beginning of their curve negotiation, which leaves them more time to react to traffic from the opposite direction of travel as well as to adjust their initial trajectory by moving to the inside of the curve.
- **Higher propensity of run-off-road crashes** – In general, in the Moreton Bay area, run-off-road crashes are 1.3 times more likely to happen on right-hand curves than on left-hand curves. When considering Mt. Mee Road specifically, right-hand curves have an even higher relative frequency of run-off-road crashes compared to left-hand curves, with a ratio of 3.2.

Sixteen potential trial curves were identified. These curves were specifically chosen for their applicability to the selected treatments that are to be trialled. The attributes associated with each potential trial curve are listed in Tables 3.1 and 3.2. Pictures of the sites are provided in Appendix C.

Table A.2 Attributes associated with each potential trial curve (Site 1 through Site 4)

Location ID	1			2		3		4	
Curve ID	A	B	C	A	B	A	B	A	B
Latitude Longitude	27° 1'32.97"S 152°46'41.53"E	27° 1'27.18"S 152°46'46.45"E	27° 1'31.92"S 152°46'44.85"E	27° 3'31.92"S 152°46'30.72"E	27° 3'13.80"S 152°46'24.51"E	27° 4'57.31"S 152°45'38.45"E	27° 4'56.10"S 152°45'47.06"E	27° 7'23.83"S 152°46'20.99"E	27° 7'29.13"S 152°46'16.63"E
Direction*	North	North	South	North	South	North	South	South	North
Radius**	30 m	46 m	46 m	305 m	305 m	94 m	150 m	229 m	122 m
Curve type	Slight compound	Single radius	Single radius	Single radius	Single radius	Single radius	Single radius	Single radius	Single radius
Grade*#^	Uphill	Downhill	Downhill	Flat	Flat	Uphill	Downhill	Downhill	Flat
Superelevation^	Positive (steep)	Positive (moderate)	Positive (moderate)	Positive (minor)	Positive (minor)	Positive (moderate)	Positive (moderate)	Positive (minor)	Positive (minor)
Surface quality^	Good	Good	Good	Good	Good	Moderate	Moderate	Moderate	Moderate
Side road/ access point	Driveway (L)	None	None	None	Driveway (L)	Minor side road (L)	Driveway (L)	Driveway (L)	Driveway (L)
Road safety barrier*	W-beam (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)
Motorcycle rub rail*	Yes (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)
Guideposts*	On barrier (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)
CAMs	Yes (N) None (S)	Yes (N) None (S)	None (N) None (S)	None (N) None (S)	None (N) None (S)	None (N) None (S)	None (N) None (S)	None (N) None (S)	None (N) None (S)
Edge line*	None (L) None (R)	None (L) None (R)	None (L) None/Kerb (R)	Solid (L) Solid (R)	Solid (L) Solid (R)	Solid (L) Solid (R)	Solid (L) Solid (R)	None (L) None (R)	None (L) None (R)
Centre line	Double barrier	Double barrier	Double barrier	Double barrier to barrier-dividing	Double barrier to barrier-dividing	Double barrier	Double barrier	Double barrier	Double barrier

Location ID	1			2		3		4	
Curve ID	A	B	C	A	B	A	B	A	B
Speed limit	60 km/h	60 km/h	60 km/h	100 km/h	100 km/h	100 km/h	100 km/h	80 km/h	80 km/h
Curve warning sign (northbound)	Right hairpin curve tightens 30 km/h	Right curve 50 km/h	None	Right curve 80 km/h	None	Winding 50 km/h (prev. curve)	Left curve 80 km/h	None	S-bend 60 km/h
Curve warning sign (southbound)	Left curve 30 km/h	Left curve 40 km/h	Right curve 40 km/h	Left curve 80 km/h	None	Left curve 60 km/h	Right curve 70 km/h	None	S-bend 60 km/h (prev. curve)
Other signs	Lane narrows	None	Steep decent	None	None	Red MC safety warning sign (prev. curve)	Red MC safety warning sign	None	None

L = left side (outside edge) of road, R = right side (inside edge) of road, N = northbound direction, S = southbound direction
**Relative to right-hand curve direction*
***Radius provided by TMR (Locations 1-4)*
#Grade was assessed using ride/drive through video footage and Queensland Government QTopo data (http://qtopo.dnrm.qld.gov.au/Mobile/)
^Qualitative approximation

Table A.3 Attributes associated with potential trial curves requiring an a-priori surface improvement (Site 5)

Location ID	5						
Curve ID	A	B	C	D	E	F	G
Latitude Longitude	27° 8'44.04"S 152°48'42.28"E	27° 8'40.21"S 152°48'40.49"E	27° 8'38.10"S 152°48'38.44"E	27° 8'35.86"S 152°48'37.79"E	27° 8'34.04"S 152°48'34.91"E	27° 8'32.01"S 152°48'34.01"E	27° 8'30.22"S 152°48'31.97"E
Direction*	North	South	North	South	North	South	North
Radius**	91 m	81 m	40 m	38 m	48 m	44 m	53 m
Curve type^	Slight compound	Single radius	Single radius	Slight compound	Single radius	Single radius	Single radius
Grade*#^	Uphill	Downhill	Uphill	Downhill	Uphill	Crest	Downhill
Superelevation^	Positive (moderate)	Positive (moderate)	Positive (moderate)	Positive (moderate)	Positive (moderate)	Positive (moderate)	Positive (moderate)

Location ID	5						
Curve ID	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Surface quality^	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Side road/ access point	None	None	None	None	None	None	None
Road safety barrier*	None (L) None (R)	None (L) None (R)	W-beam (L) None (R)	W-beam (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)
Motorcycle rub rail*	None (L) None (R)	None (L) None (R)	Yes (L) None (R)	Yes (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)
Guideposts*	Yes (L) Yes (R)	Yes (L) Yes (R)	On barrier (L) Yes (R)	On barrier (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)	Yes (L) Yes (R)
CAMs	None (N) None (S)	None (N) None (S)	None (N) None (S)	Yes (N) Yes (S)	None (N) None (S)	Yes (N) Yes (S)	None (N) None (S)
Edge line*	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)	None (L) None (R)
Centre line	Double barrier	Double barrier	Double barrier	Double barrier	Double barrier	Double barrier	Double barrier
Speed limit	60 km/h	60 km/h	60 km/h	60 km/h	60 km/h	60 km/h	60 km/h
Curve warning sign (northbound)	None	S-bend 40 km/h	S-bend 40 km/h (prev. curve)	S-bend 40 km/h (prev. curve)	S-bend 40 km/h (prev. curve)	S-bend 40 km/h (prev. curve)	S-bend 40 km/h (prev. curve)
Curve warning sign (southbound)	None	S-bend 40 km/h (prev. curve)	S-bend 40 km/h (prev. curve)	S-bend 40 km/h	S-bend 40 km/h (prev. curve)	S-bend 40 km/h	S-bend 50 km/h (prev. curve)
Other signs	None	None	None	None	None	None	None

L = left side (outside edge) of road, R = right side (inside edge) of road, N = northbound direction, S = southbound direction
**Relative to right-hand curve direction*
***Radius approximated using Google Earth measuring tool (Location 5)*
#Grade was assessed using ride/drive through video footage and Queensland Government QTopo data (http://qtopo.dnrm.qld.gov.au/Mobile/)
^Qualitative approximation derived from ride-through video and images

Compatibility assessment

A compatibility assessment was undertaken to identify groups of curves that would be compatible for use as treatment and control sites. The first stage involved assessing the compatibility of potential treatment and control curves based on the curve-specific criteria. The aim of this first stage of the assessment was to identify curves that have similar curve-specific properties and could therefore be matched with one another as treatment and control curves. Three specific attributes were deemed vital for compatibility. These were the presence of guideposts and curve alignment markers (CAMs), which themselves act as perceptual countermeasures; and curve radius, which directly affects the speed at which a curve can be traversed. The results of the first stage of the compatibility assessment are shown in Table A.4.

The second stage of the compatibility assessment involved selecting potential matched treatment and control curves that satisfy the global criteria. The aim of this second stage of the assessment was to identify potential groups of curves that could be selected for the trial evaluation. The results of the second stage of the assessment are shown in Table A.5.

Table A.4 Compatibility assessment matrix of potential trial curves (cell colours indicate compatibility between curves in corresponding row and column)

Location/Curve	1/A	1/B	1/C	2/A	2/B	3/A	3/B	4/A	4/B	5/A*	5/B*	5/C*	5/D*	5/E*	5/F*	5/G*
1/A	N/A	Yellow	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Green	Yellow	Yellow	Yellow
1/B	Yellow	N/A	Orange	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	Yellow	Yellow
1/C	Orange	Orange	N/A	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow	Green	Yellow	Green
2/A	Red	Red	Red	N/A	Green	Red	Red	Yellow	Red	Red	Red	Red	Red	Red	Red	Red
2/B	Red	Red	Red	Green	N/A	Red	Red	Yellow	Red	Red	Red	Red	Red	Red	Red	Red
3/A	Red	Red	Red	Red	Red	N/A	Yellow	Red	Yellow	Orange	Orange	Red	Red	Red	Red	Red
3/B	Red	Red	Red	Red	Red	Yellow	N/A	Red	Yellow	Orange	Orange	Red	Red	Red	Red	Red
4/A	Red	Red	Red	Yellow	Yellow	Red	Red	N/A	Orange	Orange	Red	Red	Red	Red	Red	Red
4/B	Red	Red	Red	Red	Red	Yellow	Yellow	Orange	N/A	Yellow	Yellow	Red	Red	Red	Red	Red
5/A*	Red	Red	Red	Red	Red	Orange	Orange	Orange	Yellow	N/A	Yellow	Red	Red	Red	Red	Red
5/B*	Red	Red	Red	Red	Red	Orange	Orange	Red	Yellow	Yellow	N/A	Red	Red	Red	Red	Red
5/C*	Yellow	Yellow	Yellow	Red	Red	Red	Red	Red	Red	Red	Red	N/A	Green	Yellow	Yellow	Yellow
5/D*	Green	Yellow	Yellow	Red	Red	Red	Red	Red	Red	Red	Red	Green	N/A	Yellow	Yellow	Yellow
5/E*	Yellow	Yellow	Green	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow	N/A	Yellow	Green
5/F*	Yellow	Yellow	Yellow	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow	N/A	Yellow
5/G*	Yellow	Yellow	Green	Red	Red	Red	Red	Red	Red	Red	Red	Yellow	Yellow	Green	Yellow	N/A

Green = good agreeance of geometric properties (radius, curve type, grade direction, superelevation), speed limit, signage/markers/barriers and line marking
Yellow = moderate agreeance of geometric properties (radius, curve type, grade direction, superelevation), speed limit, signage/markers/barriers and line marking
Orange = agreeance of only geometric properties (radius, curve type, grade direction, superelevation)
Red = no acceptable agreeance between curve properties
White = same curve
** Curve with sub-optimal pavement condition (would require surface improvement before the trial)*

Table A.5 Suggested options of trial curves and corresponding evaluation scenarios, advantages and limitations

Option	Matched curves	Evaluation scenarios	Advantages	Limitations
1	Pair one: (1/A and 1/B) Pair two: (1/C and 5/E*) or (1/C and 5/G*)	• Evaluate two different treatments in similar curve environments OR • Evaluate two variations of one treatment in similar curve environments	• Both pairs consist of low speed, tight radius curves, allowing two treatments to be evaluated in similar curve environments OR • Ability to compare two variations of the same treatment in similar curve environments	• Limits evaluation to only low speed curves (curve speed advisory generally 40 km/h or below)
2	Pair one: (1/A and 1/B) or (1/C and 5/E*) or (1/C and 5/G*) Pair two: (4/B and 3/B) or (4/B and 5/B*)	• Evaluate one treatment in two different curve environments	• Each pair represents different speed and curve radii, allowing one treatment to be evaluated in two different curve environments	• Curves 3/B, 4/B and 5/B are located in different speed limit zones, although the difference between speed limit and curve speed advisory are similar (difference = 20-30 km/h) • Cannot evaluate different treatments as they cannot be directly compared, due to different curve environments in which they are evaluated
3*	Pair one: (1/A and 1/B) Pair two**: (1/C and 5/E*) Pair three**: (1/C and 5/G*)	• Evaluate one treatment in similar curve environments OR • Evaluate three different treatments in similar curve environments OR • Evaluate three variations of one treatment in similar curve environments	• Evaluation of one treatment over three pairs of curves increases the potential to show a general effect, rather than a local effect OR • All three pairs consist of low speed, tight radius curves, allowing three different treatments to be evaluated in similar curve environments OR • Ability to compare three variations of the same treatment in similar curve environments	• Limits evaluation to only low speed curves • Data collection may be limited to one direction due to increased number of curves being evaluated
4	Pair one: (2/A and 2/B) Pair two**: (1/A and 1/B) or (1/C and 5/E*) or (1/C and 5/G*)	• Evaluate one treatment in two different curve environments	• Each pair represents different speed and curve radii, allowing one treatment to be evaluated in two different curve environments	• Curves 2/A and 2/B are very large radii curves, reducing the probability that an effect will be observed • Evaluation of different treatments could not be directly compared, due to different curve environments in which they are evaluated

** Curve with sub-optimal pavement condition (would require surface improvement before the trial)*
***Note curve 1/C is matched to both 5/E and 5/G. In this scenario, 1/C must act as the control curve with 5/E and 5/G as the treatment curves.*

A.5 Recommendations

After the identification of the suggested treatments along with the potential sites for the trial, researchers met with TMR to discuss the final recommendations for which treatments and sites should be chosen.

