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Safeguarding Vulnerable Road Users

Summary Report of PRIME Trials 2023 - 2025

Contents

Abstract and highlights

Abstract

In this phase of the research, 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 a total of 18 trial sites (13 new trial sites plus 5 sites used in previous years' research) and two comparison sites across the West Highlands of Scotland. These novel PRIME road markings were presented as a series of 'gateways' to promote safer riding by encouraging riders to go 'through the gap'. All sites were of similar (untreated) 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 15,557 motorcyclists were observed and from these 5,680 lead motorcycles were analysed in more detail. Across the trial sites, statistically significant reductions in speed were observed at 13 of the 18 trial sites. Significant changes in lateral position were observed at the final PRIME gateway marking at 14 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 14 trial sites. Statistically significant reductions in braking were observed at 4 trial sites with an increase at one site. There were statistically significant increases in the use of PRIME road markings across 17 of the 18 trial sites.

No statistically significant effects were observed at the comparison sites. These findings are discussed in relation to sustained effects, carry over effects, alternative PRIME designs, 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 a further 15,557 motorcyclists, a total of 47,770 when combined with the 32,213 analysed in Phase 1 of the PRIME trials (2020 – 2022).

> **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.**

Data analysis suggests long term sustained behaviour change following the installation of PRIME road markings.

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

Around the world, across motorised vehicles, motorcycles represent the most vulnerable road users. 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).

Within Great Britain, motorcyclists typically represent less than 1% of the total vehicle miles on roads, but account for 21% of all road fatalities (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).

Latest figures for Scotland indicate that there were 446 motorcycle casualties in 2024. This represented a decrease of 7% of whom 274 (61%) suffered serious injuries and 31 died. However, this was an increase of four fatalities from 2023 (Transport Scotland 2025). Within GB there were 340 motorcycle fatalities in 2024 compared with 315 in 2023, an increase of 25 (Department for Transport, 2025).

PRIMEs for motorcycle casualty reduction

PRIMEs provide a tool for riders to adapt their behaviour on approach to a potential hazard while optimising their expertise and enjoyment and remaining safe on the road. Phase 1 of the trials represented a 3-year investigation (2020 to 2022) of ‘Perceptual Rider Information for Maximising Expertise and Enjoyment’ (PRIMEs) on Scotland’s Trunk Road Network. Throughout Phase 1 the trial sites had been brought up to the highest standard through road engineering works. This provided an opportunity to investigate PRIMEs without extraneous variables affecting rider behaviour. The results demonstrated that the ‘PRIME’ road markings produced positive behaviour change across a range of measures that underpin keeping roads users in Scotland safe.

Following a successful funding application for Phase 2 of the research, specific activities have been conducted through 2023 to 2025 to increase the impact of the findings and expand the knowledge base above and beyond Phase 1. As in Phase 1, Phase 2 has focused on the safe navigation of bends. This remains a critical activity for motorcycle safety where motorcyclists have to make sure that: speed is suitable for the conditions; position is optimised for entering and travelling through the bend; and braking is minimised whilst travelling around the bend. With the need to reduce motorcycle casualty rates on the UK’s roads remaining a key focus for road safety, Phase 2 provided a unique opportunity to expand the scientific knowledge base of PRIMEs into critical areas that were not possible in Phase 1.

The key aim of this phase of the research has been to conduct further research to consolidate our understanding of the benefits or drawbacks of installing PRIMEs based on trial site characteristics. This has been addressed through practical objectives to:

Install and evaluate PRIMEs across 18 trial sites and expand the PRIMEs dataset to 40 trial sites and 50,000 motorcycles – by the end of 2025, data were collected at 18 trial sites (13 new trial sites plus 5 sites used in previous years' research) and two comparison sites. In total, 47,770 motorcycles were observed by the end of Phase 2. While not reaching 50,000 motorcycles this reflects the opportunistic nature of the sample.

Address specific research questions for: untreated roads, right-hand bends, and further reductions in speed – each year during Phase 2 these specific research questions were investigated. These have been detailed in each year's technical reports and integrated in this summary report.

Conduct a meta-analysis to provide guidance on identifying sites where PRIMEs might be beneficial or not – as part of earlier Phase 2 work (outside of RST funding) with the development of the Installation Toolkit, a thematic analysis of bend characteristics was conducted to provide insights into which bends might benefit the most from PRIMEs and also those that may not. The findings from Phase 2 will be considered in any update of the Installation Toolkit so that practitioners can make informed decisions about installing PRIMEs at their own proposed locations

Use Human Factors participatory methods to promote wider acceptance of PRIMEs by motorcyclists and other road users – this has been developed through informal outreach activities and also through public engagement activities throughout Phase 2

Feedback and disseminate results to Government ministers, road safety stakeholders, academia and riders themselves – Project PRIME has been able to disseminate research findings throughout Phase 2 to a variety of professional interest and stakeholder audiences

Provide substantive evidence beyond Phase 1 of site characteristics and benefits of PRIMEs at different locations – through the expanded scientific knowledge for PRIMEs generated through Phase 1 and Phase 2, conference/stakeholder presentations and scientific journal papers, there is now a substantial peer-reviewed and academically accepted basis to the science behind PRIMEs.

Unique research in the West Highlands

Based on formal reviews and analyses of collision data, 13 new trial sites were identified in the West Highlands ranging from Glencoe, Oban, Inveraray, Loch Lomond and towards Stirling and Crieff. Five trial sites were revisited from previous years' research. Two new

comparison sites were also included where data were collected but PRIME road markings were not installed. At one comparison site data were collected over two different years to investigate behavioural consistency.

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 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 in accordance with best practice.

Over 47,500 motorcycles observed

In Phase 2 a further 15,557 motorcycles were manually counted and coded across all the trial sites (a total of 47,770 when combined with the 32,213 analysed in Phase 1). Motorcycles carrying a passenger/pillion (N=1,634) represented 10.5% of the total sample of motorcycles. The largest proportion of motorcycles were classified as being part of a group (N=8,970), accounting for 57.65% 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, further reinforcing the social nature of motorcycling.

Statistically significant changes in rider behaviour

Lead motorcycles (N=5,680) accounted for 36.51% of the total sample of motorcycles and were analysed in more detail. Results across the 18 trial sites are summarised below:

Speed – statistically significant reductions in speed were observed at 13 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 14 trial sites with motorcyclists riding in better positions on approach to the bend. Trends were observed at two other sites.

Lateral position at the apex of the bend – statistically significant changes in lateral position were observed at 14 trial sites. A trend was observed at two other sites.

Braking behaviour – statistically significant reductions in braking were observed at 9 trial sites. Trends were observed at two other sites.

Use of the PRIME road markings – statistically significant increases in the use of PRIMEs were observed at 17 trial sites. Trends were observed at one other site.

At the comparison sites a trend was observed in the data for one site in between the 2024 Baseline and 2025 PRIME data. Overall, these results indicated that while minor speed differences were observed at this comparison site they were not statistically significant and the results can be regarded as generally consistent across 2024 and 2025.

