Safeguarding Vulnerable Road Users: Summary Report of PRIME Road Trials 2020 to 2022

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Open Road Simulation Ltd has expertise across a range of specialist areas including transport (road safety, vulnerable road users, driver and rider behaviour), simulation solutions (driving and motorcycle simulation) and expert witness activities (driver and rider psychology).

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Abstract

Innovative road markings for motorcyclists, designed as Perceptual Rider Information for Maximising Expertise and Enjoyment (PRIMEs) were installed on the approach to demanding bends at 22 trial sites and two comparison sites across the West Highlands of Scotland. These road markings were presented as a series of 'gateways' to encourage safer riding. All sites were of similar standards in relation to road surface and environment. Video data were collected to measure motorcycle speed, lateral position, braking and use of the road markings, before and after the PRIME road markings were installed.

A total of 32,213 motorcyclists were observed. Across the trial sites, statistically significant reductions in speed were observed at 10 trial sites. Significant changes in lateral position were observed at the final PRIME gateway marking at 15 trial sites with motorcyclists riding in better positions on approach to the bend. Statistically significant changes in lateral position at the apex of the bend were observed at 13 trial sites. Statistically significant reductions in braking were observed at nine trial sites. There were statistically significant increases in the use of PRIME road markings across 18 of the 22 trial sites.

No statistically significant effects were observed at the comparison sites. These findings are discussed in relation to sustained effects, the 'Road Safety Framework to 2030' and the 'Safe System' approach to reducing motorcycle casualties.

Highlights

- This research is a world-first and the largest road trial investigation of PRIME road markings involving 32,213 motorcyclists
- Unique PRIME road markings for motorcyclists produced statistically significant positive behavioural changes in speed, lateral lane position and braking at sites around the Scottish Highlands
- This in-depth study identifies important behavioural factors that support Transport Scotland's 'Road Safety Framework to 2030' and the 'Safe System' approach to motorcycle casualty reduction

Executive summary

Motorcyclists account for only 2.2% of registered vehicles in Scotland but represented 14% of all Killed or Seriously Injured (KSI) casualties in 2019 (Transport Scotland, 2020). More generally, motorcyclists are around 51 times more likely to be killed on the road than car drivers. This makes them one of the most vulnerable road user groups on public roads (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022).

In response, the Scotland Road Safety Framework has identified motorcyclists as a Priority Focus Area with a target of 30% reduction in motorcyclists killed or seriously injured by 2030 (Transport Scotland, 2021).

PRIMEs for motorcycle casualty reduction
This report presents the results from a 3-year investigation of 'Perceptual Rider Information for Maximising Expertise and Enjoyment' (PRIMEs) on Scotland's Trunk Road Network. This is a unique and innovative approach to casualty reduction that sets out to 'prime' rider behaviour by developing unique road markings for motorcyclists. The road markings provide a tool for riders to adapt their behaviour on approach to a potential hazard therefore optimising their expertise and enjoyment while remaining safe on the road.

The current work is focused on developing PRIMEs to assist motorcyclists approaching demanding bends where it is important that:

- speed is suitable for the conditions
- lane position is optimised for negotiating the bend
- motorcyclists do not have to initiate braking whilst negotiating the bend

The PRIME road markings were designed as a set of three 'gateways' so that motorcyclists might ride 'through the gap' to put them in the correct position for the bend and allow them to adjust their speed and braking prior to the bend.

Unique research in the West Highlands
Based on formal reviews and analyses of collision data, 22 sites were identified in the West Highlands ranging from Glencoe, Oban, Inveraray, Loch Lomond and towards Stirling and Crieff. Two comparison sites were also included where data were collected but PRIME road markings were not installed. Where necessary, all sites had been brought up to similar standards prior to data collection.

This research followed a conventional 'pre- and post-intervention' method, where baseline data were compared with data collected once the PRIME road markings had been installed. Data were captured at each site using small and inconspicuous roadside video cameras in order to analyse speed, lateral position, braking behaviour and use of the PRIME road markings.

The PRIME road markings were installed using 3M™ Stamark™ High Performance permanent tape. They underwent a range of design specification, user acceptance, evaluation, and non-prescribed road sign application activities prior to being installed on public roads for the trials. Independent road safety audits were also conducted before and after the PRIME road markings were installed.

Over 30,000 motorcycles observed
In total 32,213 motorcycles were manually counted and coded across all the trial sites. Motorcycles carrying a passenger/pillion (N=3,281) represented 10.19% of the total sample of motorcycles. The largest proportion of motorcycles were classified as being part of a group (N=19,568), accounting for 60.75% of the total sample of motorcycles. This would indicate that while motorcyclists did not generally carry a passenger/pillion they were likely to be riding with other motorcyclists, reinforcing the social aspect of motorcycling.

Lead motorcycles (N=9,919) accounted for 30.79% of the total sample of motorcycles and were analysed in more detail. Results across the 22 trial sites are summarised below:

- **Speed** – statistically significant reductions in speed were observed at 10 trial sites. Trends were observed at four other sites
- **Lateral position at the final PRIME road marking** – statistically significant changes in lateral position were observed at 15 trial sites with motorcyclists riding in better positions on approach to the bend. Trends were observed at three other sites.
- **Lateral position at the apex of the bend** – statistically significant changes in lateral position were observed at 13 trial sites. A trend was observed at one other site.
- **Braking behaviour** – statistically significant reductions in braking were observed at nine trial sites. Trends were observed at 15 other sites.
- **Use of the PRIME road markings** – statistically significant increases of PRIMEs were observed at 18 trial sites. Trends were observed at three other sites.

At the comparison sites as expected, no differences in rider behaviour were observed. At one site a trend for reduced braking was observed but this was due to temporary traffic management in the area affecting traffic flow on specific data collections periods.

Rider interviews indicated that the majority of motorcyclists were supportive of PRIME road markings and felt they could be particularly useful to inexperienced motorcyclists or tourists with many riders stating that "anything that makes the roads safer is a good thing". Almost two-thirds of the motorcyclists interviewed did not remember seeing the PRIMEs and, in most cases, they did not feel the PRIMEs would have influenced their riding. Taking these two observations together, this could indicate an unconscious or implicit influence of PRIMEs in the behaviours observed across the trial sites.

Long-term effects of PRIMEs

Additional research was conducted to investigate rider behaviour changes over one-year and two-year periods. At the one-year review site the same results were observed in 2021 and 2022 indicating that behavioural effects of PRIMEs remained constant. At the two-year review site the same results were observed in 2020 and 2022 for speed reduction and position changes at the final PRIME road marking and apex of the bend indicating that behavioural effects of PRIMEs were still apparent two-years later. The only difference was that trends for reduced braking that were present in 2020 were not apparent in 2022.

Largest motorcycle study of its kind

As far as the research consortium are aware, this is the most in-depth investigation of motorcycle rider behaviour to date. With 32,213 motorcycles manually counted, coded and analysed, the results provide substantial evidence that PRIME road markings had strong, sustained, and long-term effects on speed, position and braking. There was no evidence that PRIMEs had a detrimental effect on rider behaviour. In addition, while the collision data are low and not always known for each site, since the start of the trials there have been no motorcycle injury collisions at any of the previously identified cluster sites.

Transport Scotland pioneering world-leading and world-class research

This research underpins the development of bespoke motorcycle road safety measures by Transport Scotland and an important step in reducing motorcyclist road casualties.

To date, the work has been published twice in the world-leading scientific journal 'Transportation Research Part F: Traffic Psychology and Behaviour' meaning that this research has been peer-reviewed to the highest standard by the academic community.

By demonstrating the positive influence of PRIMEs on rider behaviour and rider safety, this work showcases Transport Scotland as a leader in this initiative for the UK and the world. It highlights the important role of employing Human Factors expertise in road safety initiatives beyond the current work and in casualty reduction and road user behaviour more widely.

Safeguarding Vulnerable Road Users:

Motorcycle Safety in Scotland using Applied Psychology to Influence Rider Behaviour

22
trial sites

2
comparison sites

1,792
hours
of video data

239
working days
of video data

32,213 motorcycles
9,919 lead motorcycles

297,570
video frames
counted to
calculate
motorcycle
speed

12,949 motorcycles in 2020

1,500
miles each
weekend

750
square miles
of territory

9,594 motorcycles in 2021

50,000
total research
miles

PRIMEs
support the
Safe System
approach

9,670 motorcycles in 2022

Statistically significant results

10 sites with speed reductions
15 sites with position changes at the final PRIME
13 sites with position changes at the apex of the bend
9 sites with reduced braking
18 sites with increased use of PRIMEs

Project funders and partners

1 Introduction

This report provides a summary of road trial investigations conducted during the motorcycle seasons of 2020, 2021 and 2022. Research findings are presented, and the reader is signposted to more in-depth analyses contained in scientific journal papers that have been peer-reviewed by the academic community and published during the course of the work.

The practical aim of this research was to inform road safety engineering measures and reduce motorcycle casualties through the installation of novel road markings designed as 'Perceptual Rider Information to Maximise Expertise/Enjoyment' (PRIMEs).

This is a new and innovative approach to casualty reduction that sets out to 'prime' behaviour through the use of dedicated road markings for motorcyclists. The road markings have been designed to provide a tool for motorcyclists to adapt their behaviour on approach to a potential hazard therefore optimising their expertise and enjoyment while remaining safe on the road.

Transport Scotland recently published its 'Road Safety Framework to 2030' with a long-term goal for road safety where no-one dies or is seriously injured by 2050 (Transport Scotland, 2021). Building on the strength of the previous 2020 Framework, it proposes a 'Safe Systems' approach to road safety delivery as set out in the National Transport Strategy Delivery Plan (Transport Scotland, 2020). This will be achieved by developing a more forgiving road system that addresses human vulnerability and fallibility to prevent deaths and serious injuries.

In support of this mission and the research aim, specific objectives have been identified:

- to inform road safety treatments for motorcyclists, address Action 8 of the Strategic Road Safety Plan and reduce motorcycle casualties
- to support rider training and road user education initiatives, encouraging motorcyclists and other road users to consider motorcycling as a wider reaching activity
- to feed into rider information initiatives already developed to support Transport Scotland's and the Scottish Government's work in this area (e.g. 'LiveFastDieOld' (https://livefastdieold.scot)

Throughout this work a key focus was the need to implement safety measures that can reduce motorcycle casualties and reach out to and engage with, the motorcycling community. Underpinning this philosophy was the understanding that for engineering measures to be effective, they need to be evidence-based, located where they are most likely to make a difference and developed from the motorcyclist's perspective (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022).

This research built upon previous work in New Zealand that Prof Stedmon was directly involved with, where Perceptual Counter-Measures (PCMs) were trialled to support motorcycle safety on bends through the correct combination of safe speed, lateral position, and effective braking prior to the bend (Hirsch, Moore, Stedmon, Mackie, and Scott, 2017; Hirsch, Scott, Mackie, Stedmon and Moore, 2018).