TMR has identified a preference for trialling a single type of treatment in different curve speed/curve radii environments. More specifically, TMR identified a preference for trialling the treatment in both low-speed and high-speed environments. Based on this preference, it is suggested that Option 4 from the compatibility assessment be selected. It is recommended to consider as treatment-control the pairs of curves 2/A-2/B and 1/A-1/B. It is noted that, as 1/A and 1/B are in the same direction and in close proximity, 1/A will need to act as the control location to prevent bias from traversing the treatment before traversing the control site.

It is suggested that the PCM should be applied only at the designated treatment location, without installing any 'pre-warning' treatment at curves located upstream of the designated treated curve. This suggested approach is justified on the following basis:

a. In some combinations, the curve immediately upstream of the designated treated curve would act as a control
b. If the trialled treatment proves effective, it is likely that road authorities would limit its implementation to single critical curves; thus, it is important that the trial considers this condition (unless road authorities would decide to systematically implement the treatment also for the first "non-critical" curve located upstream of the target critical curve)
c. Applying a PCM treatment to non-critical curves also may potentially decrease riders' compliance with the treatment in the medium to long term, once they start realising that some of the treated curves may not be critical.

Furthermore, considering Option 4 would also provide the following two additional benefits:

- The possibility of trialling a treatment over two different curve speed/curve radii environments. In particular, TMR have expressed interest in determining whether PCM may be able to mitigate a known safety issue with curves characterised by a larger radius, such as in the case of the pair of curves 2/A-2/B.
- The possibility of determining if the suggested PCM may be able to mitigate the potential risks associated with a driveway/road located on the outside of a curve that can create the illusion of being the continuation of the major road. This type of scenario is present in curve 1/A and cannot be solved with traditional approaches such as CAMs.

On the basis of discussions at the workshop, the best candidate treatments for the trial are the peripheral transverse line marking or the modified peripheral transverse line marking be trialled. These two treatment recommendations, along with their relative benefits and limitations, are outlined in Table A.6.

Table A.6 Recommended shortlist of treatments and trial site combinations (only one combination will be trialled)

Shortlisted Option	Matched curves	Treatment	Benefits	Limitations
I	(2/A and 2/B) (1/A and 1/B) (Option 4)	Peripheral transverse line marking	• Peripheral transverse line markings have been previously trialled and are known to have some effect. • This study can aim to replicate these results in an Australian road environment. • Simplicity of the treatment may be desirable for ease-of-application.	• Countermeasure previously successfully trialled – Little novel information may be gained other than validate/challenge previous findings.
II	(2/A and 2/B) (1/A and 1/B) (Option 4)	Modified peripheral transverse line marking	• This study can aim to provide new knowledge about an as yet unproven treatment. • This treatment is based on a previously trialled treatment with a known effect (peripheral transverse line markings).	• Modified peripheral transverse line markings have not previously been trialled and the effect of the modifications are therefore unknown.

Trials have already been undertaken in New Zealand (Hirsch et al., 2018) that show the efficacy of using peripheral transverse line markings as a PCM. Additionally, Victoria is undertaking a PCM trial using modified peripheral line marking with variable line spacing (Victorian Department of Transport, 2021, personal communication). As both of these trials have/are likely to show the effectiveness of the specific countermeasures being trialled, it is decided that the best use of this project is to trial a **modified version of the peripheral transverse line marking** (without the variable spacing that is planned for the Victorian trial) (i.e. shortlisted **option II** in Table A.1) to gain new information about the efficacy of this countermeasure and to inform whether it can be superior to those having already been, or in the process of being, trialled.

Note that the presence of existing roadside guide posts will be controlled during the trial. All the four selected trial sites have existing guide posts on the roadside in the direction of travel along right curves. Roadside guide posts are also present at the corresponding control sites that are matched to those treated sites. Therefore, it will be possible to separate the potential effect of those delineators from the effect of the trialled perceptual line marking. Nonetheless, this control approach would not allow to identify a potential synergy between roadside guide posts and the trialled treatment (i.e., if the treatment may become more effective when coupled with roadside guide posts compared to being installed on its own).

A decision to use water-based paint for the line marking in this trial was taken based on a trade-off between TMR preference for this specific trial and friction performance. The rationale for the adoption of this type of paint is that it would be easier to be removed by at the end of the trial if TMR will decide to do so. A longer lasting type of paint would be considered in the future if this type of marking if proven successful during the trial.

As for the reduction of friction caused by water-based paint, this should be mainly limited to the micro friction (i.e., the friction due to the surface of each grain), while the macro friction should remain unaffected by the application of this type of paint (i.e., the friction due to the gaps between the grains). Being the reduction of friction caused by water-based paint limited to the micro friction, it should still allow for motorcycles to travel over the painted area safely under normal riding conditions. However, such marginal reduction in friction may cause still instability under extreme riding conditions (i.e., racing-style behaviour). Actually, a perceived impression of friction reduction on the painted areas, although still within a safe level, could be an additional motivation for riders to follow the trajectory that is implicitly suggested by the treatment as well as deter extreme riding behaviour.

Appendix B Workshop with Stakeholders

B.1 Workshop Summary

A workshop with project stakeholders was held to present the findings of the literature review, obtain feedback on perceptual countermeasure (PCM) designs identified in the literature review, and to determine which PCMs should be trialled as part of this study. The workshop was divided into the following sections:

1. Introduction to project background and aim.
2. Presentation on the differences between covert and overt PCM designs, and following discussion of their benefits/disbenefits.
3. Presentation and following discussion on PCMs being used for speed control, lane positioning, or both goals.
4. Presentation and following discussion on how motorcyclists are taught to negotiate curves.
5. Presentation and following discussion on when and where PCMs should be used.
6. Poster presentations of the PCM designs identified in the literature, including an image and a description of each PCM design, the vehicle type(s) targeted in the respective study, trial results, and key findings.
7. Facilitated discussion on the presented PCM designs to allow workshop participants to share their thoughts and ideas.
8. Identification of the PCM designs which participants would like to trial as part of this study (through vote of each of the presented designs).

Based on the vote held during the workshop, the top three PCM designs that participants were willing to consider for the trial were (in the provided priority order):

1. Peripheral transverse line markings with variations on the width of the line markings and/or spacing between line markings.
2. Peripheral transverse line markings applied in conjunction with reflector guide posts.
3. Lane markings applied in conjunction with post mounted delineators or warning signs.

B.2 Workshop Minutes (by Safe System Solutions)

SAFE SYSTEM SOLUTIONS
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[Website]

THE UNIVERSITY of ADELAIDE

MINUTES

MEETING TITLE	SAG6222 - Motorcycle Rider Perceptive Countermeasures - Workshop	
DATE	Tuesday 3 March 2020	
TIME	10:00 - 14:00	
LOCATION	Queensland Transport and Main Roads (TMR), 61 Mary Street, Brisbane	
CHAIR & FACILITATORS	Paul Gottke	Austroads / TMR
	Tana Tan (TT)	Safe System Solutions Pty Ltd
	Chris Stokes (CS)	Centre for Automotive Safety Research, University of Adelaide
ATTENDEES	Simon Harrison (SH)	Queensland Transport and Main Roads – Safer Roads
	Tristan Robertson (TR)	Queensland Transport and Main Roads – North Coast
	Spike Wilson (SW)	Queensland Transport and Main Roads – Safer Roads
	Rob Mothersole (RM)	Queensland Transport and Main Roads - North Coast
	Tracey Smith (TS)	Queensland Transport and Main Roads – Safer Speeds
	Evan Coulson (EC) - Skype	Victoria Department of Transport
	Beck McKinney (BM) - Skype	Tasmania Department of State Growth
	Joseph Le (JL)	Transport for New South Wales
	Sarah Lepre (SL)	Transport for New South Wales
	Luke Solomon (LS)	Transport for New South Wales
	Julian Chisnall (JC)	New Zealand Transport Authority
	Lachlan Moir (LM)	Queensland Transport and Main Roads – Road Design
	Santosh Tripathi (ST)	Queensland Transport and Main Roads – Road Design
APOLOGIES	David Bobberman (DB)	Austroads
	Amit Dua (AD)	South Australia Department of Planning, Transport and Infrastructure
	Mark McDonald (MM)	Queensland Transport and Main Roads – Traffic Engineering
	Martin Jones (MJ)	Queensland Transport and Main Roads – North Coast
	Craig Hoey (CH)	Tasmania Department of State Growth
	David Moyses (DM)	Main Roads Western Australia

OBJECTIVE

The objectives of the workshop were:

a) Obtain workshop participants' views on the PCMs presented in the literature review.

b) Obtain workshop participants' input on PCMs that may be included as part of this study.

c) Determine which PCMs the workshop participants would like to see included in this study

MINUTES

The workshop was broken up into ten sessions and they, along with the minutes from each session, are presented in the table below. It is noted that Session 3 to 6 were conducted to create a general dialogue on PCMs and to obtain participants' views on PCMs. Session 7 to 9 were conducted to present the literature review to the participants in a concise manner and to obtain their input on the PCMs that may be studied as part of this project.

Session	Session Title	Minutes
1	Introduction	• TT welcomed the workshop participants. • Participants introduced themselves to the group.
2	Project Background	• PG and TT provided a background on the project (Appendix A). • TT provided an update on the project's progress and future steps (Appendix A). • TT provided a definition of PCM (Appendix A). • TT mentioned that the key outcomes of this workshop is to understand which 2-3 PCMS the participants feel the project should trial and evaluate.
3	Covert vs Overt	• TT provided an explanation and example of covert vs overt PCMs • Feedback from participants were: ○ Covert: ○ Simpler ○ Lower maintenance ○ Overt: - Riders may see this (e.g. speed advisory signs) as a challenge rather than a warning - Better to give information rather than behaviour advice - Can be costly to install and maintain (e.g. vehicle activated signs) ○ Other Notes: - We should consider who we are targeting? E.g. commuters, weekend riders, etc. - Note that this can also be classified as active vs passive instead of overt and covert. - Is the method to determine speed advice applicable for motorcyclists, noting that they were developed for vehicle drivers.
4	PCMs for speed vs lane positioning	• TT provided an explanation and example of PCMs for speed, lane positioning, and speed & lane positioning. • Feedback from participants were: ○ NZ study targeting both speed and positioning with their peripheral transverse line markings. Speed was noted to increase but the riders had better lane positioning. ○ NZ study found that cars also had better positioning due to the treatment. ○ A question was raised on what the minimum radius that PCMs can be applied and have a positive result? Can the PCMs be used for both single and compound curves? ○ The ideal route for motorcyclists shouldn't need PCM treatment. We should target curve deficiency. ○ We should keep in mind both experienced and novice riders' positions in the lane and that they may differ. For example, how do we consider returning riders or those who are on new/unfamiliar motorcycles?

