A simulator study into customer behaviour on dynamic hard shoulder motorways

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SUMMARY

This paper outlines a study for National Highways to better understand drivers' behaviour, responses and perceptions on dynamic hard shoulder (DHS) motorways. A mixed methods approach, including use of a mixed reality simulator, was used to collect both qualitative and quantitative data from motorway drivers and triangulate the results. This work provided a greater understanding of the perceptions of drivers on DHS motorways and built an evidence base of the aspects of DHS motorways which may cause higher workload for drivers.

KEYWORDS

Smart motorways, customer, research

Introduction

Background

Dynamic hard shoulder (DHS) motorways are a type of motorway where the hard shoulder can be used as an extra lane at busy times. Overhead variable message signs inform the driver of when the hard shoulder is open to drive in and when it is not. DHS motorways operate with a reduced speed limit to manage traffic flow. This is designed to reduce congestion and smooth the flow of traffic.

The 'Keeping motorists mobile' RAC Report on Motoring (2022) recommended using DHS motorways as they help traffic flow and has a better safety record. However, concerns have been raised by a few different groups that DHS motorways may be confusing for drivers. For example, Transport Focus' 2017 report into customer experience of smart motorways found that those taking part in their study felt that this type of smart motorway can cause confusion about when you can drive on the hard shoulder and when you cannot. The Customer Experience Tracker survey (2022) looked into feelings of comfort on motorways. It found that the vast majority of drivers reported feeling comfortable driving on motorways. Drivers reported feeling more confident driving on motorways with hard shoulders than without; approximately one in five drivers (22%) said they did not feel confident driving on motorways without a hard a shoulder but with emergency areas. Beyond these general surveys, however, there is limited research into confusion on DHS motorways.

A 2022 Transport Select Committee report into smart motorways presented a number of recommendations to the Department for Transport and National Highways. Recommendation 8 stated: *"The Department for Transport and National Highways should pause plans to convert dynamic hard shoulder motorways until the next Road Investment Strategy and use the intervening period to trial alternative ways in which to operate the dynamic hard shoulder to make the rules less confusing for drivers."*

Following this, WSP conducted a quantitative survey with 3,500 drivers on their experience of using smart motorways in 2022. The results from this survey showed that 68% said that they had

driven on a stretch of DHS motorways; 19% of survey respondents reported that they did not know that there were different types of motorways. In terms of confidence, 46% of the survey respondents described themselves as feeling confident driving on a DHS stretches of motorway. While the findings from this survey provided useful indications of the respondents' knowledge and understanding of DHS motorways, it was not sufficiently robust to unpack the complexities around confusion.

Aim

The aim of this study was to better understand drivers' perceptions of confusion while driving on DHS motorways. The intention was to measure behaviours, responses and perceptions to provide National Highways with evidence that could help inform potential improvements to the strategic road network.

Definition of confusion

Confusion is multi-faceted and subjective. There is no agreed academic definition of confusion with respect to driving behaviours. Broader literature was used to inform the measures and how they were analysed. For the purposes of this study, the definition used and agreed with National Highways, was based on the Cambridge Dictionary Definition of confusion:

"A situation in which people do not understand what is happening, what they should do, or who someone or something is."

The definition was interpreted in this work to cover any indication of:

- A lack of understanding of how the motorway operated.
- Increased cognitive load and potentially an impaired decision-making process reflecting uncertainty about the how the motorway operated.
- More indecision and hesitation caused by a lack of understanding of what was happening and what should be doing.
- Participants' self-reported perceptions of confusion.

Cognitive load is not necessarily synonymous with confusion. It is possible to have a high cognitive load without being confused. When interpreting the findings from this study, where indications of high cognitive load were identified, caution is taken as to whether to attribute this to confusion.

The potential challenges which come with trying to both define and measure confusion were considered throughout. Measures, such as eye tracking or self-report survey data in isolation, do not provide sufficient evidence of confusion. This was the rationale for the mixed methods design which provided a broad range of both qualitative and quantitative measures for the same issue. Using mixed methods was the most appropriate way to try and establish if some aspects of DHS motorways may be confusing to some people in some situations.

The technology

A simulation methodology was selected due to it being the most robust, cost-effective and timely method to address the research objectives. Working with a specialist partner, we used a fully immersive, mixed reality driving simulator to test drivers' behaviour, responses and perceptions when using a conventional motorway and variations of a DHS motorway. This generated evidence which was used to determine what factors, if any, contributed to driver confusion.