Long-term effects of PRIMEs

Transport Scotland funded additional research to investigate rider behaviour changes over the longer term. By revisiting previous trial sites there was an opportunity to investigate long-term behaviour change by comparing results from 2025 with previous years. It was therefore possible to compare behaviour across 5-year, 3-year and 2-year intervals. Long-term behaviour change was evident when results were compared across different years. From the five trial sites that were revisited, four demonstrated long-term effects for position at the final PRIMEs marking and three sites demonstrated long-term effects for position at the apex. There was also a long-term pattern of reduced braking at one site and across all five sites there was a long-term increase in the use of the gateways. To find that behaviour remains stable at the comparison sites and that long-term behaviour change exists up to 5-years at some sites provides valuable evidence that PRIMEs can have a long-lasting effect on rider behaviour.

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, not just in relation to the installation of PRIMEs but also in examining rider behaviour through the baseline data collected. With a total of 47,770 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.

However, it is important to highlight that braking increased at one site. In addition, while the collision data for the entire trial period are still being collated, early signs point to a reduction in motorcycle injury collisions where PRIMEs have been installed.

Project dissemination and recognition

To date, the research has been published as five scientific papers for the world-leading journal 'Transportation Research Part F: Behaviour and Psychology' (Stedmon et al, 2021, 2022), 'Ergonomics' (Stedmon et al, 2024a), 'Human Factors' (Stedmon et al, 2025b), and 'Advances in Transportation Studies: An International Journal' (Stedmon et al, 2026). Findings have also been published in the proceedings of the Chartered Institute of Ergonomics and Human Factors' Annual Conference (Stedmon et al, 2023, 2024b, 2025a). This demonstrates that the research has been peer-reviewed to the highest standard by the international academic community. Project PRIME was also recognised by a number of awards during 2023 with the Chartered Institution of Highways and Transportation (CIHT) Awards commendations: highly commended for 'Road Safety Award' and commended for 'Research Initiative of the Year'. At the Institute of Highway Engineers (IHE) Highways Awards Project PRIME won the 'Road Safety Scheme of the Year' and the 'Judges Special Merit Award'. Project PRIME was also awarded the 'Prince Michael International Road Safety Award'. At the 2025 Chartered Institute of Ergonomics and Human Factors' Annual Conference, Project PRIME won the 'Best Paper' award (Stedmon et al, 2025a).

Project PRIME toolkit and impact

Alongside the further road trials conducted during Phase 2 the project consortium have also developed an Installation Toolkit for Project PRIME. This toolkit provides summary details of the process adopted during Phase 1 of Project PRIME and includes information on site identification, design and installation considerations together with effectiveness in the context of bend characteristics. The Installation Toolkit has been developed and published separately by Transport Scotland and is available here. It is intended to assist road authorities in replicating the approach taken in the Project PRIME trials.

In 2025 the Welsh Government authorised four pilot sites of PRIMEs in Wales. The Project PRIME team have been approached by National Highways to assist with an application to the UK Department for Transport (DfT) for PRIME trials in Derbyshire and other local authorities have approached DfT. There is also interest from a number of local authorities in Scotland who are planning to install PRIMEs in their areas during 2026.

In January 2026 Project PRIME featured in the safe infrastructure theme of the DfT Road Safety Strategy to 2035. The Strategy acknowledges the positive results in Scotland and confirms that the UK Government is supporting PRIME pilot trials in new regions (Department for Transport, 2026).

Transport Scotland pioneering world-leading and world-class research

This is a project which the Scottish Government and parliamentary ministers are aware of. Reaching out to ministers of transport and tourism, this work promotes a key message in keeping motorcyclists safe in Scotland and reducing casualties, with knowledge that can be taken around the world to showcase Scotland as a pioneer in this work. Parliamentary briefings, in turn, provide further mainstream media opportunities to publicise the work and promote the Road Safety Trust's support and potential for future research funding along with wider research impact.

This research underpins the development of bespoke motorcycle road safety measures that should act as 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 and the Road Safety Trust as leaders in this initiative for the UK and the world.

Purpose

This report provides a summary of the research findings. For practitioners looking to install PRIMEs then the installation toolkit is recommended. For further research findings please refer to the conference and journal papers included in the reference section.

Funding acknowledgement

The research element of Phase 2 of Project PRIME has been primarily funded by the Road Safety Trust (ref RST:303_0_23) with additional work elements funded directly by Transport Scotland.

Introduction

This Phase 2 report provides a summary of further road trial investigations conducted during the motorcycle seasons of 2023, 2024 and 2025. 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 Project PRIME 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).

Project PRIME: Phase 1 demonstrated that innovative ‘PRIME’ road markings produced positive changes in rider behaviour that underpin keeping motorcyclists safe on Scotland’s roads. The success of this work, supported by the Road Safety Trust, showcased Scotland as a world leader in motorcycle casualty reduction. In Phase 1, data from 32,213 motorcyclists were collected between 2020 to 2022 from 22 trial sites and two comparison sites making this a ground-breaking piece of work and the largest study of its kind. Throughout Phase 1 the trial sites had been brought up to the highest standard through road engineering works. This provided an opportunity to investigate PRIMEs without extraneous variables affecting rider behaviour. The results provided strong evidence of statistically significant behaviour change when PRIMEs were installed. Behaviour change was demonstrated through reductions in speed, improved road position, reduced braking on bends and increased use of PRIME road markings.

In Phase 2 of the research, specific activities have been conducted through 2023 to 2025 to increase the impact of the findings and expand the knowledge base above and beyond Phase 1. Investigations have focused on specific research questions including the effectiveness of PRIMEs on untreated roads. This was a particular point of interest from Phase 1 as many councils and road authorities will not have resources to conduct major road engineering activities before installing PRIMEs. Also the fundamental philosophy is that PRIMEs offer a cost effective and low intrusion behaviour change tool for reducing motorcycle casualties. In addition, through the rest of Phase 2 right-hand bends and the potential to reduce speed more than has been previously observed were investigated as specific research questions each year.

These investigations are pertinent to the wider implementation of PRIMEs for motorcycle casualty reduction across the UK and further afield. More specifically, a key focus of Phase 2 has been to develop knowledge and understanding of site characteristics that influence the success of PRIMEs. With this knowledge insights may be developed about bends which may or may not benefit from the installation of 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 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'

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).

The knowledge that is being developed in Project PRIME has implications for road safety, casualty reduction and education initiatives around Scotland, the UK and at international levels. The project team have had meetings with professionals from around the UK including the other devolved administrations (Wales and Northern Ireland) and elsewhere in Europe via the Confederation of European Directors of Roads (CEDR), Hungary, South Africa and Australia

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 Great Britain, motorcyclists typically represent less than 1% of the total vehicle miles on roads, but account for 21% of all road fatalities (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).

Latest published figures for Scotland indicate that there were 446 motorcycle casualties in 2024. This represented a decrease of 7% of whom 274 (61%) suffered serious injuries and 31 died. However, this was an increase of four fatalities from 2023 (Transport Scotland 2025). Within Great Britain as a whole there were 340 motorcycle fatalities in 2024 compared with 315 in 2023, an increase of 25 (Department for Transport, 2024).

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, Scotland's 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).