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		○ A question was raised on what happens if we guide riders into a poor surface area? E.g. ruts, potholes, etc. ○ Riders may line themselves up to take the correct line and increase their speed if we provide lane positioning guidance. ○ Can we assist riders setting up their position and speed for successive curves? ○ Riders do make mistakes even when not 'pushing' the limits. ○ From the NZ study, it was found that fatigue was more of a problem on the inbound route rather than outbound route.
5	Motorcycles in curves	• TT provided a background on how different riders and motorcycles will navigate a curve. • Feedback from participants were: ○ EC provided a diagram of the 4 phases of curve negotiation. Noted that errors occur in phase 2 (entry of the curve) and 3 (the curve itself) and crashes occur in phase 4 (exit of a curve) (Appendix B) ○ Are we trying to affect perception of "tightness" or lane position? ○ How do we deploy PCMs in one curve versus 2 or 3 consecutive curves? ○ Treatment needs to be consistent and appropriate, even if targeting cars. ○ Assessment criteria as important as treatment type. We need the right treatment for the right curve. ○ Need to bring curve up to standard before applying treatment. ○ Conceptualise issues before selecting a treatment. ○ Do we need to deploy communications to the community before trialling PCMs? Need to emphasize guidance and not speed reduction. ○ Riders can read curves differently on different days, relaxed or otherwise motivated. Fatigue can also be a factor.
6	When should PCMs be used?	• Feedback from participants were: ○ Large radii or small radii curves - what are we targeting? ○ Are a series of tight curves more of a problem than single curves? ○ Large speed differential (i.e., between the straight road section leading up to a curve) can result in crashes pre-apex due to wrong curve set up. ○ As speed increases, concentration decreases when going from a twisty section to an open section. We might be seeing this happen on Mt. Mee Road. ○ Ideally trial is not in an area where superelevation is present. ○ Ideally trial is not held in an area where shadows on the road may be present. ○ Tight low speed curves have more issues. ○ Assessment framework for selection of sites that are suitable for a particular PCM. A flow chart might be a useful outcome. Could test on multiple Mt Mee Road sites, desktop audit.

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7	Viewing of PCMs	• The participants viewed all 19 PCMs that were contained in the literature review. • The 19 PCM posters contained information on the PCM, the PCM study and key study findings (Appendix C).
8	Discussion on PCMs	• TT then facilitated a discussion on PCMs after participants viewed the PCMs. The feedback from this session is as follows: ○ Preference is not to trial the coloured herring line PCM (Appendix C - page 19) that was developed by SSS and CASR. The colour gradient as a riders ride into and through a curve could be seen by riders as a challenge to ride through the curve faster. ○ If the line marking needs to be of high-friction surface by means of OmniGrip; however, some contractors may replace this more expensive treatment with cheaper treatment (e.g. painted lines). ○ Do not apply PCM across the full road width as this can be hazardous to riders. ○ Need to communicate the trial of PCMs to motorcycling communities regardless of whether the treatment is high friction or not. ○ Do not install PCMs that will provoke speed increase. ○ Do not install PCMs that will push riders towards the centrelines. (Appendix C - Page 9 and 11) ○ Need to consider maintenance issues and how the PCMs are renewed. For example, Road Edge Guide Post (REGP) would require work crew to have drawings that will enable them to accurately install posts and detailed instructions on how to replace them. ○ No 3D PCMs (Appendix C - Page 16)- maintenance issues. ○ PCMs that 'trick' may lead to riders/drivers ignoring them treatment next time ○ Threshold treatments need to consider surface bleeding, wet roads, etc. ○ Simple treatment is preferred. ○ Shadows can affect PCM effectiveness. ○ WYLIWYG treatments need to consider difference between NZ vs. Aust. Motorcycle training ○ Consider trialling 'tear drop' centrelines to encourage riders to maintain their buffer in curves. This may be applied with wide centreline treatment.
9	Voting on PCMs	• Participants then voted on the PCM which they would prefer to see trialled and noted any variations that CASR and SSS should explore. • The 3 most favoured PCMs are: 1. Peripheral transverse line markings with variations on the width of the line markings and/or spacing between line markings 2. Peripheral transverse line markings applied in conjunction with reflector guide posts. 3. Line markings applied in conjunction with post mounted delineators or warning signs. • Comments from the workshop participants were: ○ Herringbone line marking with variable spacing on the approach to a curve or where there is a change in

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		radius but not through the curve. In fixed radius curve maintain consistent line spacing. ○ Suggestion that we should consider herringbone line marking thickness variation rather than varying spacing. ○ Ease of conveying information to contractors/construction crews. ○ Consider the use of teardrop markings to widen centrelines.
10	Closing	• TT thanked the participants for their input. • TT mentioned that their input during this workshop will be considered during the PCM selection and site selection.
		Workshop closed at14:00.

B.3 Poster Slides (With Comments and Ranking on Treatments)

Post Mounted Delineators

Countermeasure Description:
Chevrons and hazard marker posts, also known as post-mounted delineators, are devices used at the roadside to delineate the road. The main purpose of a delineating device is to outline the path of the road to a road user by providing them with visual clues (Charman,2010).

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- Effective in enabling road users to select an appropriate speed on bends

Other Key findings:
- Remain visible in adverse weather conditions and at night

Workshop Participants General Comments:

CAMs need a better selection methodology to ensure consistent application.

Are we assuming the road has been appropriately signed according Part 2 MUTCD

Adds another hazard to outside of curve, explore safer alternatives

ALREADY Common PRACTICE.

EC - Trial with a combination of another treatment. i.e. treatment 6.

1

Vehicle Activated Warnings

Countermeasure Description:
Vehicle Activated Signs (VAS) are signs that automatically light up when a vehicle approaches the sign or when the vehicle approaching the sign exceeds a pre-set speed threshold. These signs often repeat a fixed warning sign and can display a message such as, 'Slow Down'.

Photo of Countermeasure:

Measurement of Success:
- Speed Reduction

Vehicle Trialed:

Results:
- These signs can reduce vehicle travel speeds by 2 km/h to 7 km/h during trials in the UK

Other Key findings:
- No reports of drivers becoming habituated to these signs

Workshop Participants General Comments:

ALREADY COMMON PRACTICE

Still see this has a role to play in certain environments

Only for exceptional sites

2

Rumble Strips

Countermeasure Description:

Rumble strips are small raised lines laid transversely across the road which result in a haptic and auditory effect in vehicles that are driven over them. They are used to alert road users to the presence of a road hazard and can be installed in a single group or in a series of groups

Photo of Countermeasure:

Measurement of Success:

- Speed Reduction

Vehicle Trialed:

Results:

Other Key findings:

- Although they can be installed on the approach to bends, it is noted that rumble strips have a lower coefficient of friction than asphalt and so may negatively affect the braking and steering capabilities of motorcycles.
- Furthermore, it is noted that there are line markings which have coefficient of friction that are similar to the that of the road surface but this coefficient of friction reduces as the lines wear down.

Workshop Participants General Comments:

Potentially good for fast speed reductions on a threshold (eg TET) however inappropriate for approaches to cornering ?TO

This could work as a 'gateway' treatment into a series of high risk curves

ALREADY common PRACTICE.

See this may be a treatment without the tactile element

Only ~~[illegible]~~ on long straights

3

Transverse Line Markings

Countermeasure Description:
Transverse lines are somewhat similar to rumble strips but do not result in a haptic and acoustic effect in vehicles that are driven over them. Instead, they work by drawing a road user's attention to the line markings which, in turn, are designed to alert the road user to a road hazard

Photo of Countermeasure:

Measurement of Success:
- Speed Reduction

Vehicle Trialed:

Results:
- They have been reported to result in low-to-moderate speed reductions (Fildes & Lahausse, 2008).

Other Key findings:
- As with rumble strips, transvers line markings will have a lower coefficient of friction than asphalt and may negatively affect the braking and steering capabilities of motorcycles.

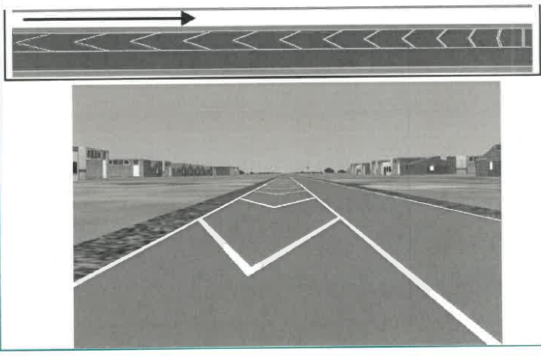
Workshop Participants General Comments:

4

Herringbone Line Markings

Countermeasure Description:
Herringbone line markings are a form of transvers line markings but the lines are painted in a herringbone pattern.

Photo of Countermeasure:



Measurement of Success:
- Speed Reduction

Vehicle Trialed:

Results:
- A literature review conducted by Fildes & Lahausse (2008) on the effectiveness of herringbone line markings noted that they did not produce any significant speed reductions on curves unless they are combined with warning signs and/or CAMS.
- However, a study in New Zealand found that herringbones line markings produced significant improvements in drivers' lane positions by flattening the drivers' paths through the bends (Charlton, 2007).

Other Key findings:
- As with rumble strips and transvers line markings, herringbone line markings strips have a lower coefficient of friction than asphalt and may negatively affect the braking and steering capabilities of motorcycles.

Workshop Participants General Comments:

Angled paint across white line not ideal from skid resist. perspective

5

Peripheral Transverse Line Markings

Countermeasure Description:
Peripheral transverse line markings are square or rectangular lines painted at intervals perpendicular to the road edge and centre line. They are usually 60 cm wide with regular or decreasing intervals and are painted over lengths of 400 m to 50 m on approach to a hazard

Photo of Countermeasure:

Measurement of Success:

- Speed Reduction

Vehicle Trialed:

Results:

- An Australian Transport Safety Bureau (ATSB, 1999) driving simulator study found that, for straight section of roads, peripheral transverse line markings were effective at reducing speeds by 11 km/h, which is a level similar to that achieved by full-width transverse line markings
- However, it is not clear if both peripheral and full-width transvers lines have a long-term effect on speed reduction.
- It was also noted that decreasing spacing between the transverse lines did not have an effect on vehicle speed (ATSB 1999).
- A case-control motorcycle specific perceptual countermeasure study by Mulvihill, Candappa & Corben (2008) found that peripheral transverse lines markings resulted in a small but significant 85th percentile speed reduction of 0.53 km/h

Other Key findings:

Workshop Participants General Comments:

Varying spacing / varying thickness

Change of shape a consideration?

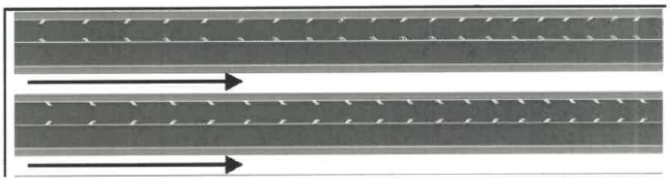
May present challenges on 2/3 successive curves

If a rider makes an error and varies from the encouraged line, have we now increased the risk by forcing them onto paint?

Like the narrowing effect of this treatment

6

Peripheral Herring Lines

Countermeasure Description:	**Photo of Countermeasure:**
Peripheral line markings may also be of the herringbone configuration and are known as peripheral herring lines. The ATSB (1999) hypothesised that peripheral herring lines would give road users an impression of an approaching lane width narrowing and, thus, the road user may reduce their travel speed	

Measurement of Success:	**Vehicle Trialed:**
• Lane Positioning • Speed Reduction	

Results:

- The ATSB study, conducted in a simulator with straight sections of roads, found that there was a reduction in vehicle travel speed when these lines were present.
- However, the speed reduction was not greater than that of transverse line or peripheral line markings.

Other Key findings:

- In France and Germany surface markings positioned along the centre line are intended to increase motorcycle separation with on-coming traffic
- Winkelbauer et al. (2012) suggest the benefits of increased separation are expected to be high and that such treatments should be installed at all motorcycle black spots and motorcycle roads

Workshop Participants General Comments:

Any advantage over 'black' markings?