The technology comprised elements of a motor vehicle – the cabin, seat, steering wheel and pedals were modelled on a Land Rover Discovery – and were mounted on a motion platform. When in the simulator, drivers wore a mixed reality headset, and could see the equipment (i.e. the steering wheel) as well as their hands, while at the same time were fully immersed within a virtual road environment. Utilising green screen technology, a boundary area was then created where all features from the real world were captured from the driver's perspective. Beyond that, everything was virtually simulated. The set up of the simulator is shown in Figure 1.

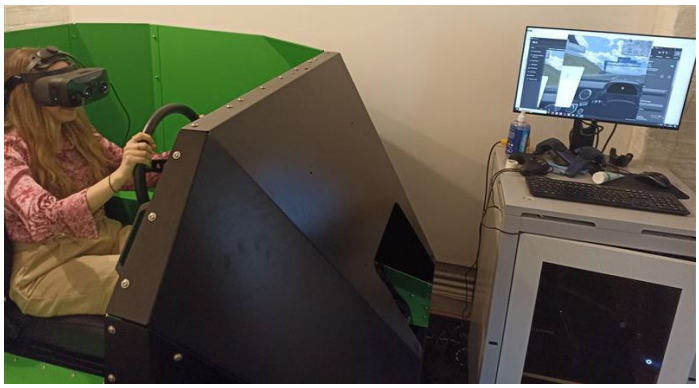

Figure 1: Simulator set up

Methodology

Sample

The sample was not statistically representative of the population, so outputs should be considered indicative from a quantitative perspective. Pre-screening data was collected on participants' level of experience with smart motorways. The sample comprised of two groups:

- 23 experienced users (had used a smart motorway more than once a week) of which there were 12 males and 11 females.
- 16 novice users (had used a smart motorway less than three times ever) of which there were 10 males and 6 females.

Recruitment

Recruitment was conducted via an independent fieldwork organisation. Participants were screened to ensure that they had valid UK driving licences. We used a segmentation designed by National Highways to screen potential participants to ensure our sample included representatives from across the spectrum of transport users.

The recruitment organisation identified suitable candidates to participate in the trial using inclusion and exclusion criteria, for example, excluding those with photosensitivity, such as epilepsy or negative reactions to bright or flashing lights.

Design

The research objective for this project was: *To obtain and triangulate qualitative and quantitative data from a mixed-reality driving simulator to better understand the behaviour, responses and perceptions when driving on a DHS motorway to identify sources of potential confusion and how they are best measured.*

Four virtual scenarios were designed for use in the simulator: dual three lane motorway (D3M) scenario, which acted as a baseline, and with three motorway scenarios (hard shoulder closed, open and mixed), which were compared to the baseline (Table 1).

Table 1: Design scenarios

Scenario name	Design	Description
D3M	Hard shoulder closed as a driving lane	Standard D3M motorway with a permanent hard shoulder for emergency use only
Closed	Hard shoulder closed as a driving lane	Smart motorway operating with the dynamic hard shoulder closed to traffic (signals blank except hard shoulder closed gateway message sign and "Hard Shoulder for Emergency Use Only" variable message signs (VMS))
Open	Hard shoulder open as a driving lane	Smart motorway operating with the dynamic hard shoulder open to traffic as a running lane
Mixed	Variable: hard shoulder open and closed as a driving lane	Smart motorway operating with sections of the dynamic hard shoulder open to traffic, and other sections closed for use in emergency only

Each participant was given an initial briefing, following which they applied the heart rate monitoring equipment. They were then taken to the simulation rig where they completed a short familiarisation drive on a D3M motorway to get used to the simulated environment. Once the participant was content and comfortable operating the simulator, they began the test scenarios.

The driving task was for participants to drive from point A to point B as they normally would (but within the UK laws, e.g. speed limit). Each scenario took the participants approximately 12 minutes; this varied depending on the speed at which they chose to travel.

Just over halfway into the trial period, it became apparent that several participants were unable to complete the full trial due to experiencing symptoms of simulator sickness. To reduce the number of dropouts due to simulator sickness, the scenarios were reduced to eight minutes (this was timed instead of stopping at point B). The eight-minute limit was used in all scenarios except for the mixed scenario which was completed from point A to point B to capture all the features of the variable hard shoulder. This helped to reduce the number of participants dropping out due to simulator sickness as they did not have to drive for as long and spent less time in the simulator.