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 more 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 should be able to be installed on existing roads quickly and efficiently or incorporated into road upgrade schemes with minimal disruption.

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

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

speed – is suitable for the conditions

road position – is optimised for entering and travelling around the bend

braking – is minimised whilst navigating around the bend

The PRIME road marking design investigated in Phase 2 comprised a series of three or five ‘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. This would generally support a better road position on approach to the bend and a better view around 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 PRIME gateway markings, there is potential for riders to adjust their braking point according to the motorcycle they were riding, their own riding style, or potentially due to weather conditions and other environmental factors (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).

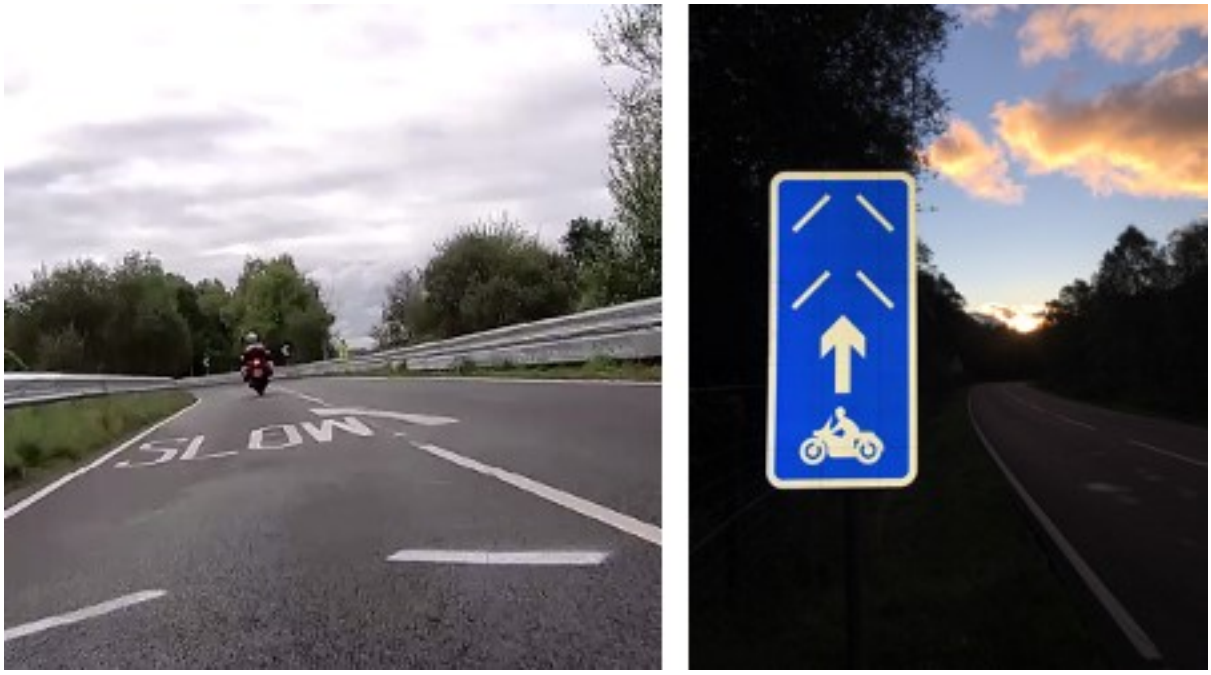

Figure 1: PRIMEs ‘gateway’ design

During Phase 1 of the trials 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% felt they would use them in the future.

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.

The final PRIME designs from Phase 1 of the trials (2020 to 2022) were utilised in Phase 2 (2023 to 2025).

Picture of PRIME trial site on approach 1

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).

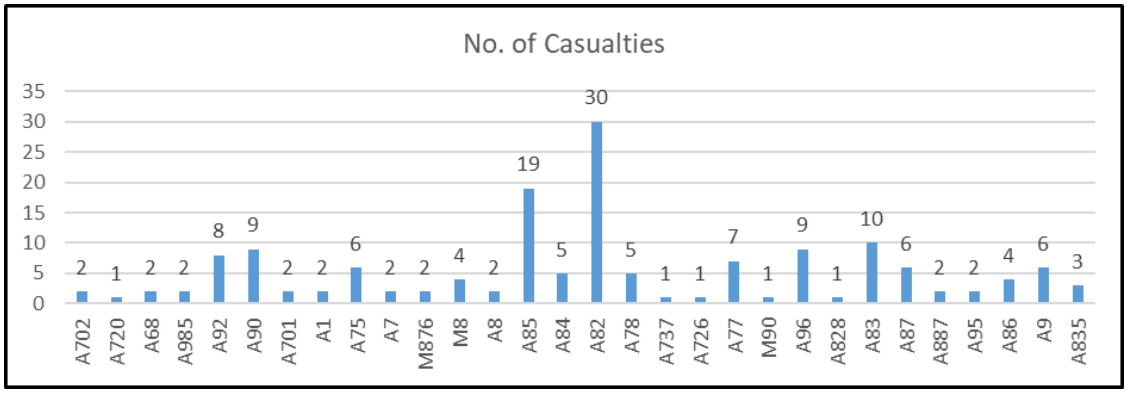

Figure 2: Chart showing distribution of motorcycle casualty profile by road number for the North West Region (from BEAR Scotland, 2019)

In order to assist with site identification for Phase 2 of these trials BEAR Scotland Ltd (North-West Unit) refreshed this collision analysis in 2021 (BEAR Scotland, 2021).

With a focus on the A83, A84 and A85, sites were identified in the region ranging from Lochawe, Tyndrum, Inverary towards Stirling and Crieff (Figure 3).