In the current research programme, this work was extended over a 3-year period through world-first trials of unique PRIME road markings for motorcyclists.

Throughout this summary report, the reader is directed to scientific publications that provide in-depth reviews, details of research design, analyses and results of specific elements of the work (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022, 2023).

The knowledge base that has been established through this work is unique and has implications for road safety, casualty reduction and education initiatives around Scotland, the UK and at international levels.

Motorcycle panel: Alex Stedmon

2 Motorcycle casualties and the scale of the problem

Around the world motorcyclists are grossly over-represented in road traffic collision statistics (de Moraes, Godin, Dos Reis, Belloti and Bhandari, 2014; Ozkan, Lajunen, Dogruyol, Yıldırım and Coymak, 2012; Vanlaar, Hing, Brown, McAteer, Crain and McFaull, 2016, Transport Scotland, 2021).

Typically, motorcyclists are around 51 times more likely to be killed on the road than car drivers (Crundall, Stedmon, Crundall, and Saikayasit, 2014; Department for Transport, 2019, Transport Scotland 2020). These statistics highlight motorcyclists as one of the most vulnerable road user groups on public roads.

In the UK, between 2015 and 2020, an average of six motorcyclists were killed and 115 were seriously injured each week in reported road casualties (Department for Transport 2021). During 2018, 354 motorcyclists were killed, a rise of 1% on 2017 when 349 motorcyclists were killed. However, motorcyclist fatalities have fluctuated with between 319 and 365 between 2011 and 2018 with no clear trend (Department for Transport, 2019).

In Scotland, motorcyclists represent only 2.2% of all registered vehicles but account for 14% of all Killed or Seriously Injured (KSI) casualties (Transport Scotland, 2020). According to the latest information around half of motorcycle casualties in Scotland took place on roads with a speed limit over 40mph (Transport Scotland, 2020). Of these casualties, 76% of motorcyclists were killed with 22% of incidents attributed to 'loss of control' (Transport Scotland 2020).

This supports previous evidence that 65% of motorcycle fatalities occur in rural areas (Department for Transport, 2009). Most incidents tend to occur on rural roads at weekends which are popular times for recreational motorcyclists to be riding (Transport Scotland 2020).

In response, the Scottish Road Safety Framework has identified motorcyclists as a Priority Focus Area with a target for a 30% reduction in motorcyclists killed or seriously injured by 2030 (Transport Scotland, 2021).

In many incidents, only the motorcyclist is involved and the causes are attributed to a poor turn or manoeuvre, exceeding the speed limit, loss of control, travelling too fast for the conditions or sudden braking (Department for Transport 2021).

With many casualties occurring on bends, there is evidence that collisions are more likely to happen on sharp bends than on gentle bends (Bissell, Pilkington, Mason and Woods, 1982; Gibreel, Easa, Hassan and El-Dimeery, 1999; Walmsley, Summersgill and Binch, 1998). In these situations, the motorcyclist tends to 'run wide' across the centre of the road making them vulnerable to oncoming traffic, hard vegetation or roadside furniture (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021). Other reasons for running wide can include a change of line once already negotiating the bend; typically to avoid potholes, debris/loose material on the road and/or slippery tar bleed patches. Straying livestock, pedestrians or cyclists, or vehicles emerging from concealed driveways can also prompt an unexpected change in road position.

Furthermore, where riders ride on the left-hand side of the road, research indicates that left-hand bends are more dangerous than right-hand bends (Stewart, 1977; Stewart and Cudworth, 1990). This is thought to be due to a greater difficultly in perceiving road curvature when riding on the inside lane of a bend, and problems with maintaining optimum viewpoints, judging correct vanishing points and/or conflicts with identifying safe braking distances (Crundall, Crundall and Stedmon, 2012; Hirsch, Moore, Stedmon, Mackie, and Scott, 2017; Hirsch, Scott, Mackie, Stedmon and Moore, 2018).

For further details of motorcycle causalities, please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2021, 2022).

PRIME road marking on the A85 at Bonawe: Alex Stedmon

3 Perceptual Rider Information for Maximising Expertise/Enjoyment (PRIMEs)

Dedicated road markings designed as 'Perceptual Counter-Measures' (PCMs) have been shown to influence road user behaviour. These are typically road markings that dictate a desired behaviour by altering how a driver might perceive and process risk factors in the environment around them (Gardener, Tate, Mackie, Stedmon, and Southey-Jones, 2017; Mulvihill, Candappa, and Corben, 2008).

From the motorcyclist's perspective, PCMs have been shown to influence rider behaviour in relation to speed, position, and braking to reinforce better rider behaviour (Hirsch, Moore, Stedmon, Mackie, and Scott, 2017; Hirsch, Scott, Mackie, Stedmon and Moore, 2018).

For a detailed review of research findings for PCMs, please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2021).

With the current research, a new approach was taken by developing a tool for motorcyclists through the design of 'Perceptual Rider Information to Maximise Expertise and Enjoyment' (PRIMEs).

The underlying philosophy of PRIMEs is to develop solutions that are cost effective to install and maintain. PRIMEs can be installed on existing roads quickly and efficiently or incorporated into road upgrade schemes.

PRIMEs provide a platform of innovative tools for motorcyclists with different riding styles. Motorcyclists are then able to adopt these tools and adapt their behaviour on approach to a potential hazard therefore optimising their expertise and enjoyment (and also their safety on the road).

Of particular importance to this research programme was the safe navigation of bends. For this to occur, motorcyclists have to make sure that:

- **speed** – is suitable for the conditions
- **position** – is optimised for entering and travelling through the bend
- **braking** – is minimised whilst travelling around the bend

The PRIME road marking design investigated in this research comprised a series of three 'gateway' markings positioned on the approach to a bend. The intention was that the PRIME road marking would encourage motorcyclists to ride 'through the gap' and use the gateways as a cue to adjust their riding prior to the bend.

Depending on whether a motorcyclist was approaching a left-hand or right-hand bend the PRIME road markings were positioned to the right-hand or the left-hand side of their lane respectively to support a better road position and view on approach to the bend and through the bend itself. This road positioning technique is common in advanced riding courses and the police rider's handbook (Mares, Coyne and MacDonald, 2020).

With a series of three PRIME gateway markings, there was potential for riders to adjust their braking point according to the motorcycle they were riding, their own riding style, or perhaps even due to weather and other environmental effects (i.e. in poor weather they might brake one marker back from their usual point).

The PRIME road marking used in this research was designed to potentially influence speed, position, and braking on approach to a bend (Figure 1).

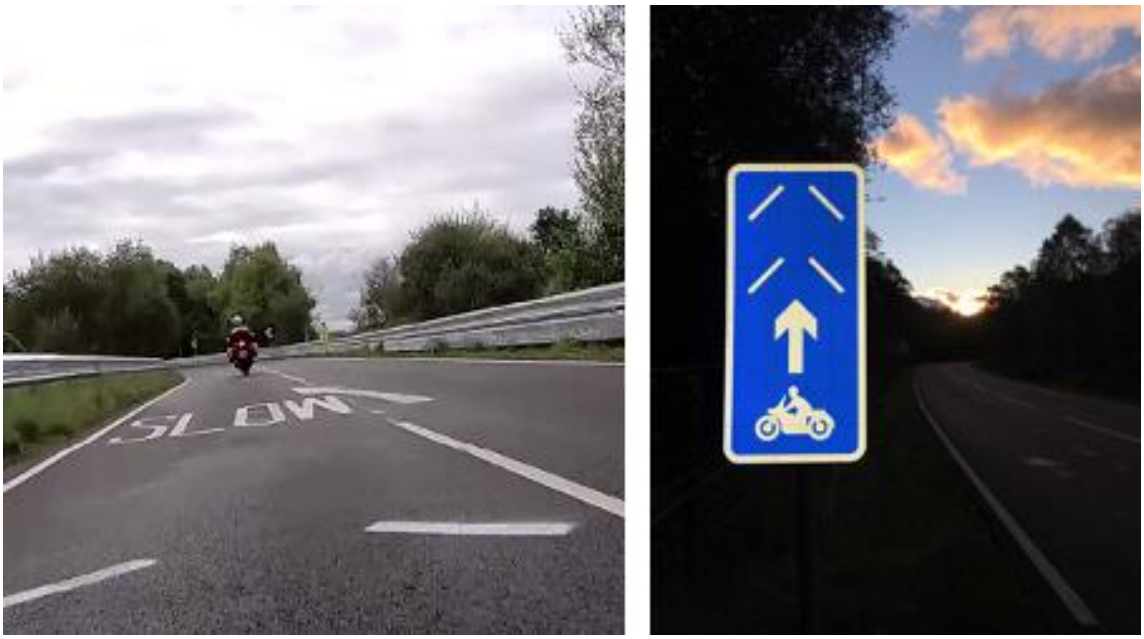

Figure 1: PRIMEs 'gateway' design
PRIME road marking (left) and PRIME road sign (right)

The PRIME road marking and road sign designs underwent a range of design specification and user acceptance activities prior to being installed at the trial sites. In order to assess user acceptance of the PRIMEs concept and initial designs, 200 rider and 200 driver interviews were conducted (Stedmon, 2020a). Result from the motorcyclists indicated that 93% felt that the road marking was a good idea; 96% felt that PRIMEs were useful concept; and 90% felt they would use them in the future. Of the 200 car drivers, 91% felt that the road marking was a good idea; 95% felt that PRIMEs were useful concept; and 70% would felt they would use them in the future.

Following on from this, a PRIMEs workshop was conducted in Glasgow with a range of participants from local IAM-Roadsmart groups and a Council Traffic Officer. The discussions at the workshop centred around reservations about being told what position to take on the road, the need for changing the line taken on a bend due to debris and other temporary factors and taking the thinking away from motorcyclists. However, these were mainly advanced riders who may not benefit as much from the PRIMEs as less experienced or untrained riders. With this in mind the participants felt that PRIMEs could work well on technically difficult bends.

An underlying aspect of implementing PRIMEs is that they should not conflict with the needs of other road users. During the workshop this was not seen as a big issue for car drivers and many of the participants felt that drivers would generally ignore the road markings. A range of design options were considered such as installing more than three on tighter bends so that the number of road markings might help inform riders of bend severity and shortening the markings to give more scope to ride around them if needed.

From this work, an on-line survey was developed and conducted to confirm design specifications for the PRIME road marking (Stedmon, 2020b). The results from 200 participants indicated that 82% of participants preferred the 'gateway' design. A range of design factors such as colour, spacing, road surface grip, signage, direction arrows and number of markings were surveyed. The options of white road markings and three gateways were rated the highest and taken forward for the road trials of PRIMEs.

PRIME trial site at Salmon Draft Southbound: Alex Stedmon

4 Trial site selection

In support of the research, an initial analysis by Transport Scotland of the Trunk Road Network identified 660 collisions involving motorcyclists between 2013 and 2017. Using STATS19 data (reported directly from Police attending accident scenes) the work highlighted the North-West region as a priority area for motorcycle casualty reduction.