Which direction of slanted herringbone is more effective?

7

Warning Signs and Line Markings

Countermeasure Description:
Warning signs and peripheral herring lines have been combined in a vehicle simulator study by Charlton (2007) to determine if this combination of perceptual countermeasure can be more effective than if the warning sign was used alone.

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- Their study found that a combination of warning signs and peripheral herring lines was more effective in reducing vehicle travel speed than when a warning sign is used without herring lines.
- The reduction in vehicle travel speed was found to be between 2.74 km/h to 5.78 km/h, depending on the bend radius and sign posted speed.
- Furthermore, the study also found that this combination of perceptual countermeasures improved lane positioning.

Other Key findings:

Workshop Participants General Comments:

Good in theory but hard to communicate to riders.

8

Low Visual Contrast Edge Lines

Countermeasure Description:
Low visual-contrast edge lines on straight roads were evaluated by the ATSB (1999) in their driving simulator study. They hypothesised that the road user's perception of an increased crash risk may result in a decrease in travel speed.

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- Although the study found that vehicle travel speed did decrease by an average of 1.88 km/h, the vehicles also travelled closer to the centreline.

Other Key findings:
- This placement of the vehicle closer to the centerline potentially increases crash risk but the risk has not yet been evaluated

Workshop Participants General Comments:

decreases buffer zone for motocyclists

9

Hatched Edge Lines

Countermeasure Description:
The effects of hatched edge lines on road users were explored by the ATSB (1999). Their hypothesis was that hatched edge lines create an illusion that the curve is tighter than it is.

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- The study found that hatched edge lines resulted in vehicles travelling between 25 cm and 38 cm closer to the centreline for both left- and right-hand bends, which is undesirable as it may increase the risk of a head on collision.
- Furthermore, the enhanced centrelines had no effect on vehicle travel speed

Other Key findings:

Workshop Participants General Comments:

10

Painted Chequered Edge Lines

Countermeasure Description:
Painted chequered edge lines were included in the study conducted by the ATSB (1999). Their theory was that the chequered lines may influence the perceived travel speed by the road user and, thus, result in a reduction in vehicle travel speed

Photo of Countermeasure:

Measurement of Success:
- Speed Reduction

Vehicle Trialed:

Results:
- The study found that chequered edge lines had little to no effect on vehicle travel speed

Other Key findings:

Workshop Participants General Comments:

11

Hatched Centre Lines

Countermeasure Description:
The effects of hatched centre lines on road users were explored by the ATSB (1999). Their hypothesis was that hatched centrelines may accentuate the curvature in the bed and, thus, reduce vehicle travel speed.

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- The study found that hatched centre lines resulted in no change in travel speed but vehicles travelled further away from the centreline by 22 cm to 35 cm for right hand bends.
- No shift in vehicle position was reported for left hand bends.

Other Key findings:

Workshop Participants General Comments:

May result in rider using wide median to overtake.

Just use wide centre lines

I would recommend investigating a combination of hatched/wide centreline with perceptual lane width narrowing.

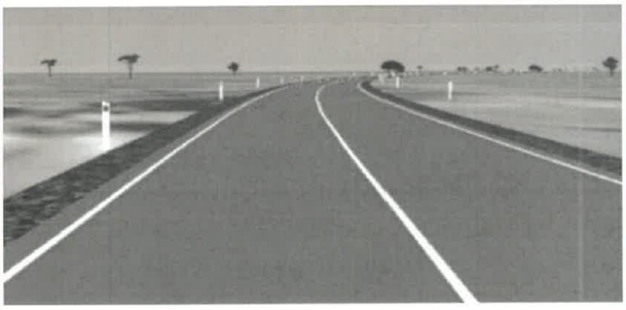
Variation of hatched ℄ ⇒ use 'tear drops' @ apex

12

Edge Lines and Reflector Guide Posts

Countermeasure Description:
The ATSB also experimented with edge lines and reflector guide posts, painted and installed, respectively, on bends to determine if this combination of delineation may result in a reduction in vehicle travel speed (ATSB 1999). Their study involved placing reflector guide posts (1) on both sides of the road, (2) on the outside bend, and then (3) with ascending post height on the outside of bends

Photo of Countermeasure:



Measurement of Success:

- Speed Reduction

Vehicle Trialed:

Results:

- When posts were place on both side of the road, they reported that vehicle travel speed increased by 1.5 km/h for left-hand bends and there was no change in speed for right hand bends.
- When the reflector posts were placed on the outside of bends, they reported that there was a 1.5 km/h decrease in speed for left-hand bends but there was a 2.1 km/h increase in speed for right-hand bends.
- When ascending height posts were placed on the outside of bends, there was a 1.4 km/h decrease in vehicle travel speed for both left- and right-hand bends.
- However, the study's authors noted that this 1.4 km/h decrease in vehicle travel speed was not statistically different to that of the case where ordinary guideposts were installed on the outside of the bend.

Other Key findings:

Workshop Participants General Comments:

Difficult to ensure long term maintenance.

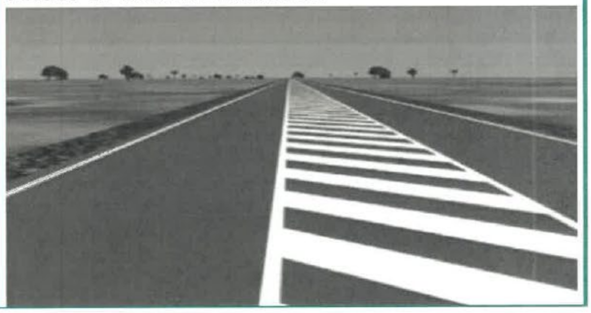
must Common treatment (General)
perhaps should try / formalise!

13

Perceptual Lane Width Narrowing

Countermeasure Description:
The simulator study conducted by the ATSB (1999) also included a study on the effects of narrow lane width on vehicle travel speed on straight roads

Photo of Countermeasure:



Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- They found that narrow lane widths of 2.5 m reduced vehicle travel speed by 2.2 km/h compared to that of a 3.0 m wide lane
- Although lane width narrowing may result in a reduction of vehicle travel speed, it is possible that road users may position their vehicles towards the centreline, and, thus, result in an increased likelihood of a crash with oncoming vehicles

Other Key findings:

Workshop Participants General Comments:

Skeptic about the effectiveness as 2.5 m is still available.

I would recommend considering a combination of hatched/wide centreline and perceptual lane narrowing.

14

Peripheral Transverse Line and Reflector Guide Posts

Countermeasure Description:
The effects of a combination of peripheral transverse lines and reflector guide posts were explored in a case-control motorcycle study by Mulvihill, Candappa & Corben (2008). Peripheral transverse lines were installed on an approach to a single bend and reflector guide posts were installed throughout a series of bends. The study also explored the effects of ascending guide post height on the approach to a single bend and through a series of bends

Photo of Countermeasure:

Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- The study found that this treatment resulted in an average speed reduction of 1.34 km/h compared to the control bends
- The ascending guide posts resulted in an average 1.49 km/h decrease in motorcycle travel speed compared to the control bends.

Other Key findings:

Workshop Participants General Comments:

Difficult to ensure long term maintenance.

Positive – except the [illegible]

15

3D Road Markings

Countermeasure Description:	Photo of Countermeasure:
3D road markings, thus far, have been shown to have negligible effects on speed and driver behaviour in general but are yet to be thoroughly investigated. They could also create driver frustration if they feel 'tricked' and there is the potential that 3D road markings could result in erratic or avoidance manoeuvres which may negate any safety effects from these types of PCMs	

Measurement of Success:	Vehicle Trialed:
• Lane Positioning • Speed Reduction	
Results:	
Other Key findings:	

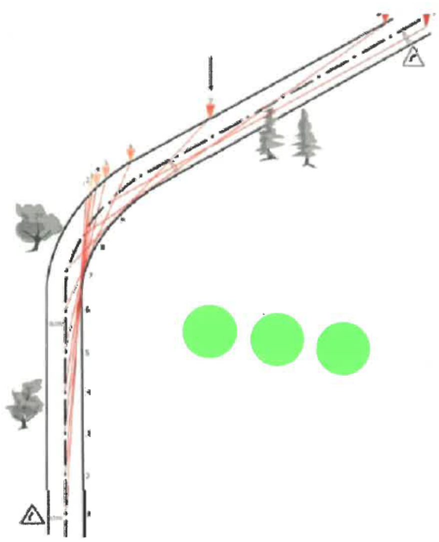
Workshop Participants General Comments:

16

Where You Look Is Where You Go (WYLIWYG)

Countermeasure Description:
The "Where You Look Is Where You Go" (WYLIWYG) treatment was conceived in Buckinghamshire County Council. It is based on motorcycle riding techniques contained in the United Kingdom's (UK) police book titled *Motorcycle Roadcraft - The Police Rider's Handbook to Better Motorcycling* (James, 2007). The treatment is based on the recommended riding practice of looking where the motorcyclists wants to go, hence the 'where you look is where you go' name. In bends, motorcyclists are advised to look for the vanishing point of the curve which gives them a cue as to how sharp the curve is and the extent of the curve.
Riders are also advised to reduce their speed on the approach to a bend to a speed at which they can travel safely around the bend. Once a rider is in a bend, they are advised to keep their eye on the vanishing point and steer their bike towards it. The treatment therefore uses conspicuous guide posts to guide the rider's direction of gaze around a curve in such a way that the motorcycle follows an appropriate trajectory (Cairney & Beesley, 2012).

Photo of Countermeasure:



Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- The study found that, for both right-hand and left-hand bends, overall travel speeds were lower in the case sites compare to control sites.
- They also observed that motorcycle positioning in the travel lane did not place the motorcyclists at an increased risk of a crash with oncoming vehicles

Other Key findings:

Workshop Participants General Comments:

#Been hearing about this treatment for a while. Let's try!

takes riders eyes away from road surface

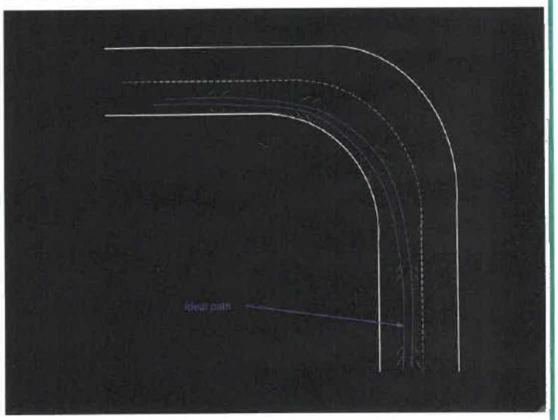
Consider UK road environment in comparison to AU/NZ before applying.

17

Herringline Guidance

Countermeasure Description:
Herringline Guidance is a treatment still in the conceptual stage. This countermeasure aims to help navigate riders around curves.

Photo of Countermeasure:



Measurement of Success:
- Lane Positioning
- Speed Reduction

Vehicle Trialed:

Results:
- No studies have been conducted on this treatment

Other Key findings:

Workshop Participants General Comments:

Different riders/bikes will differ.

18

Concept Perceptual Countermeasure

Workshop Participants General Comments:

19

Appendix C Candidate Curves for the Trial

C.1 Site 1

Figure C.1: Locations and radius of curves at Site 1

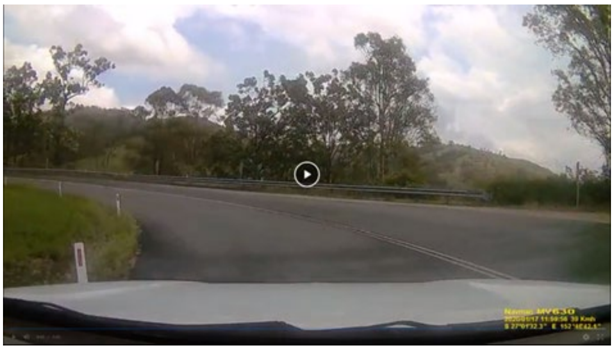
Curve Locations

Curve Radius

Source: Google Earth.