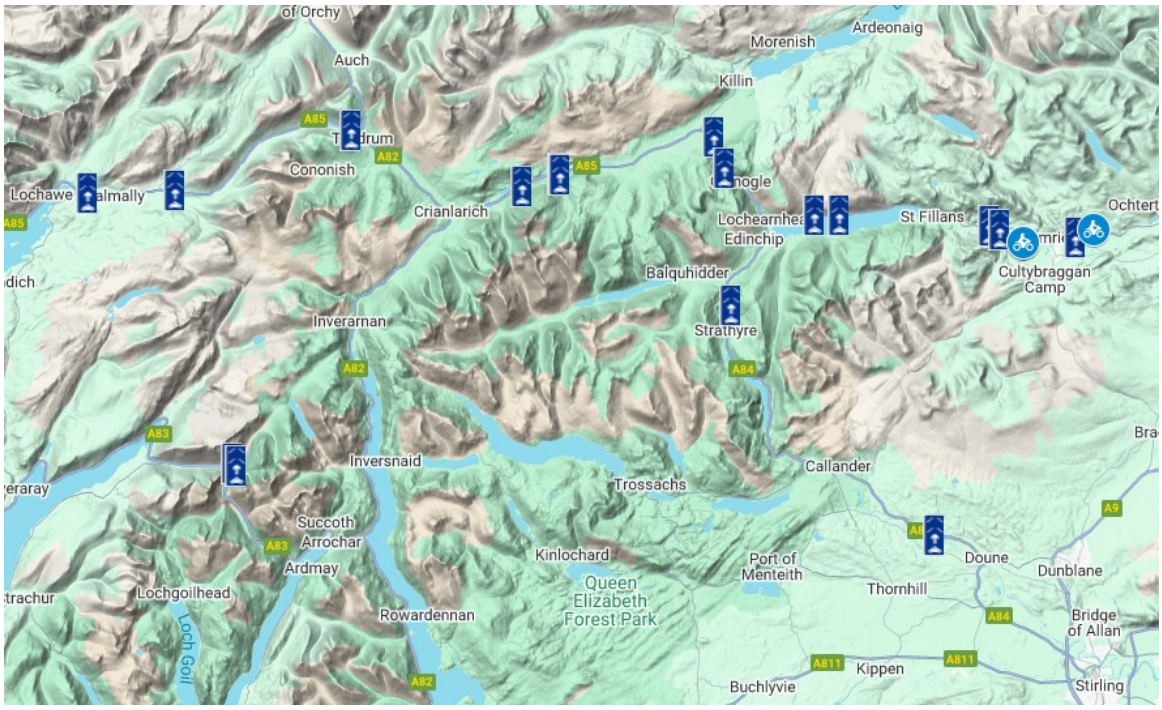

Figure 3: Map showing locations of PRIMEs trial sites 2023 to 2025

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 13 new sites were identified for inclusion in the trials and categorised as motorcycle cluster (MCL) sites or PRIME trial (PT) sites. 12 of these sites were identified for the trials in 2023 and 2024 (6 per year) which followed the approach taken during Phase 1. The research theme in 2025 sought to investigate whether a different design approach could bring about greater reductions in approach speed than previously recorded. For this reason, 5 of the 6 sites utilised in the 2025 trials had previously been used in Phase 1 which also afforded the opportunity to analyse the longer-term effects with comparisons being made with data following their initial installation. One additional new site was also included in 2025.

As in Phase 1, BEAR Scotland produced a checklist of site characteristics that each trial site was scored against to identify suitable locations however the “untreated roads” approach was adopted for Phase 2 with no upgrades being made to the site locations prior to the trials commencing.

The trial sites were spread over a large geographic area and 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 with the same comparison site

(Tullybannocher) being used in 2024 and 2025. 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). A summary of the PRIMEs trial sites is presented below (Table 1).

2023 sites

Site	Code	Road	Heading	Bend type
Landrick	PT21	A84	North	Left-hand
Strathyre	MCL30	A84	South	Left-hand
Glenogle	MCL06	A85	South	Left-hand
Mid Lix	MCL29	A85	North	Left-hand
Dalkenneth	MCL09	A85	West	Left-hand
West Lodge	MCL31	A85	East	Left-hand
Lawers Lodge - *comparison*	n/a	A85	West	Left-hand

2024 sites

Site	Code	Road	Heading	Bend type
Dalmally	MCL34	A85	East	Right-hand
Strone Hill	MCL36	A85	West	Right-hand
Clifton	MCL35	A85	East	Right-hand
Ardveich House	MCL33	A85	West	Right-hand
Dunira East	MCL32	A85	East	Right-hand
Dalchonzie	PT22	A85	West	Right-hand
Tullybannocher - *comparison*	n/a	A85	West	Right-hand

2025 sites

Site	Code	Road	Heading	Bend type
Butterbridge - *revisited from 2022*	PT02	A83	North	Left-hand
Butterbride – *East*	PT02	A83	East	Right-hand
Loch Lubhair - *revisited from 2020*	PT04	A85	East	Left-hand
Rob Roy's Dip - *East 1 revisited from 2020*	PT03	A85	East	Right-hand
Rob Roy's Dip - *East 2 revisited from 2020*	PT03	A85	East	Left-hand

Site	Code	Road	Heading	Bend type
Dalkenneth – *revisited from 2023*	MCL09	A85	West	Left-hand
Tullybannocher - *comparison*	n/a	A85	West	Right-hand

Table 1: showing descriptions of PRIMEs trial sites 2023 to 2025

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

Figure 4: These images illustrate some of the left-hand and right-hand bend trials sites where PRIME road markings were installed throughout 2023 to 2025

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; Winkelbauer et al, 2021).

Participants

This research relied on an opportunistic sample of motorcyclists. Across all the trial sites 15,557 motorcycles were observed and from these 5,680 lead motorcycles were analysed in more detail.

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: Images showing cameras attached to trees or roadside posts

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).

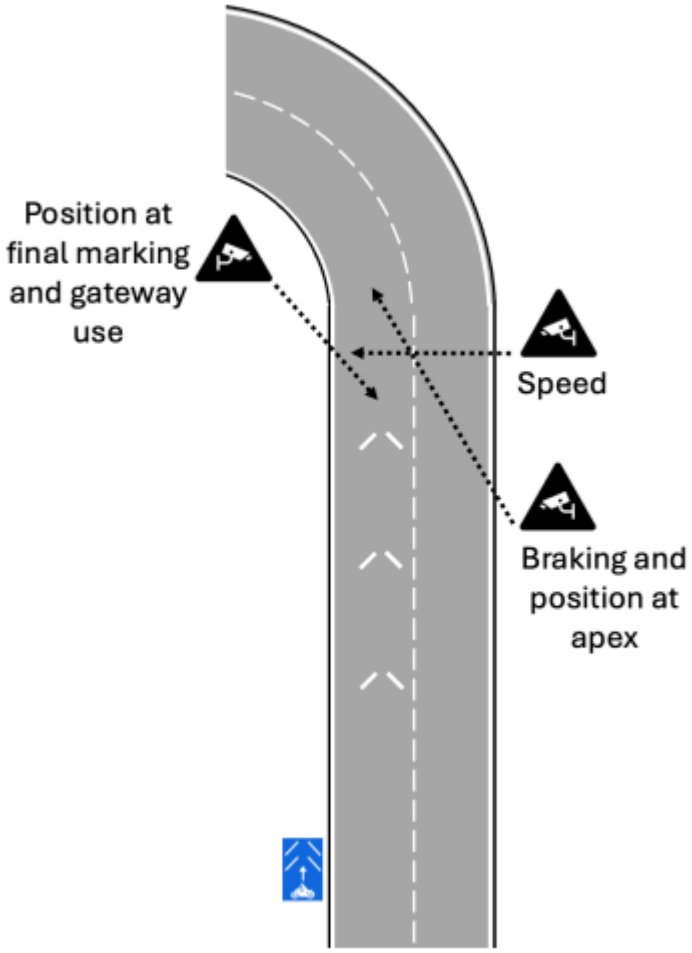

Figure 6: Image showing camera positions at each trial site

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).

Design

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

In 2023 and 2024 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 – three to four (2023) or six or eight (2024) weeks after the PRIME 1 data collection

In 2025 the key research question was whether PRIMEs could promote further speed reductions beyond previous results. By re-visiting trial sites where speed reductions were not apparent, it was possible to investigate if installing different PRIME gateway road marking formats could provide a stronger cue for riders to reduce their speed.

It was decided to investigate the potential for installing 5 PRIMEs instead of 3 PRIMEs at the trial sites that were selected for 2025. Two formats (‘tight’ or ‘extended’) were developed depending on the characteristics of the approach to the bend where the original 3 PRIMEs had been installed (Figure 7).