Following this, BEAR Scotland Ltd (North-West Unit) conducted an in-depth review of collision cluster sites between 2008 and 2017. This work identified sites within a 100m radius where three or more personal injury accidents (PIAs) involving a motorcyclist or pillion had occurred (Figure 2).

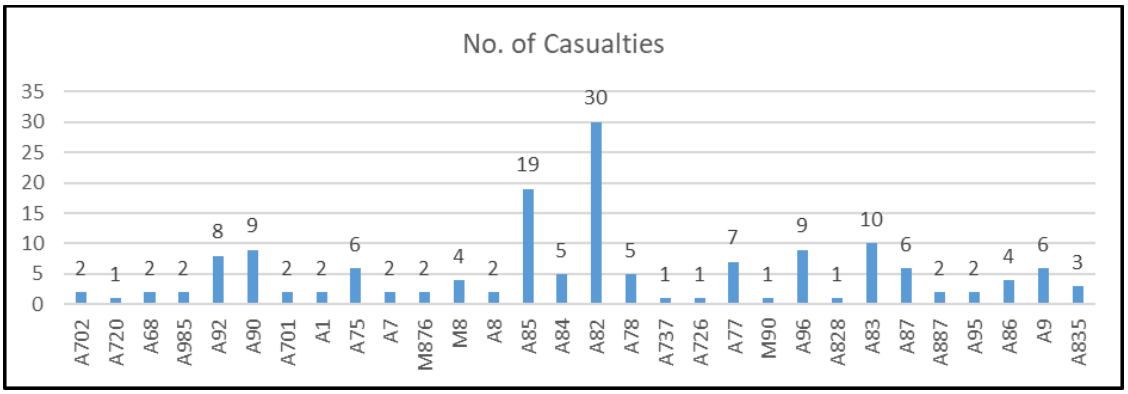

Figure 2: Motorcycle casualty profile for the North-West Region
(from: BEAR Scotland, 2019)

For more information on the review of collision cluster sites please refer to BEAR (2019, 2021)

With a focus on the A82, A85 and A83, sites were identified in the region ranging from Glencoe, Oban, Inveraray, Loch Lomond and towards Stirling and Crieff (Figure 3).

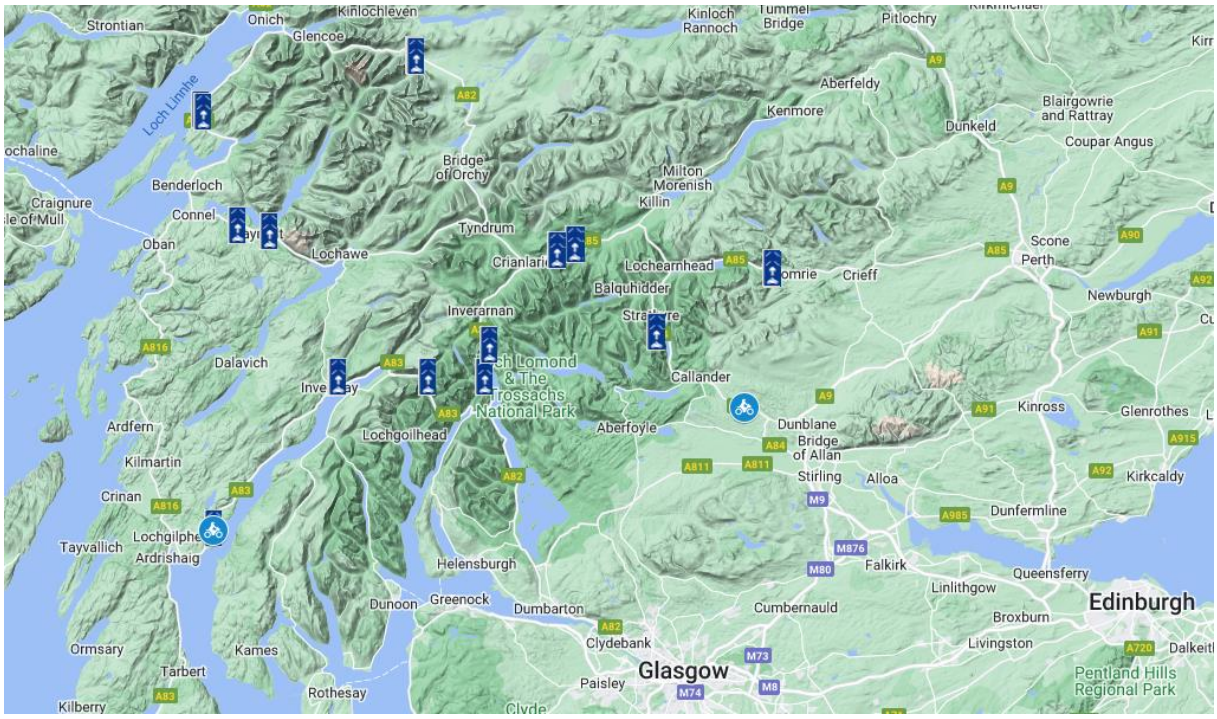

Figure 3: PRIMEs trial sites

Expert reviews were conducted for each potential site (e.g. complex geometry, tightening or double apexes, descents and inclines prior to bends, bends off fast sections of road) and 22 trial sites were identified and categorised as motorcycle cluster (MCL) sites or PRIME trial (PT) sites.

In addition, BEAR Scotland produced a checklist of site characteristics that each trial site was scored against to identify suitable locations and to also help plan the scheduling of any upgrades required.

The trial sites were spread over a large geographic area of approximately 750 square miles. They represented a range of bends on rural roads with speed limits over 40mph in line with recent casualty statistics (Transport Scotland, 2020).

Two comparison sites were also included in the trials where data were collected but PRIME road markings were not installed. The comparison sites were of a similar standard to the PRIME trial sites. Due to the wide variety of bends and road characteristics on the Trunk Road Network, these comparison sites were not regarded as experimental control conditions (i.e. where identical conditions are usually compared statistically). All trial sites were brought up to similar standards prior to data collection. A summary of the PRIMEs trial sites is presented below (Table 1).

Site	Code	Road	Heading	Bend type
2020				
Appin House – *north*	PT-05	A828	North	Left-hand
Appin House – *south*	PT-06	A828	South	Left-hand
Kingshouse – *north*	PT-07	A82	North	Right-hand
Kingshouse – *south*	PT-07	A82	South	Left-hand
Loch Lubhair – *east*	PT-04	A85	East	Left-hand
Loch Lubhair – *west*	PT-04	A85	West	Right-hand
Rob Roy's Dip – *east 1*	PT-03	A85	East	Right-hand
Rob Roy's Dip – *east 2*	PT-03	A85	East	Left-hand
Rob Roy's Dip – *west 1*	PT-03	A85	West	Right-hand
Rob Roy's Dip – *west 2*	PT-03	A85	West	Left-hand
2021				
Taynuilt – *west*	MCL-04	A85	West	Left-hand
Inveruglas – south	MCL-11	A82	South	Left-hand
Runacraig – *north*	MCL-21	A84	North	Left-hand
Runacraig – *south*	MCL-21	A84	South	Left-hand
Dunira – *west*	MCL-08	A85	West	Left-hand
Bonawe – *east*	MCL-07	A85	East	Left-hand
Landrick Bends – *comparison*	n/a	A84	North	Left-hand
2022				
Dailnamac – *east*	PT-20	A85	East	Left-hand
Pulpit Rock – *north*	PT-11	A82	North	Left-hand
Butterbridge – *north*	PT-02	A83	North	Left-hand
Middle Kames – *south*	PT-12	A83	South	Left-hand
Salmon Draft – *north*	MCL-03	A83	North	Left-hand
Salmon Draft – *south*	MCL-03	A83	South	Left-hand
Carrick – *comparison*	n/a	A83	North	Left-hand
Dunira – *revisited from 2021*	MCL-08	A85	West	Left-hand
Rob Roy's Dip – *revisited from 2020*	PT-03	A85	West	Right-hand

Table 1: PRIMEs trial sites

Images from a selection of the trial sites are presented below (Figure 4).

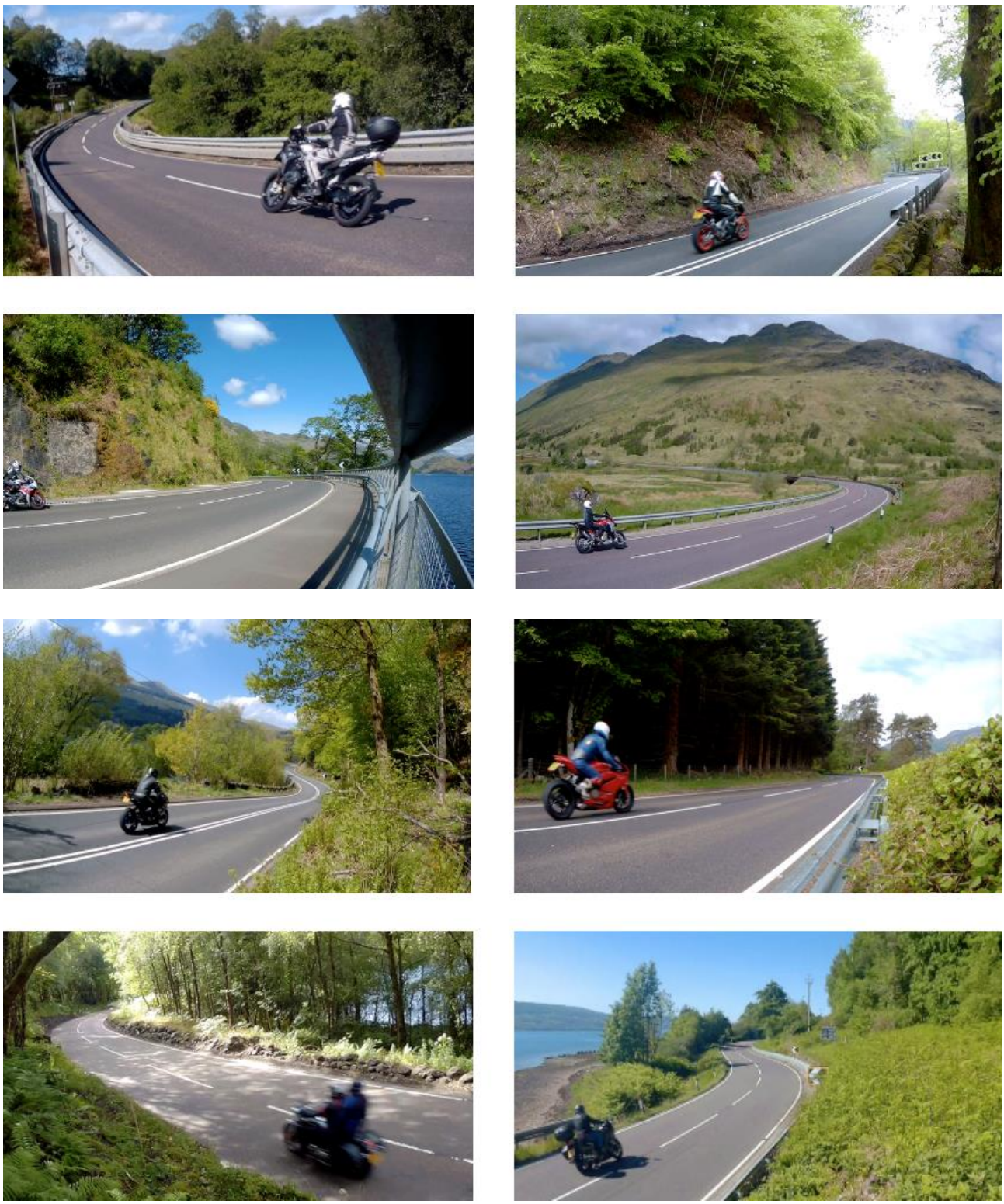

Figure 4: Selection of trial site images

These images illustrate some of the left-hand and right-hand bend trials sites where PRIME road markings were installed throughout 2020 to 2022.