Figure C.2: Views of the approach and mid curve for Curve A at Site 1 (southbound direction)

Approach View



Mid-curve view

Figure C.3: Views of the approach and mid curve for Curve B at Site 1 (southbound direction)

Approach View

Mid-curve view

Figure C.4: Views of the approach and mid curve for Curve C at Site 1 (southbound direction)

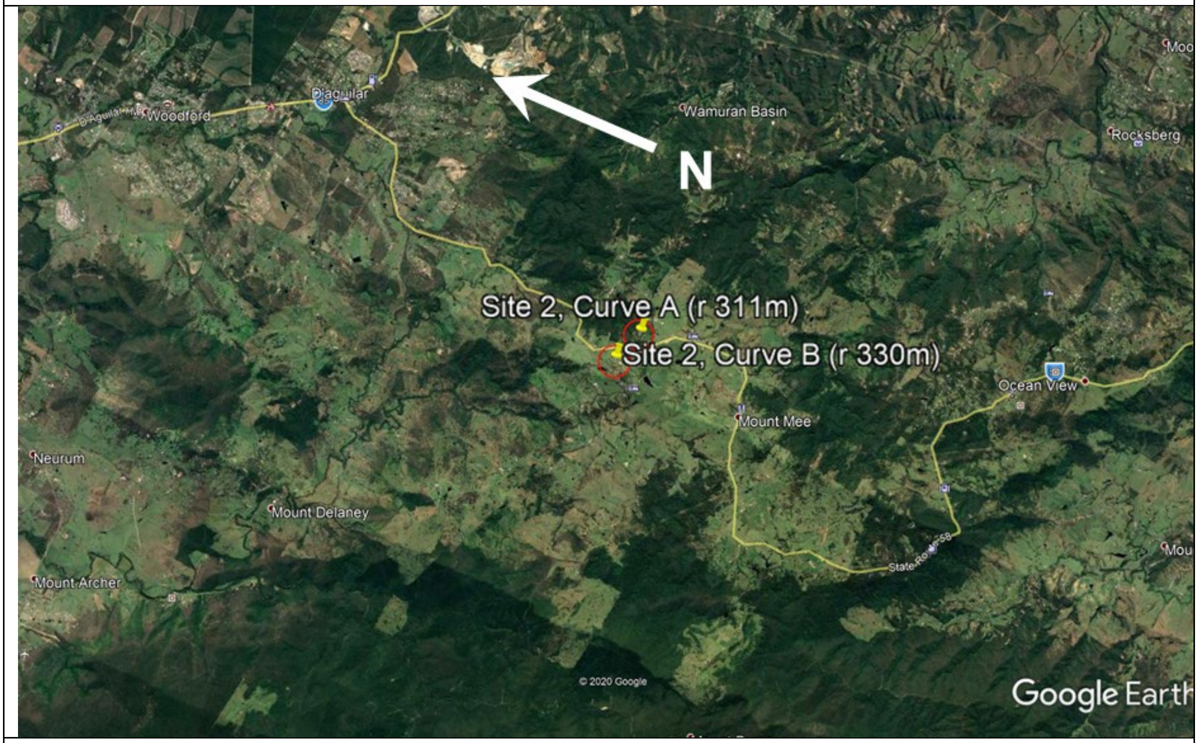
Approach View

Mid-curve view

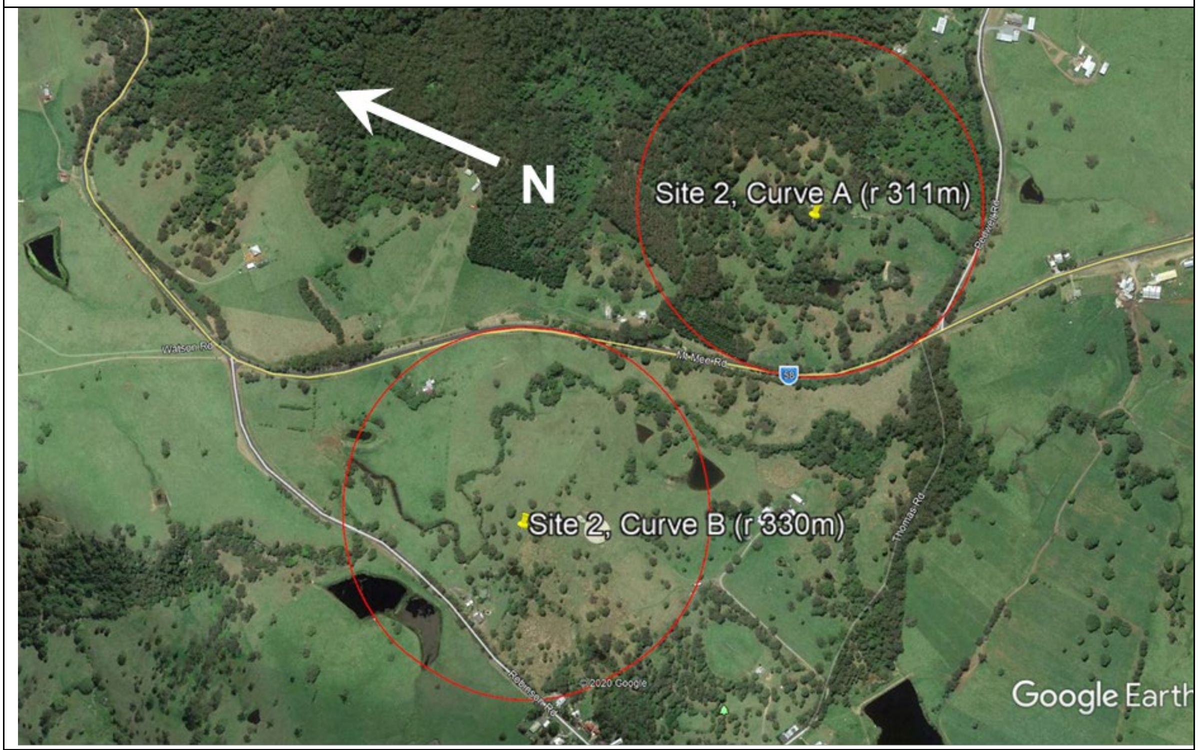
C.2 Site 2

Figure C.5: Locations and radius of curves at Site 2

Curve Locations



Curve Radius



Source: Google Earth.

Figure C.6: Views of the approach and mid curve for Curve A at Site 2 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.7: Views of the approach and mid curve for Curve B at Site 2 (southbound direction)

	
Approach View	*Mid-curve view*

C.3 Site 3

Figure C.8: Locations and radius of curves at Site 3

Curve Locations

Curve Radius

Source: Google Earth.

Figure C.9: Views of the approach and mid curve for Curve A at Site 3 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.10: Views of the approach and mid curve for Curve B at Site 3 (southbound direction)

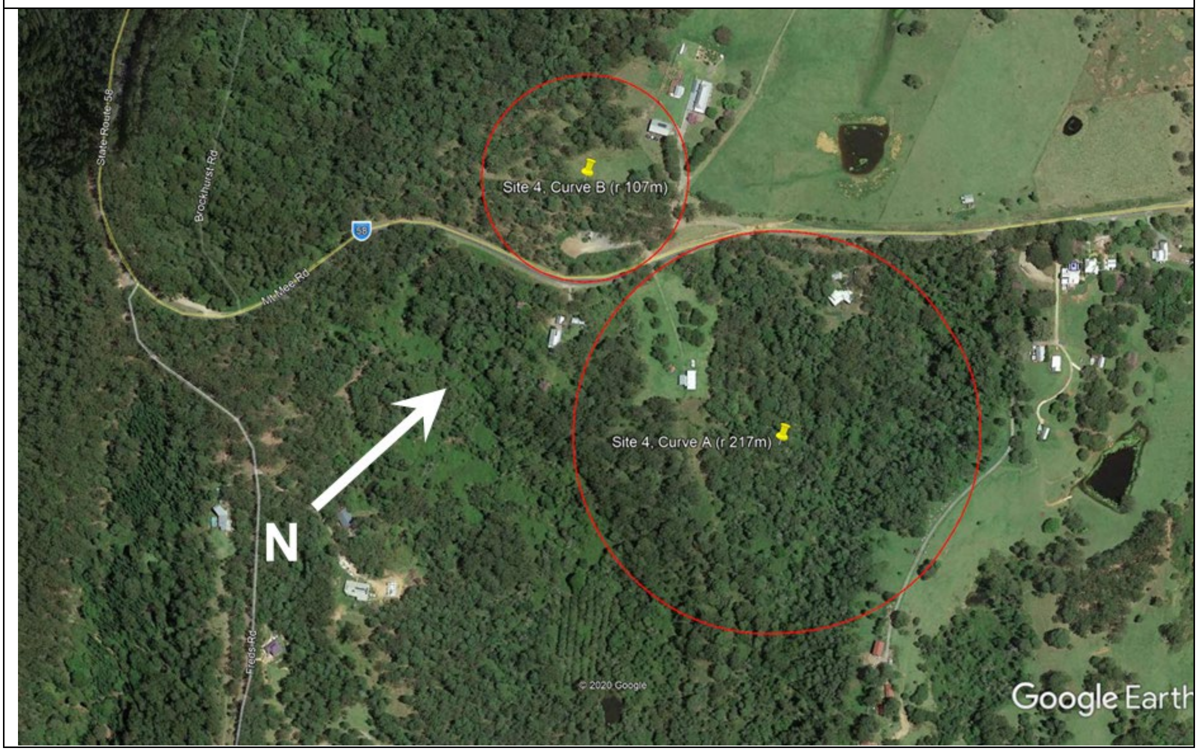
	
Approach View	*Mid-curve view*

C.4 Site 4

Figure C.11: Locations and radius of curves at Site 4

Curve Locations

Curve Radius



Source: Google Earth.

Figure C.12: Views of the approach and mid curve for Curve A at Site 4 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.13: Views of the approach and mid curve for Curve B at Site 4 (southbound direction)

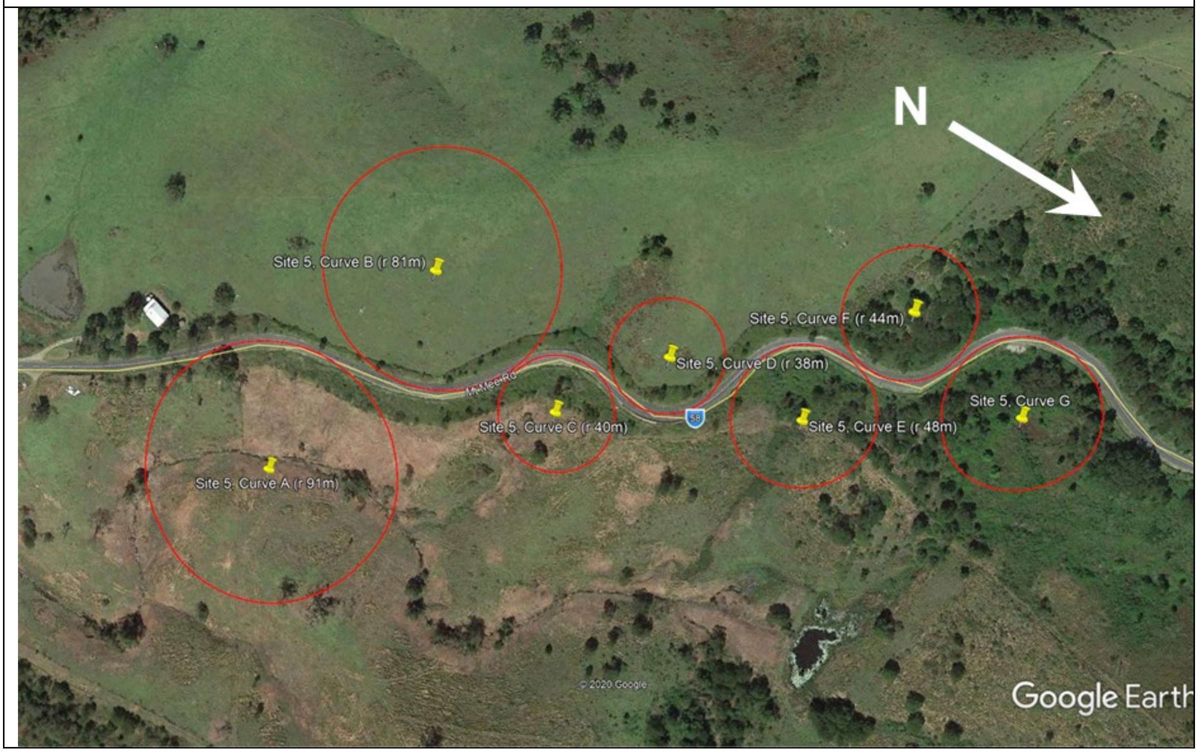
	
Approach View	*Mid-curve view*

C.5 Site 5

Figure C.14: Locations and radius of curves at Site 5

Curve Locations

Curve Radius



Source: Google Earth.