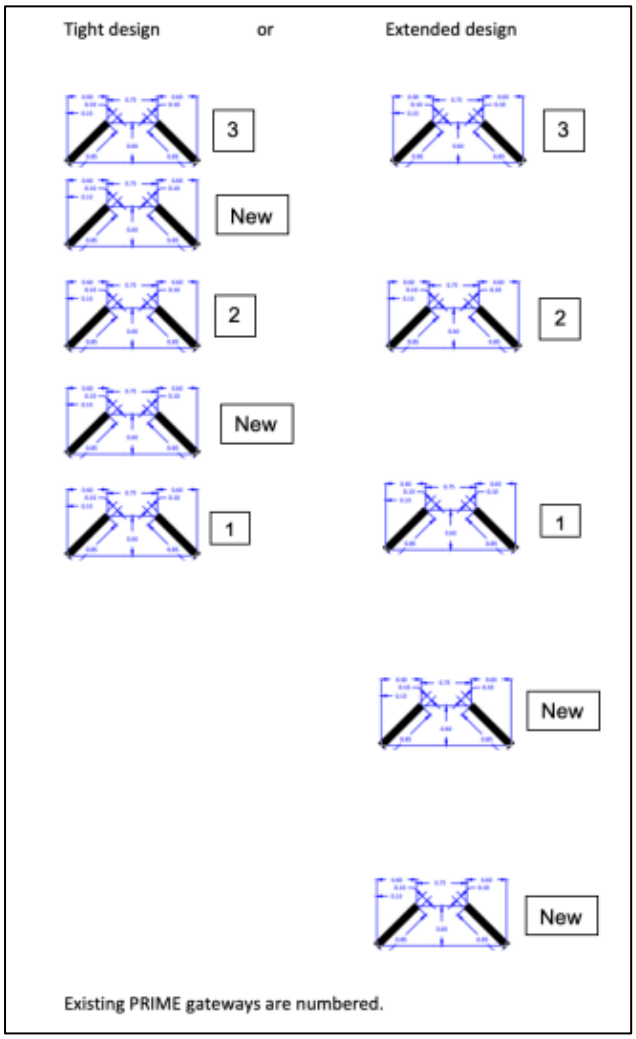

Figure 7: Image showing the ‘tight’ and ‘extended’ 5 PRIME design formats

For bends where less road space ahead of any preceding bend might compromise the installation of the extended design, the tight format was used. This design allowed for the placement of two additional PRIME road markings in between the original 3 PRIMEs (left format in Figure 10). For bends with more road space ahead of any preceding bend the extended format was used. This design allowed for the placement of two additional PRIME road markings in advance of the original 3 PRIMEs (right format in Figure 10).

This selection of trial sites provided a 4:2 split for left-hand vs right-hand bends but more importantly a 3:3 split for tight and extended formats for 5 PRIMEs. It was decided to revisit Tullybannocher (the comparison site from 2024) as that would provide an opportunity to compare data for overall behavioural consistency at a site where no PRIMEs were installed.

The bends that were selected for the 2025 trials are detailed below (Table 2).

Site name	Classification from the toolkit	Direction	85th% speed range (mph)	Proposed PRIME design
Butterbridge East	Fast flat from a straight	Right	n/a (new site)	Extended
Butterbridge	Fast downhill from a straight	Left	55.9	Extended
Loch Lubhair East	Fast flat from a bend	Left	53.7	Tight
Rob Roy's Dip East 1	Slow flat from a straight	Right	47.1	Extended
Rob Roy's Dip East 2	Fast downhill from a bend	Left	51.6	Tight
Dalkenneth	Slow flat from a bend	Left	40.7	Tight

Table 2: Showing proposed PRIMEs designs for trial sites

To provide for a comparison between the 5 PRIME design formats trialled in 2025 the data collection was undertaken as specified below.

For sites where new 5 PRIME installations were made

- Baseline 1 – baseline data collection without PRIMEs installed
- Baseline 2 – baseline data collection without PRIMEs installed
- 3 PRIMEs NEW – data collection the weekend after 3 PRIMEs were installed
- 5 PRIMEs – data collection the weekend after 5 PRIMEs were installed

For sites where the 5 PRIME installations were added to the existing 3 PRIME installations:

- 3 PRIMEs OLD – baseline data collection with previous 3 PRIMEs
- 3 PRIMEs OLD – baseline data collection with previous 3 PRIMEs
- 5 PRIMEs – data collection the weekend after 5 PRIMEs were installed
- 5 PRIMEs – data collection the weekend after 5 PRIMEs were installed

Note: In 2025 any existing PRIME markings were re-instated at the time of 5 PRIME installations to ensure consistency of appearance with existing markings.

With this approach any effects of PRIMEs on riding behaviour could be determined against the baseline measures.

A range of dependent variables were identified to capture data about the potential influence of PRIMEs on rider behaviour (Table 3).

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 3: Table showing dependent variable and associated measures

Procedure

Prior to data collection, trial sites were assessed for suitability ensuring 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).

Comparison sites were selected that were of a similar standard and did not require engineering works.

The weather during the trials was generally poorer than that experienced in Phase 1 with use being made of contingency weekends where necessary. 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 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).

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).

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.

For detailed statistical analyses for each site please refer to Stedmon, McKenzie, Langham, McKechnie, Perry and Wilson (2023, 2024, 2025).

Summary results

In total 15,557 motorcycles were observed across all the trial sites. Each of these 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 5,680 lead motorcycles were analysed in more detail (Table 4).

2023 sites

Site	Lead	Pillion	Group	Total
Landrick	183	53	377	765
Strathyre	237	55	405	704
Glenogle	223	60	500	828
Mid Lix	222	58	499	792
Dalkenneth	231	36	257	464
West Lodge	173	29	258	469
Lawers Lodge - *comparison*	272	35	362	630
Total	1,542	326	2,658	4,652
Overall total	5,680	1,195	8,907	15,557

2024 sites

Site	Lead	Pillion	Group	Total
Strone Hill	202	46	320	548
Clifton	277	50	426	696
Ardveich House	225	39	264	489
Dunira East	220	43	247	503
Carry over left	216	43	247	501
Carry over right	216	43	247	501
Dalchonzie	263	54	371	623
Tullybannocher - *comparison*	224	55	379	623
Total	2,114	428	2,945	5,196

2025 sites

Site	Lead	Pillion	Group	Total
Butterbridge	258	51	450	541
Butterbride – *East*	213	45	332	716
Loch Lubhair - East	307	77	528	921
Rob Roy's Dip - *East 1*	359	73	618	1,075
Rob Roy's Dip - *East 2*	340	76	622	1,074
Dalkenneth	304	58	390	677
Tullybannocher - *comparison*	243	61	427	705
Total	2,024	441	3,367	5,709

Summary results total

Site	Lead	Pillion	Group	Total
Overall totals	5,680	1,195	8,907	15,557

Table 4: Showing motorcycle numbers by category recorded throughout the road trials

Motorcycles carrying a passenger/pillion (N=1,195) represented 7.68% of the total sample of motorcycles. The largest proportion of motorcycles were classified as being part of a group (N=8,907), accounting for 57.25% 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 nature of motorcycling.