Camera located on fence post at Kingshouse Southbound trial site: Alex Stedmon

5 Method and analyses

This research was conducted as a quasi-experiment and combined elements of field observation with formal experimental design (Lehman, 1991). This approach allowed for conventional 'pre- and post-intervention' assessment to be conducted so that any effects of the PRIMEs on riding behaviour could be determined against the baseline measures. This approach has been used in similar research of this kind (Fildes et al, 2005; Mackie and Scott, 2015; Hirsch et al, 2017, 2018; Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022, 2023; Winklebauer et al, 2021).

5.1 Participants

This research relied on an opportunistic sample of motorcyclists. Across all the trial sites 32,213 motorcycles were observed and from these 9,919 lead motorcycles were analysed in more detail.

5.2 Apparatus

Data were captured at each site using small and inconspicuous weatherproof video cameras typically attached to roadside posts or trees (Figure 5).

Figure 5: Cameras attached to trees or roadside posts
(highlighted)

The cameras captured 1080p video at 60Hz for time periods of at least 20hrs, stored in 512Gb microSD cards. Power-packs were used to collect continuous data through the data collection periods.

At each site, three cameras were installed facing: towards the rider, behind the rider and perpendicular to the rider a short distance ahead of the last PRIME road marking (Figure 6).

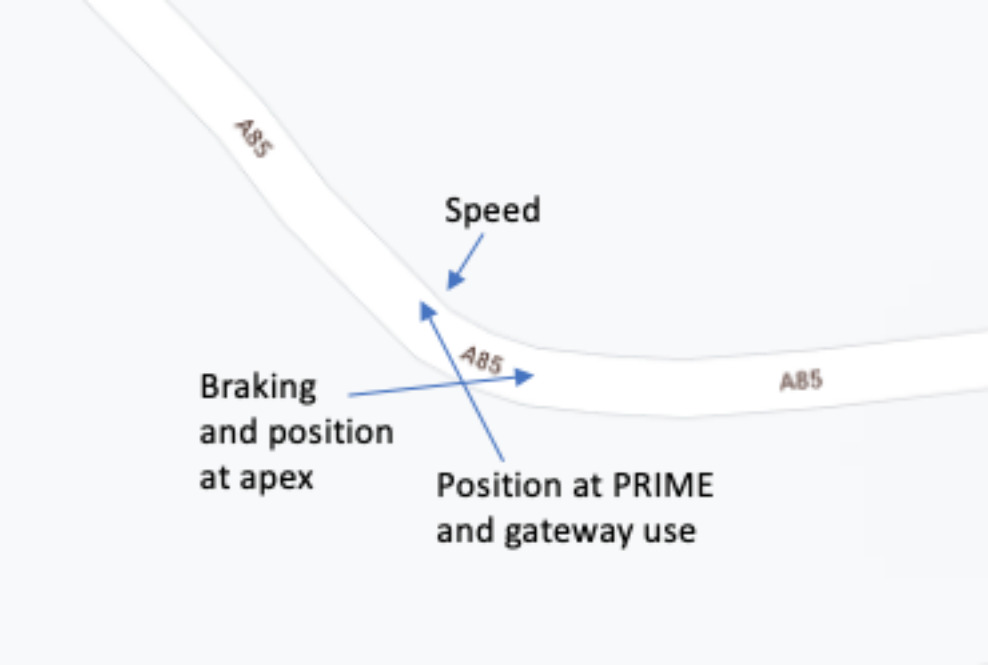

Figure 6: Camera positions at each trial site

The road markings were installed using 3M™ Stamark™ High Performance 100 mm wide permanent tape. This material was chosen because it provided increased visibility, grip and safety, even in the wet. It had also been used in previous research (Bricelj, Merkun, Brumec and Hudej, 2016). The material also offered high levels of adhesion to the road surface and provided a permanent marking that would not be disturbed by other vehicles (i.e. general traffic and heavy goods vehicles).

5.3 Design

For the research, funded by the Road Safety Trust, a specific focus on left-hand bends was proposed. Other funding provided opportunities to conducting initial investigations of right-hand bends.

The independent variable in this research was the PRIME road markings which had two levels: Baseline (without PRIMEs installed) and PRIME (with PRIMEs installed).

Baseline and PRIME data were collected on a number of occasions, as specified below:

- Baseline 1 and 2 – two separate weekends before PRIMEs were installed
- PRIME 1 – the weekend after PRIMEs were initially installed
- PRIME 2 – six or eight weeks after the PRIME 1 data collection
- PRIME 3 and 4 – to investigate the nature of sustained behaviour effects
- PRIME 5 and 6 – to investigate the nature of long-term behaviour effects

A range of dependent variables were identified to capture data about the potential influence of PRIMEs on rider behaviour (Table 2).

Dependent variable	Measure (units)	Apparatus	Reason
Speed	Miles per hour (mean, standard deviation, mode, 85th %tile)	Side facing camera to measure speed between two points (i.e. 10m apart)	To assess any changes in speed due to PRIMEs
Position	Lateral lane position at the final PRIME and at the apex (mean, standard deviation, median, mode)	Forward-facing camera to measure lateral position on approach to the bend. Rear-facing camera to measure position at the apex	To assess any changes in lateral lane position due to PRIMEs
Braking	Brake light illumination (count)	Rear-facing camera to capture brake light illumination	To assess any changes in braking on bends due to PRIMEs
Motorcyclists	Pillion, lead, group riders (count)	From video data collected for other measures	To identify rider characteristics
Use of PRIMEs	Use of the final PRIME (count)	From video data collected for other measures	To identify how many riders used PRIMEs

Table 2: Dependent variable and associated measures

In addition, rider interviews were conducted using a scripted protocol during the 2021 and 2022 road trials. These took place at the Green Welly Stop at Tyndrum and Inveraray waterfront as they were both popular meeting points and ride-out destinations for motorcyclists. The findings are presented in the summary results.

5.4 Procedure

Prior to data collection, trial sites were assessed and where necessary upgraded with various measures such as: resurfacing, line repainting, new crash barriers, vegetation removal, vehicle restraint systems (VRS), and motorcycle friendly 'bikeguard' installations. Each location therefore provided a setting where the road environment had been brought up to the best possible standard, prior to investigating rider behaviour. Comparison sites were selected that were of a similar standard and did not require engineering works. This meant that any extraneous variables were controlled as much as possible so that they would not otherwise influence rider behaviour (e.g. poor road surface, obscured views, potholes, poor safety provisions).

The weather during the trials was generally good. Contingency weekends were planned in case poor weather may have affected the numbers of motorcyclists out on the roads and integrity of the data. If light rain showers occurred the data were generally included for analyses. Only if the showers were heavy and caused wheel spray or if other vehicles had their windscreen wipers operated was the data excluded from analyses.

Data were captured during the typical motorcycle season (i.e. May to September). Weekends were chosen for as this was generally when motorcyclists ride for leisure/social purposes.

Each weekend cameras were set up at every trial site and recorded all road traffic during Saturday and Sunday from 09:00 to 17:00. Power supplies were replenished through the weekend and cameras were collected on Sunday evenings.

Care was also taken to make sure that no changes to the sites were undertaken during the pilot trials (i.e. scheduled road works).

5.5 Ethics and risk assessment

An independent review of potential ethical issues was conducted by Dr Martin Langham who acted as an external auditor for the project. Approval was granted in accordance with general principles of the British Psychological Society and International protocols.

A risk assessment was also conducted in order to safeguard the research activities. Induction training was undertaken so that roadside safety protocols were adhered to and the correct PPE was worn at all times.

The design for the PRIME road markings and road sign went through a formal application process for authorisation of non-prescribed traffic signs (Road Traffic Regulations Act 1984: Sections 64 and 65). Approval was granted prior to the trials taking place. Following on from this, independent road safety audits were conducted in accordance with the Design Manual for Roads and Bridges (DMRB) to oversee the safe installation of PRIMEs at all trial sites.

For more details on the method and analyses, please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2021, 2022).

5.6 Data analyses

Once the data had been processed, they were then analysed in a number of ways.

Initially Baseline 1 and Baseline 2 datasets were compared by conducting a T-Test (t) to identify any differences between them. Where any significant differences were observed, effect size was calculated using Cohen's (ds) equation.

Where the Baseline 1 and Baseline 2 datasets were observed to be the same (i.e. there was no significant difference) they were combined into a single dataset (i.e. 'Baseline'). Where any difference was observed, Baseline 1 and Baseline 2 were kept as separate datasets and compared individually with the PRIME 1 and PRIME 2 datasets.

Speed and lateral position data were analysed using one-way Analysis of Variance (ANOVA) techniques. Where any significant results were observed, effect size was calculated using a partial eta squared (η^2) analysis. Post-hoc Bonferonni-Hoch analyses were conducted in order to determine where significant differences occurred between the datasets. Tests for effect size were conducted using Cohen's (ds) calculations.

Braking behaviour and use of PRIMEs datasets were analysed using Chi Square (X^2) tests. Where any significant results were observed, effect size was analysed using Cramér's V (V) calculations. Further post-hoc analyses were performed by calculating standardised residuals in order to determine where significant differences occurred between the datasets.

Due to project restraints and as the data processing relied on specific and discrete manual counts, one researcher (Prof Stedmon) conducted the data processing and analyses. This researcher reviewed and re-checked data during the data processing activities. During the 2020 trials intra-rater reliability was assessed instead of inter-rater reliability (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021). This followed the process set out by Mackey and Gass (2005) where ratings were conducted at different time intervals (i.e. *T1* and *T2*) and then analysed in the same way as inter-rater reliability. Cohen's Kappa (k) calculations were conducted for samples of data for speed, lateral position and braking in the 2020 road trials. For speed and braking perfect matches were observed (k=1.0) due to the discrete nature of these data. For lateral position k=0.92 indicating a very high agreement and only minor differences in coding at the thresholds between the three lane positions.