Figure C.15: Views of the approach and mid curve for Curve A at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.16: Views of the approach and mid curve for Curve B at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.17: Views of the approach and mid curve for Curve C at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.18: Views of the approach and mid curve for Curve D at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.19: Views of the approach and mid curve for Curve E at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.20: Views of the approach and mid curve for Curve F at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Figure C.21: Views of the approach and mid curve for Curve G at Site 5 (southbound direction)

	
Approach View	*Mid-curve view*

Appendix D Radar and Video Cameras

D.1 Locations of Radars and Video Cameras

D.1.1 Tight Curves

Figure D.1: Locations of radars and video cameras at the tight trial curve – Treatment site

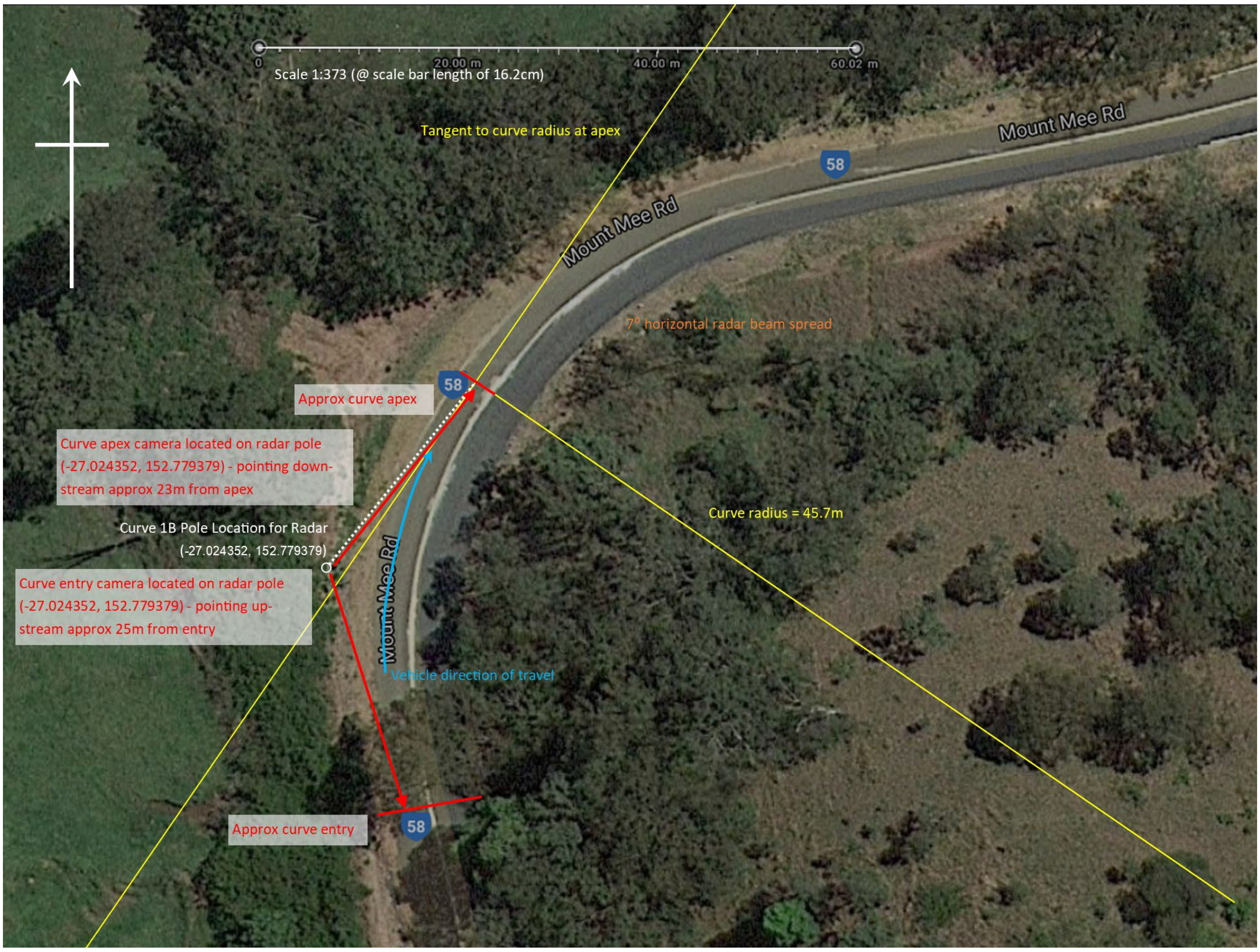
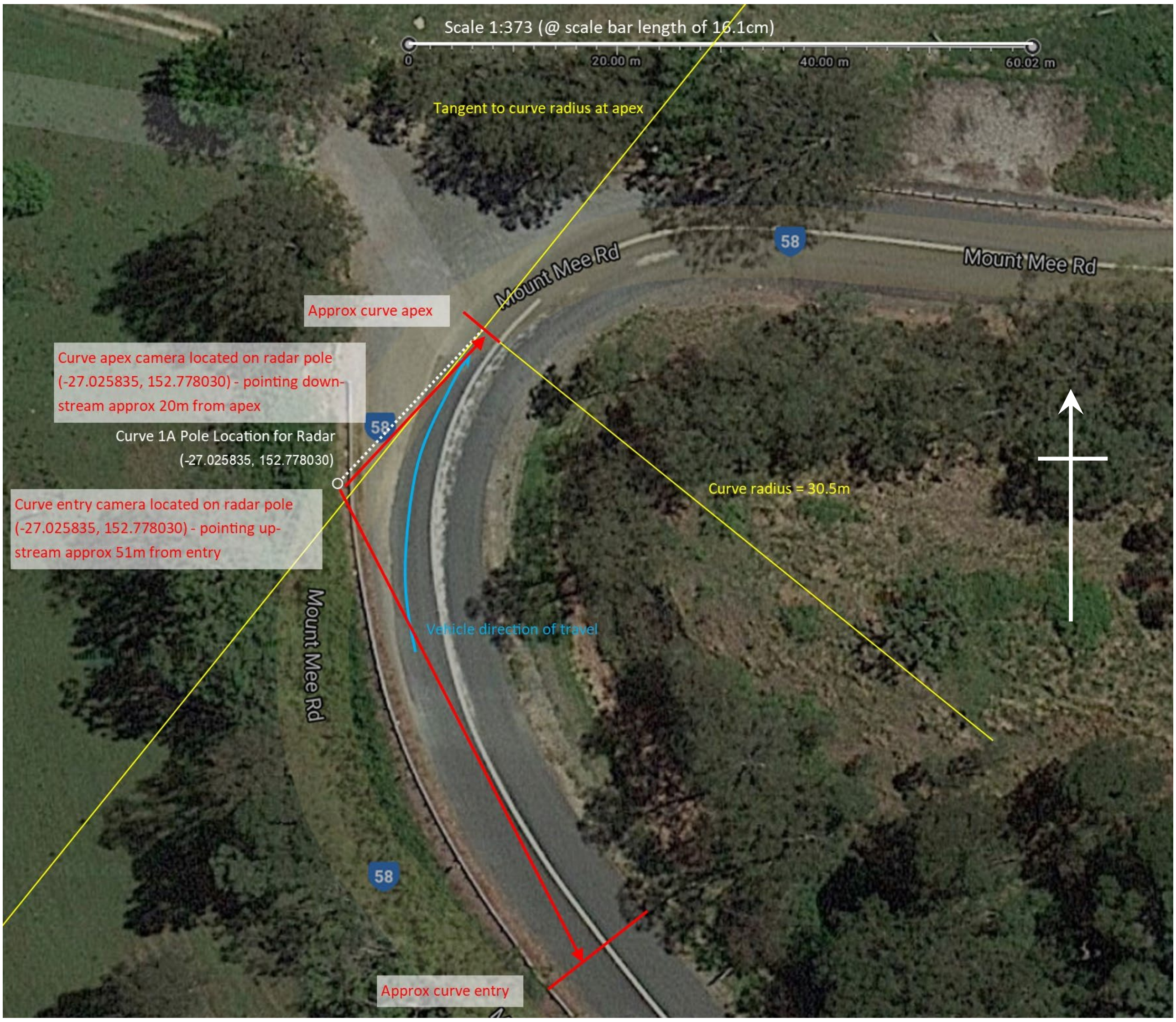


Figure D.2: Locations of radars and video cameras at the tight trial curve – Control site



D.1.2 Shallow Curves

Figure D.3: Locations of radars and video cameras at the shallow trial curve – Treatment site