Each participant was asked to drive in all four scenarios listed above. The order of the scenarios was counterbalanced to eliminate ordering effects. After each scenario, participants were invited to remove the mixed reality headset, and exit the rig. Once they had exited, they undertook a post-scenario survey along with a post-scenario interview to share their views and their experience of that particular drive.

Data collection and analysis

We collected three types of data from the simulator: driving data, eye tracking data and heart rate data. For each participant, these data types were collected under the four different driving conditions: D3M, closed, open and mixed (unless they were unable to complete the full trial for reasons stated above). The measures and analysis approach is outlined in Table 2. Correlation analyses were carried out between different streams of data to confirm interpretation of the results.

Table 2: Measures and analysis approach

Research questions	**Data collection**	**What was measured**	**Analysis approach**	**How customer behaviours, responses and perceptions were inferred**
Did participants drive faster on average in the D3M/closed scenarios? Did participants make more frequent changes to speed in the open/mixed scenarios? Did participants make more lane changes in the D3M/closed scenarios? Was there a difference between the way experienced and novice smart motorway users behaved in the different scenarios?	Driving data from simulator	Average speeds, top speed, lowest speed and where they occurred Speed limit compliance Lane change behaviour	The analysis examined differences relating to: The four scenarios: were there differences between the four scenarios for each participant? Experienced and novice smart motorway users	Changes to driving speed, especially at transition points, are likely to relate to indecision and hesitation. It should be noted that these changes may also reflect an adjustment to conditions.
Did participants spend longer looking at features in the open and mixed scenarios? Did participants have an increased pupil diameter in the open and mixed scenarios? Was there a difference between the way experienced and novice smart motorway users behaved in the	Eye tracking software	Features the driver looked at, especially at transition points Length of fixations on signage and other road features, especially at transition points Pupillometry: an increase in pupil diameter is as an indicator of emotional arousal, given that confusion is an emotion, pupillometry may indicate confusion	The analysis examined differences relating to: The four scenarios: were there differences between the four scenarios for each participant? Experienced and novice smart motorway users	Through length of fixation, we inferred: understanding / or lack of it cognitive load indecision and hesitation

Research questions	**Data collection**	**What was measured**	**Analysis approach**	**How customer behaviours, responses and perceptions were inferred**
different scenarios?				
Were participants' heart rates higher during the open and mixed scenarios? Did participants have a lower heart rate variability in the open and mixed scenarios?	Heart rate monitor	Heart rate and heart rate variability (HRV)	The analysis examined differences relating to: The four scenarios: were there differences between the four scenarios for each participant?	Heart rate and HRV are physiological indicators of changes of emotional arousal and/or level of cognitive load during the driving task
Did participants give more indications of confusion (lack of understanding, high cognitive load) in the open and mixed scenarios?	Post-scenario surveys (Administered immediately after each simulation task)	Understanding of: the difference between the four scenarios what to do / when what to do under different conditions they didn't experience (e.g. if they had broken down) what the roadside information was telling them (comprehension/clarity) whether there was any roadside information such as signs, VMS, road markings that they saw but did not understand Experience of increased cognitive load (workload): perceptions of elements of the road they found easy or difficult how taxing they found the task whether they found anything about the experience confusing how safe / confident / comfortable they felt	The analysis examined differences relating to: The four scenarios: were there differences between the four scenarios for each participant? Experienced and novice smart motorway users	Self-reported confusion. Self-reported understanding of the four different scenarios. Self-reported understanding of what to do in each of the four scenarios. Self-reported identification of elements that caused confusion.

Research questions	Data collection	What was measured	Analysis approach	How customer behaviours, responses and perceptions were inferred
Did participants give more indications of confusion (lack of understanding, high cognitive load) in the open and mixed scenarios?	Structured interview (Administered immediately after the survey)	Structured qualitative interviews fully explored participants' perceptions of the experience and the reason behind driving decisions. This provided an overview of their driving behaviour, responses and perceptions without disrupting or distracting from the simulated task.	The analysis examined differences relating to: The four scenarios: were there differences between the four scenarios for each participant? Experienced and novice smart motorway users	Analysis drew out themes, drawing out evidence to identify which elements were confusing. Directly, through self-reported: confusion and what caused it understanding of the four different scenarios understanding of what to do in each of the four scenarios

Findings

We triangulated the data sources to provide indicative findings that addressed the research objectives. The main findings to note are discussed below.

From the interviews, participants showed a preference for receiving more (and up to date) information in dynamic hard shoulder scenarios, especially from variable message signs.