For detailed statistical analyses for each site please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2021, 2022, 2023).

Motorcyclist using PRIMEs: Alex Stedmon

6 Summary results

In total 32,213 motorcycles were observed across all the trial sites. Each of these 32,213 motorcycles were manually counted and coded in relation to whether they were a lead or following motorcycle (i.e. 'lead'), solo rider or carrying a pillion (i.e. 'pillion'), and individual motorcycle or riding as part of a group (i.e. 'group'). From these 9,919 lead motorcycles were analysed in more detail (Table 3).

Site	**Motorcycles**			
	Lead (N)	**Pillion (N)**	**Group (N)**	**Total (N)**
2020				
Appin House – *north*	188	44	223	395
Appin House – *south*	205	55	247	412
Kingshouse – *north*	315	170	1,041	1,225
Kingshouse – *south*	382	128	772	1,601
Loch Lubhair – *east*	390	161	841	1,355
Loch Lubhair – *west*	555	182	1,135	1,749
Rob Roy's Dip – *east 1*	452	163	827	1,354
Rob Roy's Dip – *east 2*	562	162	826	1,753
Rob Roy's Dip – *west 1*	430	188	1,129	1,352
Rob Roy's Dip – *west 2*	568	188	1,128	1,753
	4,047	**1,441**	**8,169**	**12,949**
2021				
Taynuilt – *west*	275	93	638	959
Inveruglas – *south*	207	113	665	1,171
Runacraig – *north*	311	154	959	1,566
Runacraig – *south*	330	135	725	1,305
Dunira – *west*	624	133	881	1,574
Bonawe – *east*	437	105	626	1,191
Landrick Bends – *comparison*	364	203	968	1,828
	2,548	**936**	**5,462**	**9,594**
2022				
Dailnamac – *east*	290	87	532	879
Pulpit Rock – *north*	254	152	1,029	1,615
Butterbridge – *north*	513	127	868	1,362
Middle Kames – *south*	249	62	368	582
Salmon Draft – *north*	620	146	1,060	1,667
Salmon Draft – *south*	571	173	1,050	1,747
Carrick – *comparison*	401	58	526	878
Dunira – *revisited from 2021*	207	42	217	445
Rob Roy's Dip – *revisited from 2020*	219	57	287	495
	3,324	**904**	**5,937**	**9,670**
Total	**9,919**	**3,281**	**19,568**	**32,213**

Table 3: Motorcycle numbers throughout the road trials

Motorcycles carrying a passenger/pillion (N=3,281) represented 10.19% of the total sample of motorcycles. The largest proportion of motorcycles were classified as being part of a group (N=19,568), accounting for 60.75% of the total sample of motorcycles. This would indicate that while motorcyclists did not generally carry a passenger/pillion they were likely to be riding with other motorcyclists, reinforcing the social aspect of motorcycling.

Lead motorcycles (N=9,919) accounted for 30.79% of the total sample of motorcycles and were analysed in more detail. Results from the 22 trial sites are summarised below (Table 4).

Site	Rider Behaviour				
	Speed	**Position at PRIME**	**Position at Apex**	**Braking**	**Use of Gateway**
2020					
Appin House – *north*		Sig			Trend
Appin House – *south*	Sig	Sig	Sig	Trend	Sig
Kingshouse – *north*	Trend	Sig			Sig
Kingshouse – *south*		Sig	Sig	Trend	
Loch Lubhair – *east*		Sig	Sig	Sig/Trend	Sig
Loch Lubhair – *west*	Sig	Sig	Sig	Sig	Sig
Rob Roy's Dip – *east 1*		Sig		Trend	Sig
Rob Roy's Dip – *east 2*		Sig	Sig	Trend	Sig
Rob Roy's Dip – *west 1*	Sig	Sig	Sig	Trend	Sig
Rob Roy's Dip – *west 2*	Sig	Sig	Sig	Trend	Sig
2021					
Taynuilt – *west*	Sig		Sig	Trend	Sig
Inveruglas – *south*	Trend	Trend	Sig	Sig	Trend
Runacraig – *north*	Sig	Trend			Sig
Runacraig – *south*	Sig	Trend		Sig	Sig
Dunira – *west*	Sig	Sig	Sig	Sig/Trend	Sig
Bonawe – *east*	Sig		Trend	Trend	Trend
Landrick Bends*	*No effect*	*No effect*	*No effect*	*Trend*	*No effect*
2022					
Dailnamac – *east*		Sig	Sig	Sig/Trend	Sig
Pulpit Rock – *north*			Sig	Sig/Trend	Sig
Butterbridge – *north*		Sig		Trend	Sig
Middle Kames – *south*	Trend	Sig		Sig	Sig
Salmon Draft – *north*	Sig			Sig/Trend	Sig
Salmon Draft – *south*	Trend	Sig	Sig		Sig
Carrick*	*No effect*	*No effect*	*No effect*	*No effect*	*No effect*

Table 4: Results for PRIME road marking across the 22 trial sites

**as this was one of the comparison sites no effects for rider behaviour were expected*

6.1 Key findings of the 2020 PRIMEs trials

During the 2020 motorcycle season PRIME road trials were conducted at 10 trial sites in the West Highlands on the A828, A82 and A85 (i.e. Appin House, Kingshouse, Loch Lubhair and Rob Roy's Dip). These trial sites included a range of left-hand and right-hand bends.

In total 12,949 motorcycles were manually counted and coded across all the trial sites and from these 4,047 lead motorcycles were analysed in more detail.

Speed was significantly reduced at four trial sites across left-hand and right-hand bends. A trend for reduced speed was observed at another site. Statistically significant effects were observed across all the trial sites for positive changes in road position at the point of the final PRIME road marking. Similarly, for motorcycle position at the apex of the bend, statistically significant effects were observed across seven of the 10 trial sites. This indicated positive changes in road position with motorcyclists taking a wider path around both left-hand and right-hand bends.

While braking was one of the key variables measured in the pilot trials, this did not appear to be a high incidence activity. A significant reduction in braking was observed for both left-hand and right-hand bends at the Loch Lubhair trial site. A number of trends for reduced braking were observed at other sites.

Across eight of the 10 trial sites, significant results were observed for increased use of the PRIMEs. This provided strong evidence that motorcyclists were going 'through the gap' at the final gateway marking and therefore in the desired position prior to the bend.

For detailed statistical analyses, please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2021).

A selection of bends illustrate the changes in road position due to PRIMEs (Figure 7).

Figure 7: Changes in road position
(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed)

6.2 Key findings of the 2021 PRIMEs trials

During the 2021 motorcycle season PRIME road trials were conducted at six trial sites and one comparison site on the A85, A82, and A84 (i.e. Taynuilt, Inveruglas, Runacraig, Dunira, Bonawe and Landrick Bends).

In total 9,594 motorcycles were manually counted and coded across all the trial sites and from these 2,548 lead motorcycles were analysed in more detail.

Speed was significantly reduced at five trial sites. A trend for reduced speed was observed at another site. A statistically significant effect was observed at one trial site for a positive change in road position at the point of the final PRIME road marking with similar trends at three other sites. For motorcycle position at the apex of the bend, a statistically significant effect was observed at three trial sites along with a trend at another site. This indicated positive changes in road position with motorcyclists taking a wider path around left-hand bends.

As in 2020, braking was not a high incidence activity. A significant reduction in braking was, however, observed at three sites and trends for reduced braking at three sites.

Across four of the six trial sites, significant results were observed for increased use of the PRIMEs. Trends for increased use of PRIMEs were observed at the other two sites. This provided strong evidence that motorcyclists were going 'through the gap' at the final gateway marking and therefore in the desired position prior to the bend.

At the comparison site no effects were observed, as expected. However, a trend for reduced braking was observed but this was due to a temporary situation affecting traffic flow on specific data collections periods.

For detailed statistical analyses please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2022).

A selection of bends illustrate the changes in road position due to PRIMEs (Figure 8).

Figure 8: Changes in road position
(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed)

6.3 Key findings of the 2022 PRIMEs trials

During the 2022 motorcycle season PRIME road trials were conducted at six trial sites and one comparison site on the A83, A82, and A85 (i.e. Dailnamac, Pulpit Rock, Butterbridge, Middle Kames, Salmon Draft and Carrick).

In total 9,670 motorcycles were manually counted and coded across all the trial sites and from these 3,324 lead motorcycles were analysed in more detail.

Speed was significantly reduced at one trial site and trends for reduced speed were observed at two other sites. Statistically significant effects were observed for changes in road position at the final PRIME road marking at four sites. Motorcyclists were riding 'through the gap' and maintaining positions closer to the centre of the road. At the apex of the bend, statistically significant effects were observed at three of the six trial sites with motorcyclists taking a wider line around the bend.

Statistically significant reductions were observed for late braking, braking on the bend and total braking across four of the six trial sites. Similar trends for reduced braking were observed at these sites and one other trial site.

Across all six trial sites there was a significant increase in the use of the final PRIME gateway marking.

At the comparison site no effects were observed, as expected, as no PRIMEs were installed and no other effects on rider behaviour were evident.

For detailed statistical analyses, please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (submitted).

A selection of bends illustrate the changes in road position due to PRIMEs (Figure 9).

Figure 9: Changes in road position
(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed)

6.4 Long-term effects of PRIMEs

Transport Scotland supported further research in 2022 by revisiting a site from 2020 and 2021 to investigate the nature of long-term effects over one-year and two-year periods (Table 5).

Site	Rider Behaviour				
	Speed	**Position at PRIME**	**Position at Apex**	**Braking**	**Use of Gateway**
One-year interval					
Dunira 2021	Sig	Sig	Sig	Sig/Trend	Sig
Dunira 2022	Sig	Sig	Sig	Sig/Trend	Sig
Two-year interval					
Rob Roy's Dip 2020	Sig	Sig	Sig	Trend	Sig
Rob Roy's Dip 2022	Sig	Sig	Sig		Sig

Table 5: Long-term effects of PRIMEs on rider behaviour

At Dunira, when the results from 2022 were compared back to the results for 2021, the same effects were apparent one-year later, indicating long-term behaviour change effects from installing PRIMEs at this trial site.

At Rob Roy's Dip, when the results from 2022 were compared back to the results for 2020, the same statistically significant effects were apparent two-years later, indicating long-term behaviour change effects from installing PRIMEs at this trial site. However, the trends in reduced braking that were present in 2020 were not apparent in 2022.

The results from this additional work indicated that PRIMEs had a long-lasting effect on behaviour across all three of the key criteria PRIMEs are designed for (i.e. speed, position and braking).

Motorcyclists meeting at the Green Welly in Tyndrum: Alex Stedmon

6.5 Rider interviews

In total, 100 rider interviews were conducted during 2021 and 2022 at the Green Welly Stop in Tyndrum and Inveraray waterfront. In all cases, prior verbal consent was obtained and field notes were recorded afterwards.