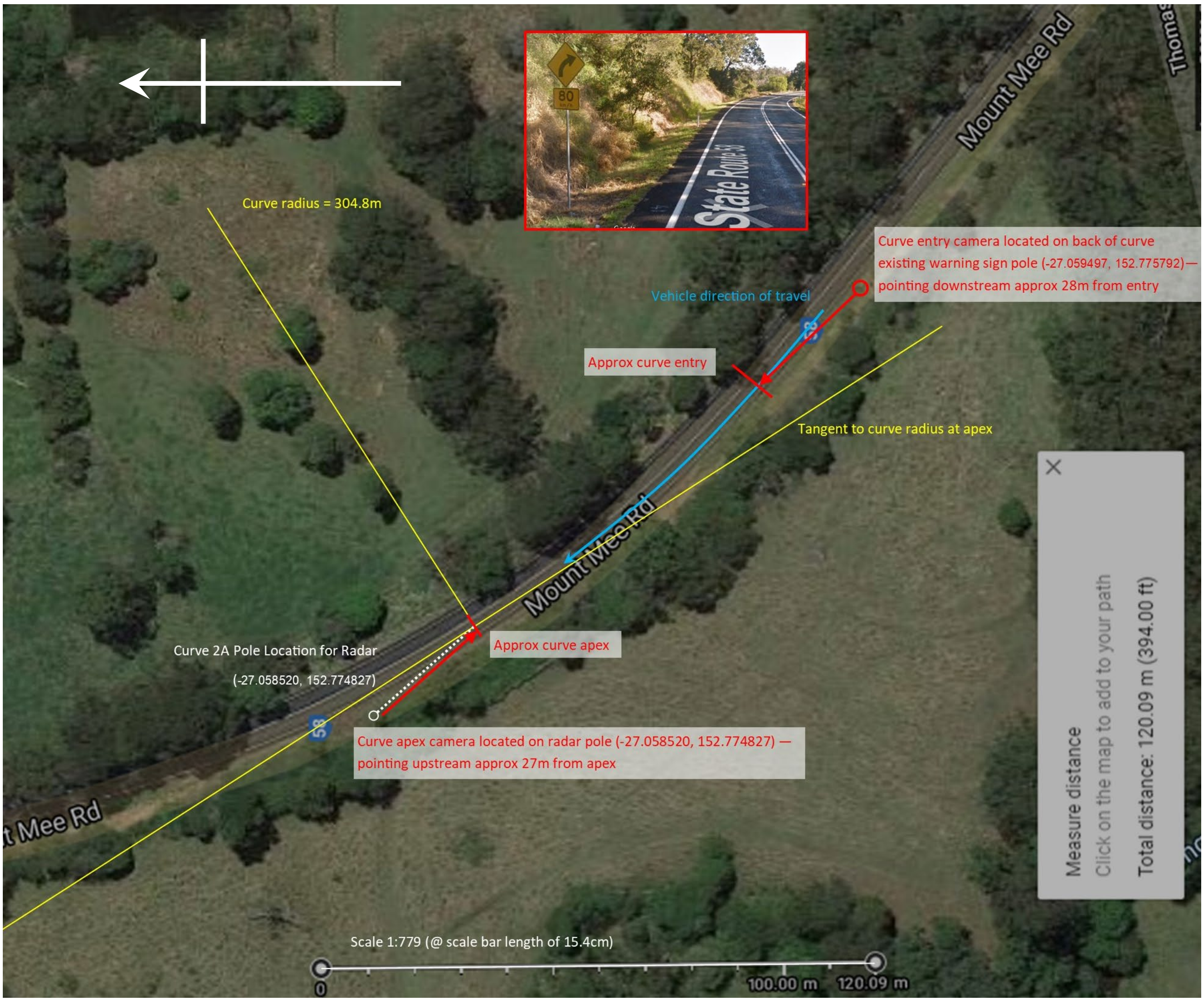
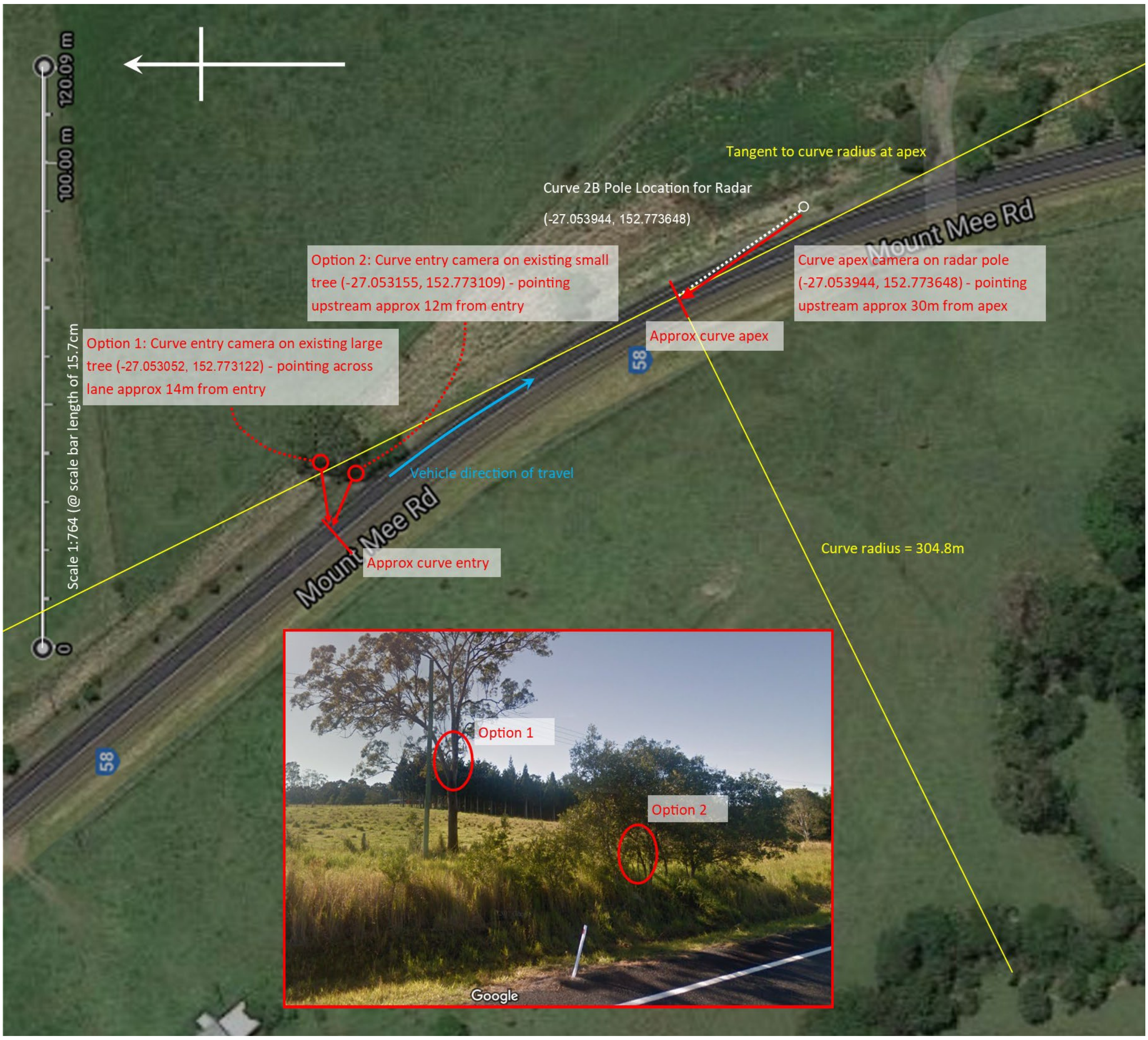


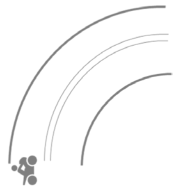
Figure D.4: Locations of radars and video cameras at the shallow trial curve – Control site



D.2 Video Cameras - Views and Reference Scale for Lane Position

Figure D.5: Camera views and reference scale used for measuring lane position - Entry of the trial curves

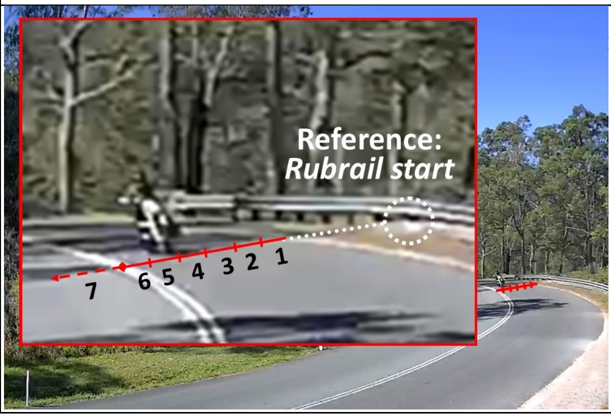
Tight Curves (Pair 1)



Shallow Curves (Pair 2)

Treatment

Control



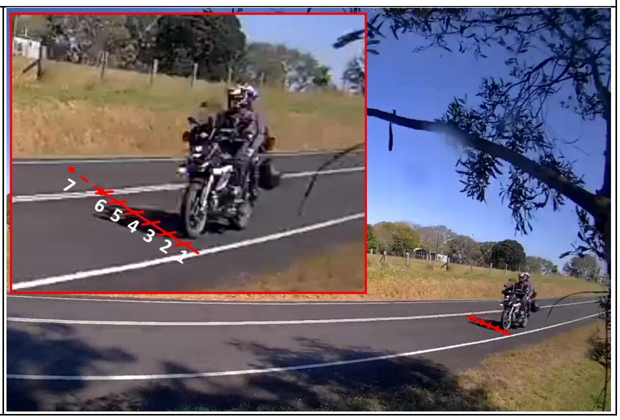
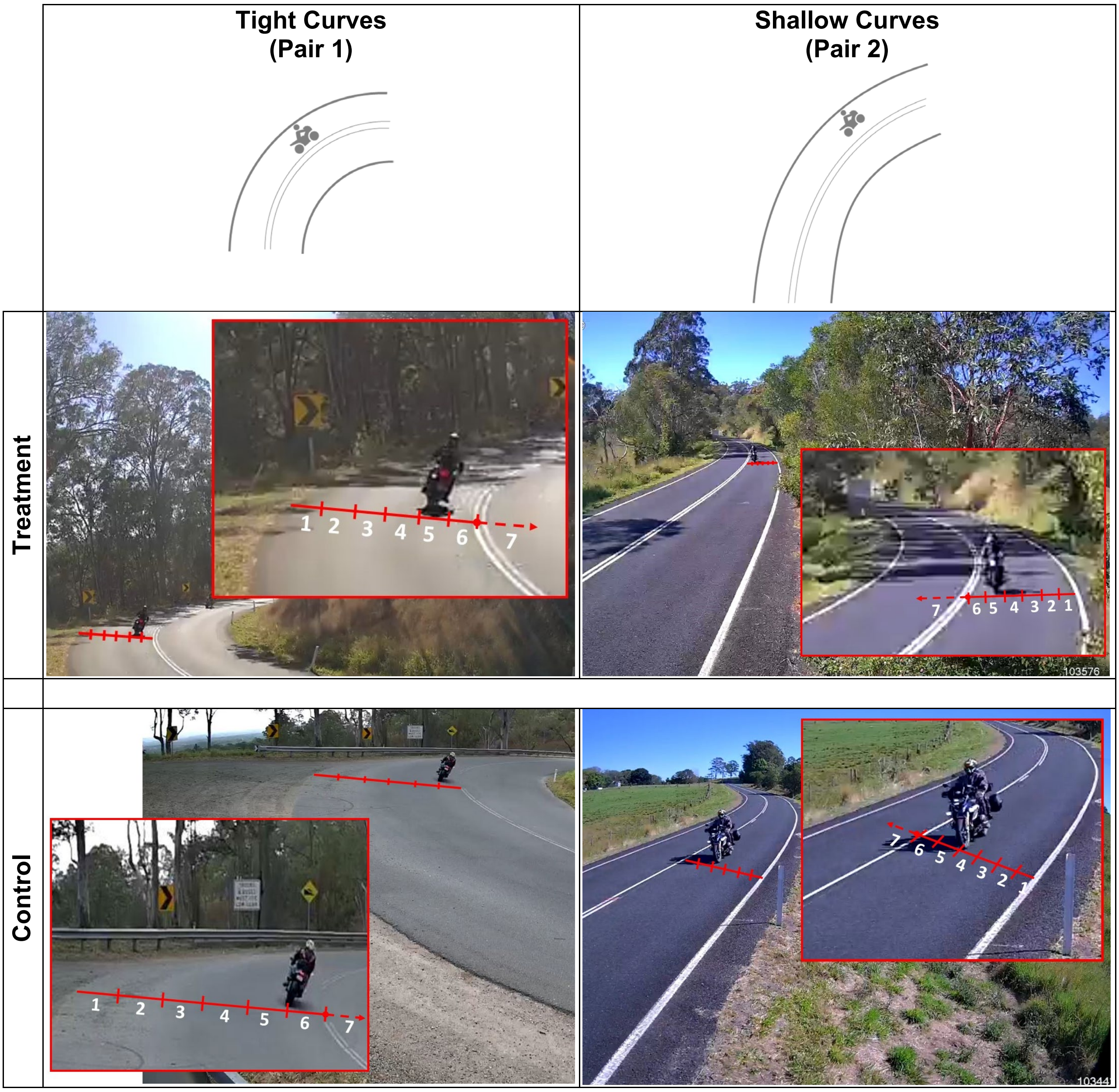
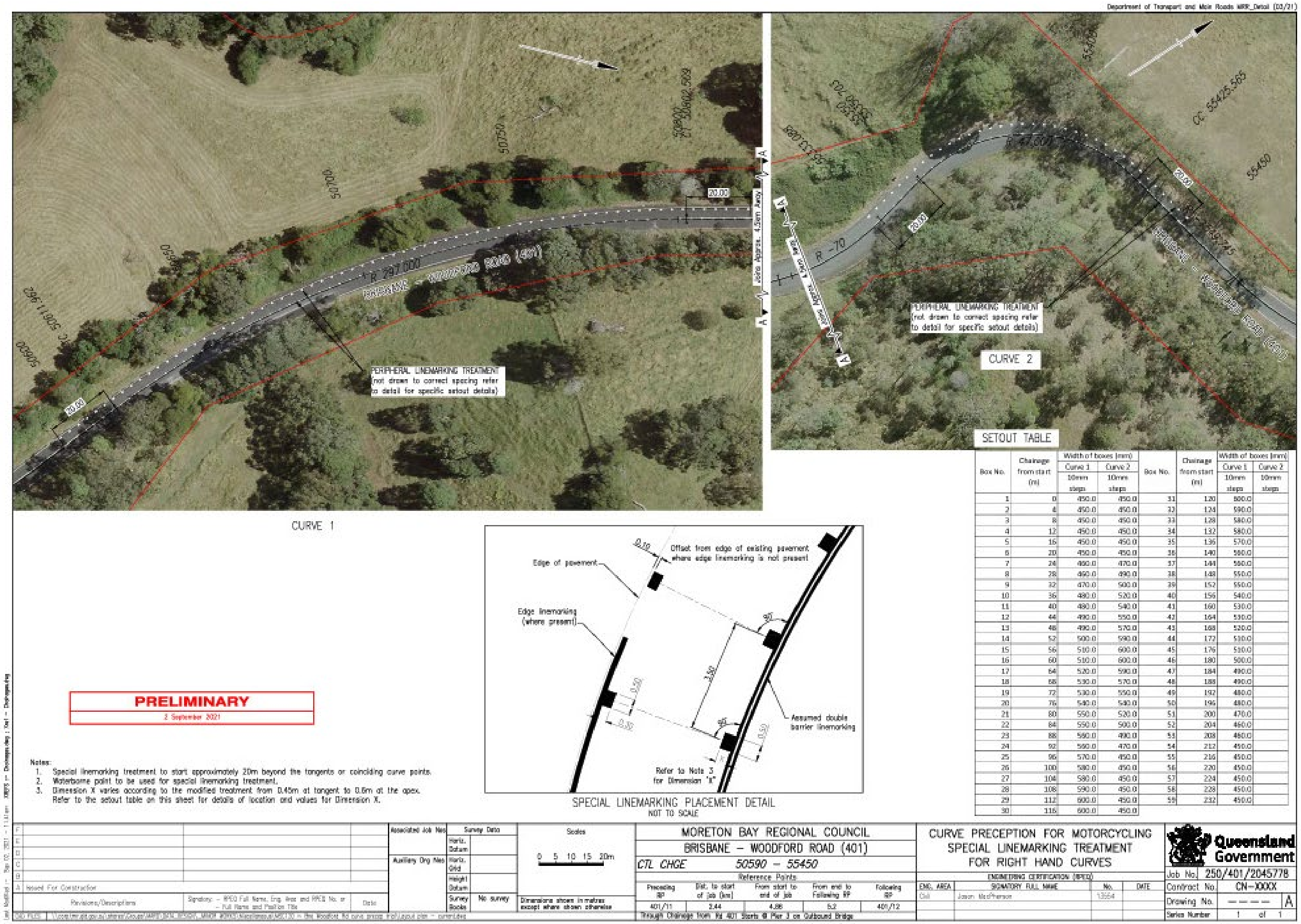