The main aspects participants displayed more uncertainty or higher cognitive load about were:

- Whether the hard shoulder was open or not
    - Higher mean heart beats per minute were recorded in the mixed scenario, potentially indicating higher cognitive load.
    - Less experienced smart motorway user participants showed reduced heart rate variability, potentially indicating higher cognitive load.
    - Participants showed some uncertainty over the 'congestion use hard shoulder' sign in the interviews, with many interpreting it to mean use the hard shoulder if they considered the traffic to be congested rather than an invitation to use it
    - Participants showed a lack of understanding over the purpose of the hard shoulder lane, with some being unsure when it was open/closed.
- When variable mandatory speed limits ended
    - Driving data showed more speeding in mixed/open scenarios, potentially suggesting participants did not know what the speed limit was. (This may have been exacerbated by the need to turn their head to be able to see the speedometer.)
    - Participants showed some uncertainty over when the variable speed limit ended, being unsure when it returned to national speed limit.
- What happened to the hard shoulder lane at interchanges and junctions
    - Participants had some uncertainty over through junction running layout, specifically which lane they should be in when the variable hard shoulder was in operation.
- The purpose and use of emergency areas

- Some participants were unsure about, or unfamiliar with what emergency areas were, did not recognise them, and were not sure what they were for.
- Some reported they did not know the distance to the next emergency area.

Other considerations such as difficulty with the overall concept of driving on hard shoulders, whether they typically drove on DHS motorways regularly and personal preferences around driving habits were important.

We discovered that confusion is a very subjective concept. Everyone has their own definition of it because we all experience and deal with situations differently, so it was almost impossible to measure 'confusion' in a driving context. We concluded that this study provided useful insights into behaviour, reactions and perceptions when driving on DHS motorways, but was unable to fully assess the concept of confusion on such roads.

Strengths

It is important to note the strengths and limitations of this study which may have affected the results. This study was exploratory to see whether aspects of confusion existed, could be identified, and could be measured. It also provided a detailed understanding of the use of mixed reality simulation technology as a research tool, its capabilities and limitations.

One of the key strengths of this study was that it enabled us to develop a methodology which could explore and understand drivers' behaviours, responses and perceptions on DHS motorways. We applied the research questions to an innovative piece of technology in the form of the mixed reality simulator and achieved the minimum sample size which meant that we could have confidence in the emerging findings.

The design of the method meant that participants were in a safe, controlled environment to help respond to the research questions. Using a range of different methods within one study enabled us to triangulate findings to give greater confidence in the strength of the indicative findings.

Limitations

Several participants suffered from simulator sickness and had to stop the trial early due to feeling unwell. For those participants who did complete some of the drives, their data was used. However, their opinions and driving behaviour may have been affected by feeling unwell, resulting in having more difficulty driving in the simulator or concentrating on the road environment. This may have caused them to feel overall more confused and overwhelmed.

At times the simulator caused some defects in traffic, for example cars appearing out of nowhere or cars driving 'through' the participant. This limited the realism of the simulation and made it difficult for participants to drive as they normally would. It also made it more difficult for participants to notice features of the road as they focused on the simulator glitches instead. There were also some instances where there was not much traffic in the simulator, which sometimes confused participants when they saw the sign 'congestion use hard shoulder'. Most of these glitches were solved after the first days of the trial.

Certain features of the simulator could have been improved by using human factors principles to make the user experience more realistic and user-friendly, and easier for participants to adapt to – for example, future studies will make the location of the speedometer more obvious for people to see on the dashboard.

In some cases, participants self-reported understanding the road layout in the trial, but did not comply with the scenario, suggesting they did not in fact understand it. For example, some participants drove in the hard shoulder when it was closed. This highlighted the benefits of the

multi-method approach. We should not rely upon self-reporting alone; it is also necessary to observe participants' behaviour to get a full picture.

Conclusions

This work provided insight into the drivers' behaviours, responses and perceptions when on DHS motorways. It provided an evidence base that was sufficiently detailed for National Highways and the Department for Transport to respond to the Transport Select Committee's recommendation to explore the role of confusion in drivers' experience of DHS motorways. There were a few elements of DHS operation that seemed to increase cognitive load and uncertainty compared to D3M motorways. However, 'confusion' was found to be too broad a topic to distinguish. This work will support National Highways in their work to provide easy-to-use solutions and more enjoyable journeys on the network for the public.

References

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