Lead motorcycles (N=5,680) accounted for 36.51% of the total sample of motorcycles and were analysed in more detail.

Results from the Phase 2 trial sites are summarised below (Table 5).

Rider behaviour 2023

Site	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Landrick	Sig	No effect	Sig	No effect	Sig

Site	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Strathyre	Sig	Sig	No effect	No effect	Sig
Glenogle	Sig	Sig	Sig	Sig	Sig
Mid Lix	Sig	Sig	Sig	No effect	Sig
Dalkenneth	Trend	Trend	Sig	Trend	Sig
West Lodge	Sig	Sig	Sig	Sig	Sig
Lawers Lodge*	*No effect*	*No effect*	*No effect*	*No effect*	*No effect*

Rider behaviour 2024

Site	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Dalmally	Sig	Sig	Sig	No effect	Sig
Strone Hill	Sig	Sig	Sig	No effect	Sig
Clifton	Sig	Sig	Sig	No effect	Sig
Ardveich House	Sig	Sig	Sig	No effect	Sig
Dunira East	Sig	Sig	Trend	No effect	Sig
Carry over left	Sig	Trend	No effect	No effect	Trend
Carry over right	Sig	Sig	Sig	No effect	Sig
Dalchonzie	Trend	No effect	Trend	No effect	Trend
Tullybannocher*	*No effect*	*No effect*	*No effect*	*No effect*	*No effect*

Rider behaviour 2025

Site	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Butterbridge	Sig	Sig	No effect	Sig	Sig
Butterbridge – *East*	Trend	Sig	Sig	No effect	Sig
Loch Lubhair - East	Sig	Sig	Sig	Sig	Sig
Rob Roy's Dip - *East 1*	No effect	Sig	Sig	Sig**	Sig
Rob Roy's Dip - *East 2*	Sig	Sig	Sig	No effect	Sig
Dalkenneth	Trend	Trend	Sig	Trend	Sig

Site	Speed	Position at PRIME	Position at Apex	Braking	Use of Gateway
Tullybannocher*	Trend***	No effect	No effect	No effect	No effect

Table 5: Showing results for PRIME road marking across the Phase 2 trial sites

** denotes comparison sites*

*** denotes only incidence of increased braking observed*

**** denotes trend in reduced and increased speed observed*

Sig denotes statistically significant effects observed

Trend denotes a trend in data

Key findings of the 2023 PRIMEs trials

During the 2023 motorcycle season PRIME road trials were conducted at 6 trial sites and one comparison site in the West Highlands on the A84 and A85 (i.e. Landrick, Strathyre, Glenogle, Mid Lix, Dalkenneth and West Lodge). These trial sites were all left-hand bends.

In total 4,652 motorcycles were manually counted and coded across all the trial sites and from these 1,542 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. Statistically significant effects were observed across four of the trial sites for positive changes in road position at the point of the final PRIME road marking with a trend in positive changes observed at one other. Similarly, for motorcycle position at the apex of the bend, statistically significant effects were observed across five of the six trial sites. This indicated positive changes in road position with motorcyclists taking a wider path around left-hand bends.

While braking was one of the key variables measured in the trials, this did not appear to be a high incidence activity. A significant reduction in braking was observed at two trial sites (Glenogle and West Lodge). A number of trends for reduced braking were observed at other sites.

Across all of the 6 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, et al, (2025b).

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

Figure 8: Images showing changes in road position

(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed

Key findings of the 2024 PRIMEs trials

During the 2024 motorcycle season PRIME road trials were conducted at six trial sites and one comparison site on the A85 (i.e. Dalmally, Strone Hill, Clifton, Ardveich House, Dunira East and Dalchonzie). These trial sites were all right-hand bends.

In total 5,196 motorcycles were manually counted and coded across all the trial sites and from these 2,114 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 five of the trial sites for a positive change in road position at the point of the final PRIME road marking. For motorcycle position at the apex of the bend, a statistically significant effect was observed at four trial sites along with a trend at another two sites. This indicated positive changes in road position with motorcyclists taking a wider path around right-hand bends.

As in 2023, braking was not a high incidence activity with no changes in braking behaviour observed. Across five of the six trial sites, significant results were observed for increased use of the PRIMEs. Trends for increased use of PRIMEs were observed at one other site. 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.

During 2024 Transport Scotland supported additional research to investigate the potential for the behaviour change effects of PRIMEs to be carried over to subsequent bends where PRIME markings were not installed. Whilst this was limited to two sites, the results indicated that the significant reductions in speed were sustained at the subsequent bends. These results are discussed further in the discussion section below.

For detailed statistical analyses please refer to Stedmon et al, (2026)

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

Figure 9: Images showing changes in road position

(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed)

Key findings of the 2025 PRIMEs trials

During the 2025 motorcycle season PRIME road trials were conducted at six trial sites (five of which had been used in previous years) and one comparison site on the A83 and A85 (i.e. Butterbridge, Butterbridge East (new), Loch Lubhair, Rob Roy's Dip and Dalkenneth).

In total 5,709 motorcycles were manually counted and coded across all the trial sites and from these 2,024 lead motorcycles were analysed in more detail.

Speed was significantly reduced at three trial sites 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 five sites with a trend observed at one other site. 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 five of the six trial sites with motorcyclists taking a wider line around the bend.

Significant reductions in braking were observed at two sites however an increase in braking was observed at another site. As no material changes were made to that trial site it may be anomalous and that there is insufficient data to explore this single episode specifically.

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

At the comparison site, in general the results were as expected. However, a trend was observed for a speed reduction and also an increase when compared to previous datasets.

A selection of images illustrate the typical changes in road position due to PRIMEs (Figure 10).

Figure 10: Images showing changes in road position

(left-hand images = without PRIMEs installed, right-hand images = with PRIMEs installed)

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

Discussion

Without counting the comparison sites where no statistically significant effects were observed, or carry-over sites where no PRIME road markings were installed, 61.9% (i.e. 78 out of 126 possible 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 50.8% that were statistically significant (i.e. 64 out of 126 possible results) and a further 17.9% indicated positive trends in the data (i.e. 14 out of 126 possible results).

Overall, the results for Phase 2 of the PRIME road trials provide continued strong evidence for a range of beneficial effects of PRIMEs on rider behaviour at a range of bends. Across all three key measures (i.e. speed, position and braking) significant effects were observed at different sites during the 2023 to 2025 trials.

As with Phase 1, there were no instances of statistically significant increases in speed, dangerous positioning, or decreased use of the PRIME gateways. However, for the first time in the research, increases in braking were observed at one site (Rob Roy's Dip East 1) and this is discussed below. Taken together these observations suggest that PRIMEs did not have a detrimental impact on rider behaviour. At sites where statistically significant changes were not observed, results were broadly consistent with sites where PRIMEs were not installed. As such, 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 greater insights into rider behaviour.

Speed, position, braking and use of 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 13 of the 18 trial sites.