Figure D.6: Camera views and reference scale used for measuring lane position – Apex of the trial curves



Appendix E Treatment Installation



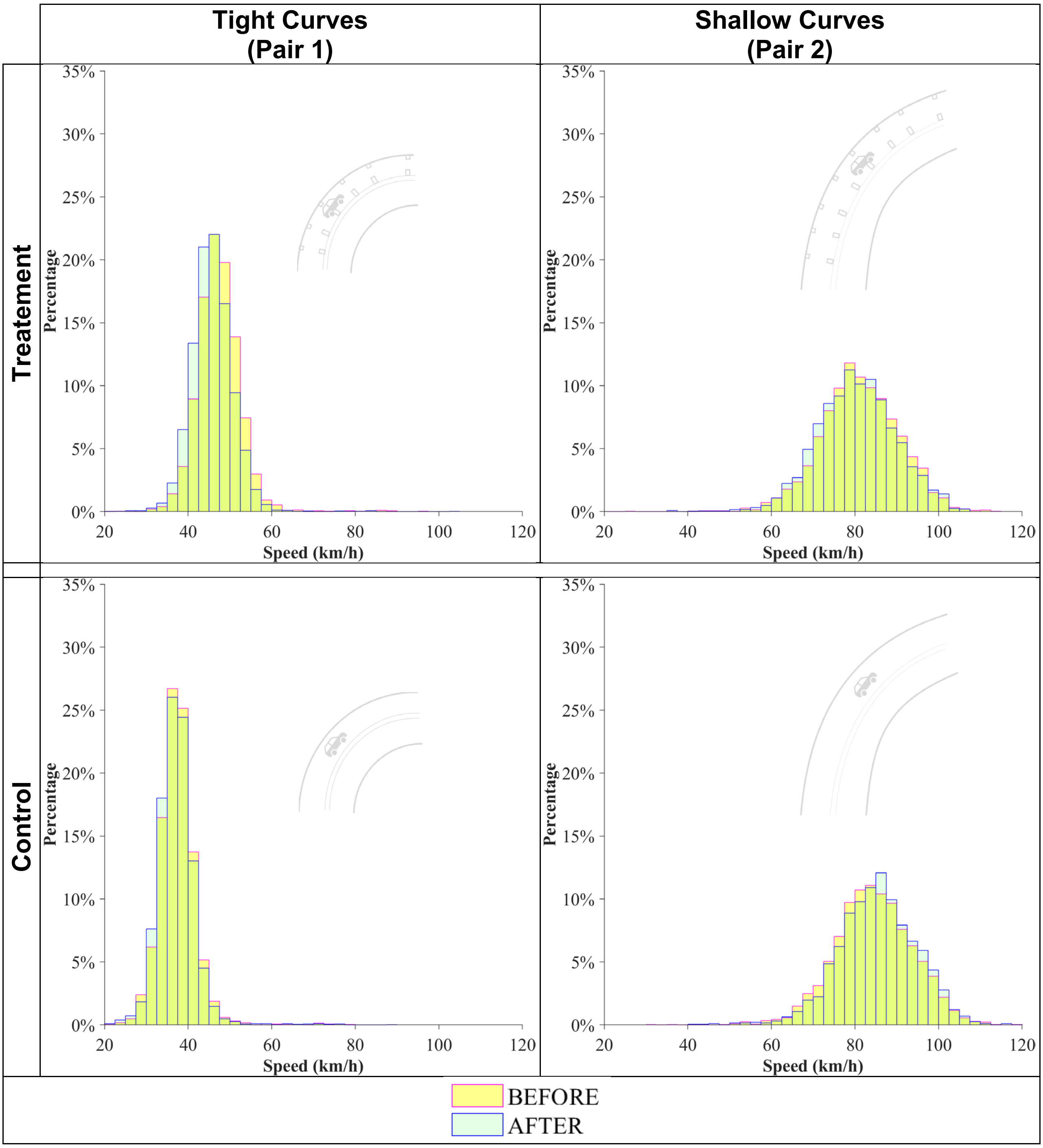
SETOUT TABLE

Box No.	Chainage from start (m)	Width of boxes (mm) Curve 1 10mm steps	Width of boxes (mm) Curve 2 10mm steps	Box No.	Chainage from start (m)	Width of boxes (mm) Curve 1 10mm steps	Width of boxes (mm) Curve 2 10mm steps
1	0	450.0	450.0	31	120	600.0	
2	4	450.0	450.0	32	124	590.0	
3	8	450.0	450.0	33	128	580.0	
4	12	450.0	450.0	34	132	580.0	
5	16	450.0	450.0	35	136	570.0	
6	20	450.0	450.0	36	140	560.0	
7	24	460.0	470.0	37	144	560.0	
8	28	460.0	490.0	38	148	550.0	
9	32	470.0	500.0	39	152	550.0	
10	36	480.0	520.0	40	156	540.0	
11	40	480.0	540.0	41	160	530.0	
12	44	490.0	550.0	42	164	530.0	
13	48	490.0	570.0	43	168	520.0	
14	52	500.0	590.0	44	172	510.0	
15	56	510.0	600.0	45	176	510.0	
16	60	510.0	600.0	46	180	500.0	
17	64	520.0	590.0	47	184	490.0	
18	68	530.0	570.0	48	188	490.0	
19	72	530.0	550.0	49	192	480.0	
20	76	540.0	540.0	50	196	480.0	
21	80	550.0	520.0	51	200	470.0	
22	84	550.0	500.0	52	204	460.0	
23	88	560.0	490.0	53	208	460.0	
24	92	560.0	470.0	54	212	450.0	
25	96	570.0	450.0	55	216	450.0	
26	100	580.0	450.0	56	220	450.0	
27	104	580.0	450.0	57	224	450.0	
28	108	590.0	450.0	58	228	450.0	
29	112	600.0	450.0	59	232	450.0	
30	116	600.0	450.0				

Appendix F Speeds of Light and Heavy Vehicles

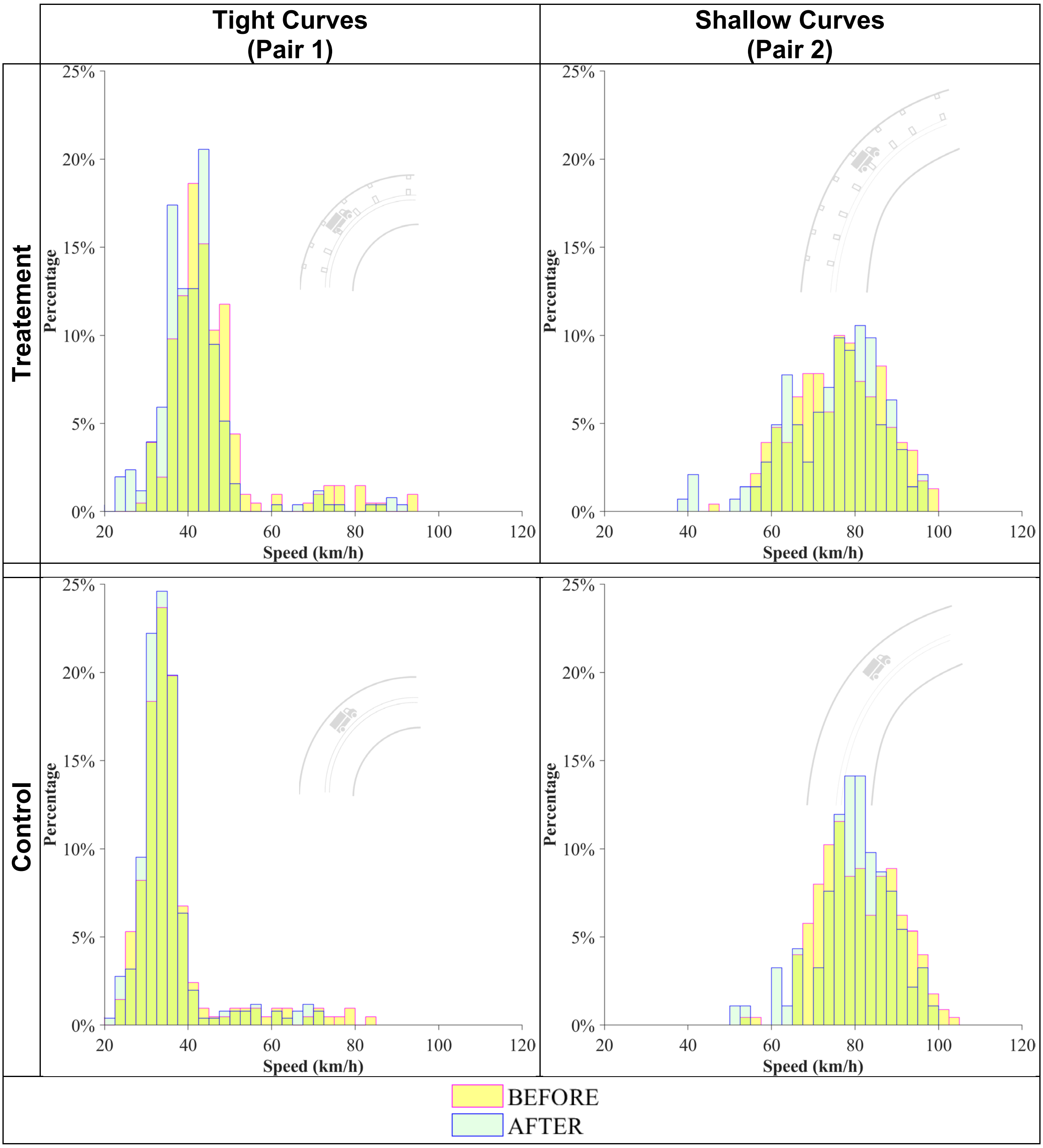
F.1 Light Vehicles

Figure F.1: Distribution of speed at the apex of the right-hand curve in each trial site – Light vehicles



F.2 Heavy Vehicles

Figure F.2: Distribution of speed at the apex of the right-hand curve in each trial site – Heavy vehicles



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