The aim of the interviews was to provide insights into how motorcyclists who had experienced the PRIMEs had perceived them (i.e. did they remember passing them/paying attention to them?). In addition, it was important to capture how motorcyclists felt the PRIMEs might have influenced their behaviour (i.e. in relation to speed, position and braking).

This provided three main ways to look at the results and consider how they related to the video data captured at the trial sites:

- if motorcyclists did not remember the PRIME road sign/markings but behaviour changes were apparent from the video data, then this could indicate a more unconscious processing of the PRIMEs and intuitive behavioural influences
- if motorcyclists remembered the PRIMEs but did not feel they influenced their behaviour, this again could indicate a more implicit processing of the PRIMEs
- if motorcyclists remembered the PRIMEs and felt they influenced their behaviour, this could indicate a more explicit processing of the PRIMEs

Had motorcyclists been aware of the PRIMEs on their journey that day, and if so, whereabouts? From the interviews 32 motorcyclists remembered observing the PRIME road sign or road markings; 59 motorcyclists did not remember them and 9 were not sure if they had seen them. Of the 32 who remembered seeing them, 18 stated they remembered the road sign in particular. This could mean that they were not as aware of the road markings and any behavioural effects apparent from the road markings could have been more aligned with the 59 that did not remember them

Did they feel the PRIMEs had influenced their riding? The responses to this question were separated out for the 32 motorcyclists who remembered observing the PRIMEs, 59 motorcyclists who did not remember them, and the 9 who were not sure if they had seen them.

For the 32 motorcyclists who remembered the PRIMEs, in most cases (N=22) they did not feel the PRIMEs affected their riding. The responses were stated in terms of "that's how I would be riding anyway" or "I don't think I changed my behaviour because of them".

Of this group only a few motorcyclists either felt the PRIMEs had influenced their behaviour (N=6) or were not sure if the PRIMEs had influenced their behaviour (N=4). These motorcyclists (N=10) were asked how, or how might, PRIMEs have affected their behaviour. Responses focused on speed (N=8), position (N=9) and braking (N=6).

For the 59 motorcyclists who did not remember observing the PRIMEs four participants were identified as not travelling through PRIMEs trials sites. Of the 55 who had passed through any of the PRIME trial sites on their way to Tyndrum or Inveraray, in most cases (N=47) they did not feel the PRIMEs affected their riding. The responses were stated in similar terms to the motorcyclists who had remembered them.

Of this group only a few motorcyclists either felt the PRIMEs had influenced their behaviour (N=6) or were not sure if the PRIMEs had influenced their behaviour (N=2). These motorcyclists (N=8) were asked how, or how might, PRIMEs have affected their behaviour. Responses focused on speed (N=6), position (N=8) and braking (N=6).

For the 9 motorcyclists who were not sure if they had observed the PRIMEs, 6 felt that their behaviour would not be influenced by them and 3 felt their behaviour would. Overall, they felt that PRIMEs could influence speed (N=6), position (N=7) and braking (N=5).

Where motorcyclists did not state a specific influence, most were unsure of the exact influence PRIMEs might have on rider behaviour.

Do you think PRIMEs are a good or bad idea? This question was asked of all participants and overall, most responses were positive (N=89) and with fewer negative responses (N=11). In general, those who felt they were a good idea expressed it in terms of "anything that makes the roads safer is a good thing", "for less experienced riders it's a good idea", and "for those who do not know the roads it is a good idea". Of those who felt they were a bad idea the general comments were "we don't need more white pain on the road" or "I don't want to be told how I should be riding".

An interesting observation was that many participants responded by saying "it wouldn't affect my riding but I can imagine for less experienced riders, tourists or overseas riders it would be helpful". This was not a specific question in the interview (i.e. how beneficial the PRIMEs might be for other riders) as we were interested in the personal experience and viewpoint of riders themselves. However, such responses, indicated that some motorcyclists felt they would not need to use the PRIMEs in relation to their own riding but could see the benefit for others (and this was primarily focused on those with less experience and less geographic knowledge).

Overall observations
Almost two-thirds of the motorcyclists interviewed did not remember seeing the PRIMEs on their way to Tyndrum or Inveraray. In addition, in most cases, motorcyclists did not feel the PRIMEs would influence their riding. Taking these two observations together, this could indicate an unconscious or implicit influence of PRIMEs in the behaviours observed at the trial sites.

It was decided to stop collecting data once 100 riders had been reached. This is because there came a point where the responses became similar and data saturation was reached. However, conversations continued as they were a good opportunity to inform riders of the PRIME road markings and material they were made of.

While the responses were generally positive for PRIMEs, some comments focused on "putting too much white paint on the road" or "being told how to ride". After the informal conversations were completed a quick overview was given about the material used for the PRIME road markings and their purpose. When motorcyclists were more familiar with the idea that the markings had the same or greater traction qualities as the road surface they were more positive about them. Some motorcyclists suggested using yellow markings so that the idea of white paint on the road was less of an issue.

PRIME road sign near Buachaille Etive Mòr on the A82: Alex Stedmon

7 Discussion

Without counting the comparison sites where no statistically significant effects were observed, 69.2% (i.e. 108 out of 156 possible results) of the results across all 3-years of road trials indicated a statistically significant effect or positive trend for rider behaviour due to the installation of PRIME road markings. These can be broken down into 47.4% that were statistically significant (i.e. 74 out of 156 possible results) and a further 21.8% indicated positive trends in the data (i.e. 34 out of 156 possible results).

Overall, the results for the PRIME road trials provide strong evidence for a range of beneficial effects of PRIMEs on rider behaviour on a range of bends. Across all three key measures (i.e. speed, position and braking) significant effects were observed at different sites during the trials.

There were no instances of statistically significant increases in speed, dangerous positioning, increases in braking or decreased use of the PRIME gateways. These observations provide further evidence that PRIMEs did not have a detrimental effect on rider behaviour. As such, even at locations where no statistically significant effects were observed, PRIMEs were no worse than not installing them at all.

This means that there could be benefits of PRIMEs at these locations which were not sensitive enough during statistical analyses to illustrate significant effects and where further research could provide further insights into rider behaviour.

7.1 Speed, position, braking and use of the final PRIME road marking

A discussion of the results for speed, position, braking and use of the final PRIME gateway road marking is presented below.

Speed

There was a statistically significant reduction in speed at 10 of the 22 trial sites. The majority of bends throughout the trials were characterised as sharp left-hand bends. Some were approached from long straight sections of road where motorcyclists were more likely to be carrying speed into the bend (i.e. Appin House south, Taynuilt, Runacraig south, Dunira). In addition, some of the approaches (i.e. Rob Roy's Dip west 1 and west 2) were on undulating or downhill sections that could have exacerbated the issue of carrying speed into the bend. Other trial sites were more technical and involved more complex bends and limited views around the bends (i.e. Loch Lubhair east, Runacraig north, Bonawe, Salmon Draft north).

Statistically significant speed reductions were in the order of 3.69% to 8.06% slower when PRIMEs had been installed. These reductions in speed were typically around 1.73mph and 3.28mph respectively. Previous research has indicated long-term speed reductions of 3kmh (1.86mph) to 4kmh (2.49mph) for all vehicle types when PCMs were installed (Martindale and Urlich, 2010), and these results would seem to support that finding.

Speed data across the PRIME road trial sites were within the prescribed speed limits and comparable with national data indicating an average free-flow motorcycle speed of 51mph (Department for Transport, 2015). In Scotland the average speed of motorcycles on national speed limit single carriageways is 60mph (Transport Scotland, 2021).

In this research, across the three years, the fastest average speeds were observed at Kingshouse south (54.5mph), Taynuilt (48.9mph) and Butterbridge (48.9mph). These observations were as expected as these were the most open stretches of road. The slowest average speeds across the three years were observed at Appin House north (36.0mph), Runacraig south (35.0mph) and Pulpit Rock (34.7mph) which some of the more technically demanding bends investigated.

Position at final PRIME road marking and apex of the bend
In previous research, speed reductions have tended to be relatively modest with lane keeping more reliably influenced (Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson, 2021, 2022).

For motorcycle position at the final PRIME road marking, statistically significant effects were observed at 15 of the 22 trial sites. In all cases motorcyclists were moving closer to the centre of the road, into the PRIME gateway position, and riding 'through the gap'.

This provides evidence that PRIMEs influenced rider position across a range of bends. In addition, where significant effects were observed they were sustained throughout all the PRIME data collection weekends and showed that PRIMEs had a lasting effect at these locations.

For motorcycle position at the apex of the bend, statistically significant effects were observed across 13 of the 22 trial sites. This indicated positive changes in road position with riders taking a wider line around the left-hand bends.

This provides strong evidence that PRIMEs continued to influence rider position after the final PRIME road marking and through the bend itself. In all cases the effects were sustained over the PRIME data collection weekends ranging from 6 to 8 weeks.

Braking
While braking was one of the key variables measured in the PRIME road trials, this did not appear to be a high incidence activity. The low incidence for braking, in itself, was a positive observation as it can be dangerous for motorcycles to initiate braking on a bend. Such behaviour can destabilise the motorcycle which then tends to become more upright and travel in a straighter direction going forward. This often accounts for motorcyclists losing control on bends. Research has shown that motorcyclists tend to brake first on a bend before adjusting their steering but will tend to swerve first on a straight road before braking (Stedmon, Crundall, Crundall, Irune, Saikayasit, van Loon and Ward, 2010).

Statistically, significant reductions in braking behaviour (i.e. braking late, braking on the bend and total braking) were observed across nine of the 22 trial sites.

Apart from Pulpit Rock and Middle Kames, these PRIME road trial sites were generally approached from straights into and sharp left-hand bends. It might have been expected that motorcycles could be carrying excess speed into bends and so a significant reduction in braking at these sites is a positive outcome of installing PRIMEs.

Use of the final PRIME road marking
Across 18 of the 22 trial sites statistically significant results were observed for increased use of the final PRIME road marking.

This provides strong evidence that motorcyclists were riding 'through the gap' at the final gateway marking and therefore in the desired position prior to the bend. These effects were observed throughout the PRIME data collection weekends illustrating sustained effects.

Overall, PRIMEs had a range of effects on speed reduction, lane position, braking and use of the final PRIME road marking. Taken together, these trials provide strong evidence that PRIMEs have a positive effect on rider behaviour.

7.2 Sustained and long-term effects of PRIMEs

Transport Scotland supported further research to investigate the nature of potential sustained effects for PRIMEs at the trial sites.