In Phase 2 there were a mix of bend types (i.e. both left-hand the right-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. Butterbridge, Rob Roy's Dip East 1 and 2, Mid Lix). In addition, some of the approaches (i.e. Glenogle, Dalchonzie) 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, Dunira East).

Statistically significant speed reductions ranged from 1.85mph to 4.89mph when PRIMEs had been installed. 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. However, it is not clear what the speed profiles for motorcycles were from Martindale and Urlich's research.

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 Butterbridge East (57.1mph), and Butterbridge (55.9mph). This was perhaps expected as Butterbridge East was a fast straight section and Butterbridge was preceded by a fast downhill section. The slowest average speeds across the three years were observed at Glenogle (34.52mph), and Dalkenneth (40.7mph) which were some of the more technically demanding bends investigated.

In general, and in line with Phase 1 results, the speed reductions were sustained across PRIME 2 weekend data collection periods. This provides evidence that PRIMEs have an effect beyond their initial installation. In previous research the effects of PRIMEs have been demonstrated over a 1-year and 2-year period (Stedmon, 2022).

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 et al, 2021, 2022, 2023).

For motorcycle position at the final PRIME road marking, statistically significant effects were observed at 14 of the 18 trial sites. In all cases motorcyclists were moving closer to the centre of the road on the approach to left-hand bends or closer to the edge or left of the carriageway on the approach to right-hand bends, 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 14 of the 18 trial sites. This indicated positive changes in road position with riders taking a wider line around both left-hand and right-hand bends.

These results provide strong evidence that PRIMEs continued to influence rider position after the final PRIME road marking and through the bend itself (i.e. where no PRIMEs were installed). In all cases the effects were sustained over the PRIME data collection weekends.

Braking

While braking was one of the key variables measured in the PRIME road trials, this was not a high incidence activity with very little braking recorded at some sites. This was similar to the findings in Project PRIME: Phase 1 (Stedmon, 2020, 2021, 2022). The low incidence for braking, in itself, can be viewed as a positive observation. It can be dangerous for motorcycles to initiate braking on a bend as this 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 four of the 18 trial sites (i.e. Glenogle, West Lodge, Butterbridge, Loch Lubhair East).

Trends were observed at Glenogle (total braking), Dalkenneth (braking on the bend), West Lodge (braking on the bend) and Loch Lubhair East (braking on the bend) and Dalkenneth (braking on the bend).

A finding that was not expected was a statistically significant increase in braking at Rob Roy's Dip East 1 for braking late, braking on the bend, and total braking. What appears to be the case is that there were more instances of braking in the 2025 3 PRIMEs dataset across each measure of braking even though no change had been made to the trial site since the 2020 3 PRIMEs data were collected.

Given that this is the only site over the course of the six-year project where an increase in braking has been observed, it may illustrate the sensitivity of analysing low incident behaviour. This is where the knowledge base built up over the last six years, provides some confidence in knowing that where no material changes were made to the trial site it may be anomalous and there is insufficient data to explore it further.

Of these trial sites, West Lodge was a fast approach from a straight into a sharp left-hand bend. It might have been expected that motorcycles could be carrying excess speed into bends and so a significant reduction in braking at this site was a positive outcome of installing PRIMEs. For Glenogle, the approach was slower and more technical but even so the reduction in braking at this site was also a positive outcome.

Use of the final PRIME road marking

> **Across 17 of the 18 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.

These findings are in line with those from previous years of Project PRIME. Across all 35 PRIMEs trial sites (2020 to 2025) there has been a statistically significant uptake in the use of PRIMEs at 30 trial sites and trends for increased uptake at four trials sites. This demonstrates that overall positive behaviour change has been observed at 34 of 35 trials sites for increased use of the final PRIME road marking.

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. Combined with the Phase 1 results this year's results add further evidence for PRIMEs influencing road position both at the final PRIME road marking and also through the bend itself.

"Carry over" effects of PRIMEs

For 2024 an additional research question was whether PRIMEs might demonstrate behaviour change on right-hand bends. As an additional investigation there was the opportunity to collect data from two bends (left-hand then right-hand) which immediately followed one right-hand bend trial site (Dunira East) in order to assess any carry over effects. While the PRIME road sign and road markings were installed at the trial site (i.e. Dunira East) the following two bends did not receive any installations.

Results indicated that there were significant reductions in speed across all three bends, positive changes in position at the final PRIME road marking (or where it would have been) for Dunira East and Carry over Right; and a positive change in behaviour for position at the apex on the first PRIME weekend for Carry over Right. Across Dunira East and Carry over Right there was a significant uptake in PRIMEs gateways and a trend for Carryover Left. While the results are not conclusive and only apply to one site, they provide a valuable insight into potential benefits of PRIMEs beyond immediate bend installations.

Long-term effects of PRIMEs

Transport Scotland provided funding for additional research in 2025 to investigate the nature of potential long-term effects for PRIMEs at the trial sites. With only one new site (Butterbridge East) installed there was an opportunity to return to existing trials sites and investigate long-term behaviour change by comparing results from 2025 with previous years.

It was therefore possible to compare behaviour across 5-year, 3-year and 2-year intervals as outlined in Table 6. A decision was made to focus on sites from 2020 in order to extend the long-term comparison or 5 years across half of the sites.

Site name	Previous data collection year	Long term intervals
Butterbridge East (new site)	n/a	n/a
Butterbridge	2022	3 years
Loch Lubhair East	2020	5 years

Site name	Previous data collection year	Long term intervals
Rob Roy's Dip East 1	2020	5 years
Rob Roy's Dip East 2	2020	5 years
Dalkenneth	2023	2 years
Tullybannocher (comparison)	2024	1 year

Table 6: showing details of PRIME sites utilised to analyse sustained effects

The results indicated that statistically significant long-term behaviour change for position at the final PRIME road marking was observed at four of the five existing sites (80%). At the apex of the bend, riders took a wider line around the bend at three trial sites (60%). Sustained reductions in braking were only observed at one site (20%) but this illustrated a long-term behaviour change over a 5-year period. For use of gateways, long-term behaviour change was observed at all the existing trials sites (100%). These results are summarised below (Table 7).

Site name	Time period	Speed	Position at final PRIME	Position at Apex	Braking	Use of PRIMEs
Butterbridge East (new site)	n/a	No	No	No	No	No
Butterbridge	3 years	No	Yes	No	No	Yes
Loch Lubhair East	5 years	No	Yes	Yes	Yes	Yes
Rob Roy's Dip East 1	5 years	No	Yes	No	No	Yes
Rob Roy's Dip East 2	5 years	No	Yes	Yes	No	Yes
Dalkenneth	2 years	No	No	Yes	No	Yes
Tullybannocher (comparison)	n/a	No	No	No	No	No

Table 7: Showing details of long-term behaviour change observed

Speed reductions - 5 PRIMEs v 3 PRIMEs

Only two trial sites observed a reduction in speed due to the installation of 5 PRIMEs (i.e. Loch Lubhair East and Rob Roy's Dip East 2). These were both of the tight format (i.e. in between the original 3 PRIMEs formation). No reductions in speed were found at the trial sites that had the extended 5 PRIMEs format. No other significant effects were observed for other behaviours (Table 8).