In the 2020 PRIMEs trials there was a two-week interval between the PRIME 1 and PRIME 2 data collection weekends. In some cases, effects were sustained over this two-week timeframe across the trial sites:

- **Appin House (Northbound)** – sustained effect for position at the final PRIME road marking
- **Appin House (Northbound)** – sustained reduction in speed; sustained effect for position at the final PRIME road marking; and longer-term effect at PRIME 2 for position at the apex of the bend
- **Kingshouse (Northbound)** – sustained effect for position at the final PRIME road marking; and sustained increase in use of the final PRIME gateway
- **Kingshouse (Southbound)** – sustained effect for position at the final PRIME road marking; and sustained effect for position at the apex of the bend
- **Loch Lubhair (Eastbound)** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; sustained reduction in total and late braking; and sustained increase in use of the final PRIME gateway
- **Loch Lubhair (Westbound)** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; sustained reduction in total and late braking; and sustained increase in use of the final PRIME gateway
- **Rob Roy's Dip (Eastbound 1)** – sustained effect for position at the final PRIME road marking; and sustained increase in use of the final PRIME gateway
- **Rob Roy's Dip (Eastbound 2)** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; and sustained increase in use of the final PRIME gateway
- **Rob Roy's Dip (Westbound 1)** – sustained reduction in speed; sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; and sustained increase in use of the final PRIME gateway
- **Rob Roy's Dip (Westbound 2)** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; and sustained increase in use of the final PRIME gateway

From these results it was clear that over a range of measures, the effects were still present two weeks later.

In the 2021 PRIMEs trials there was the opportunity to extend the data collection interval up to six-weeks or eight-weeks depending on the trial site. This allowed the research to investigate if effects were still present after a longer timeframe than the 2020 trials.

Across the trial sites the following sustained effects were observed:

- **Taynuilt** – sustained trend in speed reduction; sustained effect for position at the apex of the bend; and sustained increase in use of the final PRIME gateway
- **Inveruglas** – sustained reduction in total and late braking
- **Runacraig (Northbound)** – sustained increase in use of the final PRIME gateway
- **Runacraig (Southbound)** – longer-term reduction at PRIME 2 for reduced braking on the bend and total braking; and sustained increase in use of the final PRIME gateway
- **Dunira** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; sustained reduction in total braking; and sustained increase in use of the final PRIME gateway
- **Bonawe** – trend in the data for increased use of the gateway across all PRIME weekends
- **Landrick Bends (comparison site)** – no significant effects as expected.

These results show that the sustained effects were uniform across the weekends with no apparent drop in their effect. In some cases, an initial effect was observed (i.e. a reduction in speed at some of the trial sites) and then a return towards the Baseline in subsequent weeks (but still below the Baseline levels).

In the 2022 PRIMEs trials there was a further opportunity to investigate any sustained effects between six-weeks and eight-weeks depending on the trial site. Across the trial sites the following sustained effects were observed:

- **Dailnamac** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; sustained reduction in total braking and a trend in late braking; and sustained increase in use of the final PRIME gateway
- **Pulpit Rock** – sustained effect for position at the apex of the bend; sustained reduction in late braking and a trend in total braking; and sustained increase in use of the final PRIME gateway
- **Butterbridge** – sustained effect for position at the final PRIME road marking; a trend in late braking; and sustained increase in use of the final PRIME gateway
- **Middle Kames** – sustained effect for position at the final PRIME road marking; sustained reduction in braking; and sustained increase in use of the final PRIME gateway
- **Salmon Draft (Northbound)** – sustained effect for position at the final PRIME road marking; sustained effect for position at the apex of the bend; and sustained increase in use of the final PRIME gateway
- **Salmon Draft (Southbound)** – sustained reduction in speed; sustained reduction in braking; and sustained increase in use of the final PRIME gateway
- **Carrick (comparison site)** – no significant effects as expected.

During 2022, Transport Scotland supported further research by revisiting a site from 2020 and 2021 to investigate the nature of long-term effects over one-year and two-year periods

The results from this additional work indicated that PRIMEs had a long-lasting effect on behaviour across all three of the key criteria PRIMEs are designed for (i.e. speed, position and braking).

7.3 Motorcycle distributions on the Trunk Road Network

With 32,213 motorcycles observed, classified and analysed, it was possible to provide some wider observations of the nature of motorcycling in Scotland during the three year period of 2020 to 2022.

Throughout the analyses it became apparent that specific patterns existed in the nature of motorcycling in the West Highlands. Across the PRIME road trial sites there appeared to be directional effects in motorcycle traffic through the day with clear examples of positive-skewed distributions (i.e. more motorcycles in the morning) and negative-skewed (i.e. more motorcycles in the afternoon). This is represented below (Figure 10).

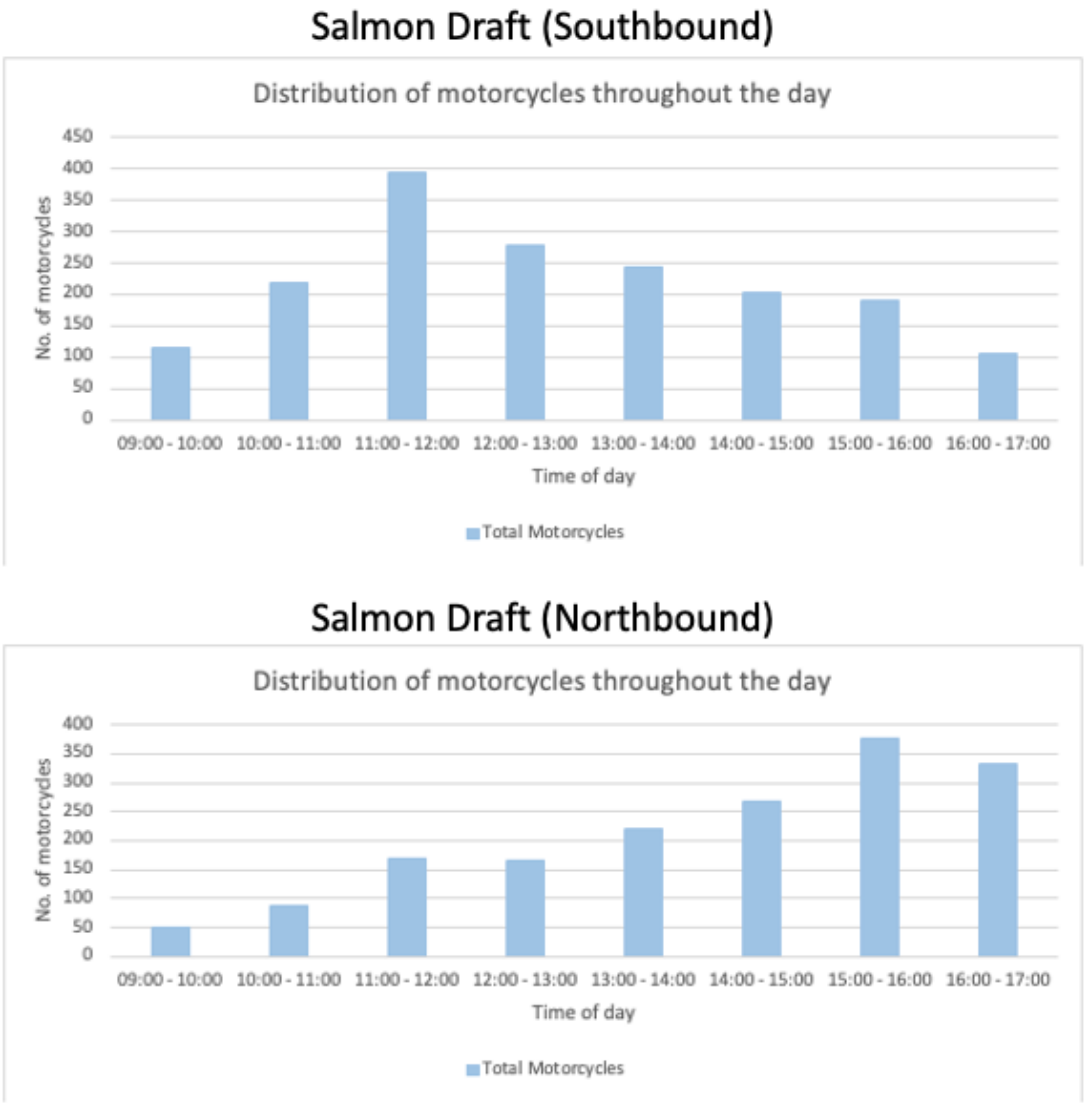

Figure 10: Positively-skewed and negatively-skewed distributions

These profiles indicate directional effects of motorcyclists 'riding out' in one direction in the morning and then returning, in the opposite direction, later in the day. This could represent local motorcyclists who were only riding out for a day and heading home later rather than weekend tourers and those on longer touring holidays.

When the distributions are plotted on the map of the PRIME road trial sites, it is possible to identify typical routes that riders might take in this area earlier in the day (Figure 11).

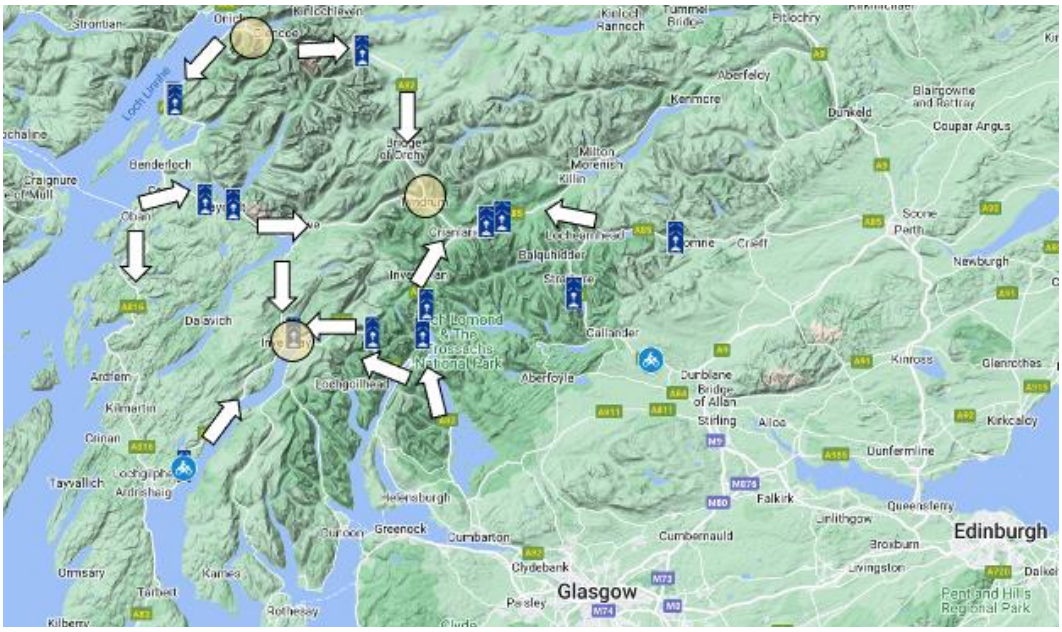

Figure 11: Flow of motorcyclists on the Trunk Road Network
(arrows indicate direction of travel in the morning)

The yellow circles indicate popular motorcycle meeting points (Glencoe, Tyndrum and Inveraray) and it is apparent from the motorcycle distributions that motorcyclists tend to ride out to these locations during the day and then return later in the day (Figure 12).

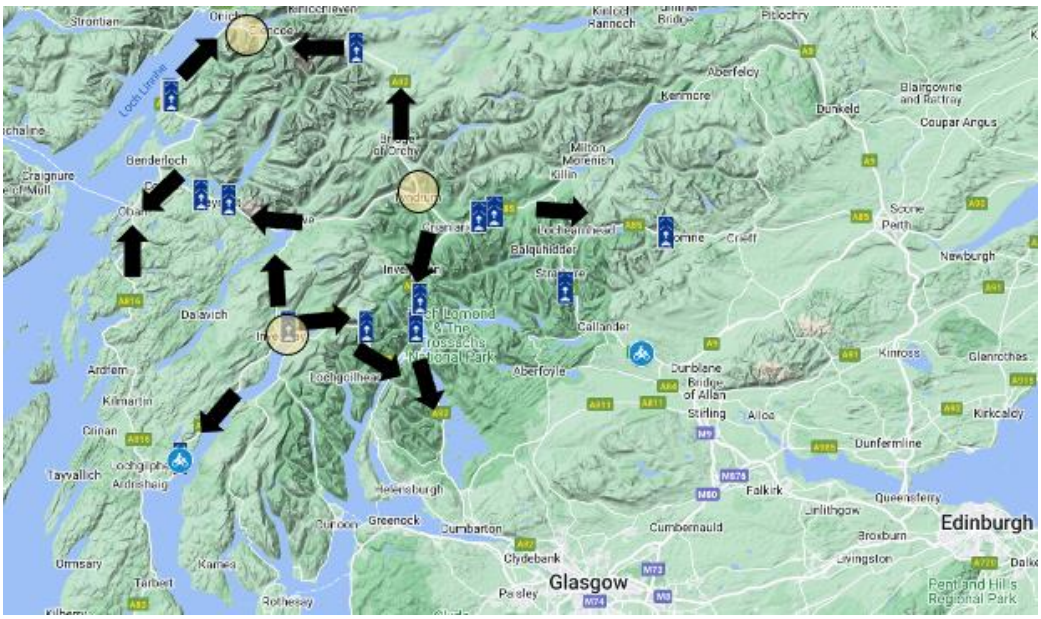

Figure 12: Flow of motorcyclists on the Trunk Road Network
(arrows indicate direction of travel in the afternoon)

From the analyses specific motorcycle flow patterns were identified in the West Highlands. Clear directional effects exist in motorcycle traffic throughout the day. For any given location it is even possible to pin-point which hour of the day most motorcycles are expected to pass by, and typical numbers. This information could be invaluable for emergency response logistics, enforcement/education initiatives, pop-up road safety campaigns, etc.

7.4 Further research questions

Throughout the course of the 3-year research programme, a number of important questions have been identified that require further research that would underpin an implementation phase for installing PRIMEs more widely for casualty reduction.

What are the effects of PRIMEs on untreated roads?

One of the benefits of Transport Scotland's investment in this research is that each trial site was optimised (i.e. resurfacing, lines/signs, barriers, and roadside vegetation/furniture management) prior to data collection. This was done to minimise any environmental variables that could affect rider behaviour. However, in the future it is likely that PRIMEs might be installed on roads where budget constraints do not allow for such engineering works. For PRIMEs to provide the cost-effective intervention they are hoped to achieve, it is vital that further research is conducted at sites where the road surface and environment has not been brought up to the best standard. This will help identify what sort of condition roads need to be in to be suitable for PRIMES and the development of an installation guide for councils and road authorities to use in the future.

Can greater speed reductions be achieved?

At locations where there are faster approaches to bends and where speed reductions were not observed at existing trial sites, it is important to investigate if a different PRIME road marking design might have a stronger 'priming' effect on rider behaviour. For example, installing a series of five gateway markings instead of three gateway markings used at all trial sites to date. This will allow the research to identify sites where speed might be influenced through the installation of more PRIME road markings or if three is an optimum number.

How do PRIMEs affect right-hand bend behaviour?

In 2020 it was possible to investigate PRIMEs at four right-hand bends. However, for the main RST funded trials left-hand bends were the primary focus. In order to extend the evidence base of PRIMEs it is necessary to include further right-hand bends in future trials so that the scientific knowledge takes both left and right-handed bends into account.

Can PRIMEs communicate different hazards to motorcyclists?

The research to date has focused predominantly on left-hand bends. Some of the research in 2020 began to investigate right-hand bends and PRIMEs were shown to provide benefits. As well as reducing motorcycle casualties on bends, more research is needed on the use of PRIMEs for other hazards that motorcyclists are vulnerable to. PRIMEs could be installed on approach to rural side-roads where drivers of emerging vehicles might fail to see motorcyclists and/or fail to judge their speed accurately. PRIMEs could be installed to help initiate lateral movement prior to the junction and present an additional cue to drivers.

How do other road users react to PRIMEs?

By virtue of collecting the motorcycle data over the last three years, video data now also exist for every other vehicle at each site during the same timeframe. It would be possible to analyse other road users (i.e. cyclists, cars, lorries, buses, etc) to understand if their behaviour has changed due to the installation of the PRIME road markings. This is a very important question as an underlying aspect of installing PRIMEs is that they should not conflict with the needs of other road users. Although PRIMEs are designed specifically for motorcycles, if other road users derive some benefit from them then this also needs to be understood. Equally, if the PRIMEs have any kind of impact on other road user behaviour then early insights into this could help with design revisions.

Which site characteristics influence the success of PRIMEs?

Underpinning the current findings, a key research question is which sites obtain the most benefit by installing PRIMEs and where might PRIMEs be less effective so that even the low cost of installing them is not wasted. This could be achieved by on some form of meta-analysis of existing and new data combined with expert motorcyclist reviews of specific trial sites to identify any road environment factors that could inform future implementation and roll out of PRIMEs more widely.

7.5 Scotland' Road Safety Framework and motorcycle casualty reduction

Transport Scotland recently published its 'Road Safety Framework to 2030' outlining a long-term goal for road safety where no-one dies or is seriously injured by 2050 (Transport Scotland, 2021). It proposes a 'Safe Systems' approach to road safety delivery as set out in the National Transport Strategy Delivery Plan (Transport Scotland, 2020). In relation to the concept of PRIMEs, the current research addresses the following pillars:

- **safe speeds** – speed limits in a Safe System are designed for crash-avoidance and reducing physical impact. Key factors that should be taken into account in any decisions on local speed limits are: history of collisions, road geometry and engineering, road function; composition of road users (including existing and potential levels of vulnerable road users); existing traffic speeds, and road environment (Transport Scotland, 2021). With these factors in mind, PRIMEs offer a potential tool for supporting speed limits where roads have already been brought up to the best possible standard. With the observed reductions in speed and no statistically significant increases in speed, PRIMEs may therefore provide a means for maintaining safe speed limits rather than drastically reducing them. However, coupled with improved position on the road and reduced braking on bends this would appear to be supporting the rider experience more holistically rather than focusing on one specific measure of performance for safety.
- **safe road use** – road users should pay attention to the road ahead and the task in hand; adapting to the conditions (weather, the presence of other users, etc.); travel at lower speeds; and give sufficient room to all other road users, no matter what their mode of travel (Transport Scotland, 2021). PRIMEs may provide motorcyclists with a tool that allows them to adapt their behaviour to the road environment and which other road users may also use as a cue for demanding bends and the presence of motorcyclists. In this way PRIMEs may help ensure that road users are risk-aware, can develop coping strategies for demanding situations, and act appropriately to keep themselves and others safe on the road (Transport Scotland, 2021). This was demonstrated by the positive results for road position both at the final PRIME road marking and at the apex of the bend.
- **safe roads and roadsides** – the environment is designed to reduce the risk of collision and to mitigate the severity of injury should a collision occur. This can be achieved through design, maintenance and the implementation of strategies to reduce casualties on the roads (Transport Scotland, 2021). This can also be promoted through positive behaviours and safer sharing of spaces, the appropriate use of speed limits and signage that provides a much more affordable and sustainable way to protect the most vulnerable road users. PRIMEs provide a low-cost and easily maintained casualty reduction initiative working in harmony with other interventions such as bike-guard and other vehicle restraint system (VRS) solutions. They can be installed on existing roads quickly and efficiently or incorporated into road upgrade schemes. From the low incidence of braking across the trial sites, this would seem indicate that motorcyclists are generally set up well for these bends but that other effects on position and speed enhance safety further.

Across these strategic pillars PRIMEs have the potential to provide a new and unique contribution to a 'Safe System' approach. There is clear evidence from the research conducted over the last 3-years that PRIMEs influence rider behaviour and it is important to begin planning for an implementation phase of work and address further research questions that will underpin the roll-out of PRIMEs more widely.

The project consortium have identified representatives from a Local Authority in Scotland with an interest in installing PRIMEs on their roads. This would provide an opportunity to widen the scope of PRIMEs in Scotland while also providing also ideal testbed for trialling a PRIMEs installation process (i.e. a user guide for authorities and councils so they can install PRIMEs without the need for expensive research).

8 Conclusion

This report summarises the 3-year programme of PRIME road trials in Scotland funded by Transport Scotland and the Road Safety Trust. Throughout this work and the wider context of psychological theory, the approach taken has provided a planned and incremental development of understanding and building of evidence to take the work forward. This has been supported through the publication of scientific journal papers that demonstrate the work has been peer-reviewed and accepted to the highest international academic standards.

To date, 32,213 motorcycles have been manually counted and coded throughout the West Highlands with 9,919 lead motorcycles analysed in detail to understand the potential influence of PRIMEs on rider behaviour.

As far as the project consortium are aware, this makes the work the largest motorcycle behaviour investigation of its kind. Overall, the scientific evidence demonstrates that PRIMEs influence rider behaviour in positive ways by reducing speed, improving road position and reducing braking.

These findings underpin Transport Scotland's 'Road Safety Framework to 2030' that has identified motorcyclists as a Priority Focus Area with a target of 30% reduction in motorcyclists killed or seriously injured by 2030 (Transport Scotland, 2021).

The concept of PRIME gateway markings provides a simple and very cost-effective solution to help reduce single vehicle crashes on our roads (which are one of the main collision types for motorcycles).

The evidence shows that if PRIMEs are installed they are used by motorcyclists and there have been no instances of a significant increase in speed, dangerous positioning, or increases in braking. These observations provide further evidence that PRIMEs did not have a detrimental effect on rider behaviour.

In addition, while the collision data are low and not always known for each site, since the start of the trials there have been no motorcycle injury collisions at any of the previously identified cluster sites.

The findings support the development of bespoke motorcycle road safety measures by Transport Scotland that provide an important step in reducing motorcyclist road casualties. By demonstrating the positive influence of PRIMEs on rider behaviour and rider safety, this work showcases Transport Scotland as a leader in this initiative for the UK and the world. It highlights the important role of employing Human Factors expertise in road safety initiatives beyond the current work and in casualty reduction and road user behaviour more widely.

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Motorcycles parked near the PRIME trial site by Buachaille Etive Mòr: Alex Stedmon