Site name	Speed	Position at final PRIME	Position at Apex	Braking	Use of PRIMEs
Butterbridge East (new site)	No	No	No	No	No
Butterbridge	No	No	No	No	No
Loch Lubhair East	Yes	No	No	No	No
Rob Roy's Dip East 1	No	No	No	No	No
Rob Roy's Dip East 2	Yes	No	No	No	No
Dalkenneth	No	No	No	No	No
Tullybannocher (comparison)	No	No	No	No	No

Table 8: Showing key results observed for 5 PRIMEs formats

Overall, this indicates that 5 PRIMEs did not have much of a benefit over installing 3 PRIMEs. However, for some locations where the tight 3 PRIMEs format might be appropriate, two of the three trial sites have shown a speed reduction. It is possible that the tight formation of 5 PRIMEs creates a more conspicuous visual cue to an approaching motorcyclist over an extended format, where a rider might be looking ahead of gateways that are spaced out more. The tight formation might provide to stronger cue in a shorter space on the road.

Dry weather v wet weather

In 2025 one of the two Baseline data collection weekends had very poor weather and with this opportunity, it was decided to collect data on two consecutive weekends in order to make comparisons between dry weather and wet weather riding behaviour.

Overall, speed was significantly reduced in wet weather at four trial sites (and a trend observed at another); position at the final PRIME changed on right-hand bends in the wet weather; riders positioned themselves closer to the apex at one trial site and there was a reduced use of PRIME gateway in wet weather at one site with a trend at another. These observations are presented below (Table 9).

Site name	Speed	Position at final PRIME	Position at Apex	Braking	Use of PRIMEs
Butterbridge East (new site)	Trend	Yes	No effect	No effect	Trend
Butterbridge	Yes	No effect	No effect	No effect	No effect
Loch Lubhair East	Yes	No effect	Yes	No effect	No effect
Rob Roy's Dip East 1	Yes	Yes	No effect	No effect	Yes
Rob Roy's Dip East 2	Yes	No effect	No effect	No effect	No effect
Dalkenneth	No effect	No effect	No effect	No effect	No effect
Tullybannocher (comparison)	Trend	No effect	No effect	Trend	No effect

Table 9: Showing key results for wet weather

Yes denotes a change in behaviour was observed.

Trend denotes a trend in data

This investigation can only be treated as a preliminary investigation into the effects of weather as it is difficult to compare sites over a large geographic area consistently in terms of amount and length of time rainfall occurred and other accompanying environmental effects such as wind strength and direction, level of exposure for each site to the elements, and even how close they are to rest areas for riders.

Rider profiles across Project PRIME

The previous findings from Project PRIME illustrate a consistent profiles of lead, pillion and group motorcyclists that across the years (Table 10).

Year	Total	Lead %	Pillion	Group
2020	12,949	31.25	11.13	63.09

Year	Total	Lead %	Pillion	Group
2021	9,594	26.25	9.76	56.93
2022	9,670	34.37	9.35	61.40
2023	4,652	33.15	7.01	57.14
2024	5,196	40.69	8.24	56.68
2025	5,709	35.45	7.72	58.98

Table 10: Showing motorcycle profiles across the PRIME road trial sites

Of the total motorcycles across the six years (N=47,770) typically around 10% (N=4,476 mean=9.37%) carried a pillion, approximately one-third (N=15,599 mean=32.65%) were lead motorcycles and just under two-thirds (N=28,538 mean=59.74%) were traveling in a group. This meant that motorcycle distributions remained similar throughout the project.

Project aims and objectives

The key aim of this phase of the research has been to conduct further research to consolidate our understanding of the benefits or drawbacks of installing PRIMEs based on trial site characteristics. This has been addressed through practical objectives to:

- install and evaluate PRIMEs across 18 trial sites and expand the PRIMEs dataset to 40 trial sites and 50,000 motorcycles – by the end of 2025, data were collected at 18 trial sites (13 new trial sites plus 5 sites used in previous years' research) and two comparison sites. In total, 47,770 motorcycles were observed by the end of Phase 2. While not reaching 50,000 motorcycles this reflects the opportunistic nature of the sample.
- address specific research questions for: untreated roads, right-hand bends, and further reductions in speed – each year during Phase 2 these specific research questions were investigated. These have been detailed in each year's technical reports and integrated in this summary report.
- conduct a meta-analysis to provide guidance on identifying sites where PRIMEs might be beneficial or not – as part of earlier Phase 2 work (outside of RST funding) with the development of the Installation Toolkit, a thematic analysis of bend characteristics was conducted to provide insights into which bends might benefit the most from PRIMEs and also those that may not. The findings from Phase 2 will be considered in any update of the Installation Toolkit so that practitioners can make informed decisions about installing PRIMEs at their own proposed locations

- use Human Factors participatory methods to promote wider acceptance of PRIMEs by motorcyclists and other road users – this has been developed through informal outreach activities and also through public engagement activities throughout Phase 2
- feedback and disseminate results to Government ministers, road safety stakeholders, academia and riders themselves – Project PRIME has been able to disseminate research findings throughout Phase 2 to a variety of professional interest and stakeholder audiences
- provide substantive evidence beyond Phase 1 of site characteristics and benefits of PRIMEs at different locations – through the expanded scientific knowledge for PRIMEs generated through Phase 1 and Phase 2, conference/stakeholder presentations and scientific journal papers, there is now a substantial peer-reviewed and academically accepted basis to the science behind PRIMEs.

The Safe System approach to 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 6-years that PRIMEs positively influence rider behaviour and it is important to begin planning for an implementation phase of work that will underpin the roll-out of PRIMEs more widely. With local authorities across Scotland and the rest of the UK expressing an interest in installing PRIMEs the scope of the project is already increasing.

Image of motorcycles parked up at a rest area

Conclusion

This report summarises Phase 2 of Project PRIME, the 3-year (2023 to 2025) programme of road trials in Scotland funded by the Road Safety Trust and Transport Scotland. 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.

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).

Across Phase 1 and Phase 2 a total of 47,770 motorcycles have been manually counted and coded throughout the West Highlands with 15,599 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 in general PRIMEs promote positive behaviour change by reducing speed, improving road position reducing braking (apart from one trial site where braking increased) and increased use of the road markings when they were installed.**

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). In addition, PRIMEs have been specifically recognised in the new Road Safety Strategy (Department for Transport, 2026).

The findings from Phase 2 will be considered in any revision of the Installation Toolkit so that practitioners can incorporate knowledge of PRIMEs into their road safety initiatives. Of particular importance are the insights for where PRIMEs may or may not be of benefit to casualty reduction.

There is also evidence that demonstrates that if PRIMEs are installed, they can have a positive effect on rider behaviour which is sustained over time and carried over to subsequent bends.

Apart from the one site where braking increased, PRIMEs did not have a detrimental effect on rider behaviour. While collision data for the entire trial period are still being collated, early signs point to a reduction in motorcycle injury collisions where PRIMEs have been installed.

The findings support the development of bespoke motorcycle road safety measures by Transport Scotland and supported by the Road Safety Trust 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 Project PRIME 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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