MORE
Multimodal Optimisation of Roadspace in Europe

Contribution to D5.6: "Assessment of potential for new technologies"

Dynamic Road Space Allocation: a role for LED Road Markings and Signing

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1 Introduction

1.1 Study context

Street user demands for capacity and provision vary by time of day, day of week and seasonally, so it makes sense to vary traffic regulations in time, to use the available space/capacity in the most efficient way. There is a long history of doing this, using two strategies:

- Allowing space to be used by multiple users, at the same time, possibly for different durations (e.g. a 20-minute loading bay also accessible to disabled, blue badge holders for up to 3 hours), and
- Varying space allocation, by time of day (e.g. a peak period, kerbside bus lane, uses in the off-peak for kerbside loading)

Currently, these regulations are conveyed to street users through a combination of kerbside traffic signs and on-carriageway road markings, but there are limits as to how far this method for communicating traffic regulations can be taken, in two respects:

- The amount of information about permitted uses at different times of day that can be displayed on a fixed sign in a meaningful way; and
- The inability to vary regulations in a dynamic way, to reflect changing patterns of demand, in real time.

There is growing interest in the dynamic use of street space, from the 'Flexi-kerb' concept developed by Arup, to the trials of real-time loading bay allocation, developed by companies such as Grid Smart Cities. All designed to squeeze more out of the limited street space and capacity, by better aligning patterns of demand with supply, in a more agile and dynamic manner.

A substantial application of this more flexible approach to traffic regulation would require a form of dynamic signing and lining, most obviously through using LED technologies. But, to date, there have been very few tests exploring the potential format or feasibility of using LED signing and road markings, either in laboratory settings, or on street.

This report sets out to address this gap, in a limited way. It describes some tests that were carried out to compare LED signs and road markings with conventional physical signs and painted road markings, in controlled laboratory conditions, with groups of motorists and professional drivers, at UCL's new PEARL facility, in East London.

The focus was on kerbside access regulations, and the allocation of the carriageway to particular road user groups, in particular, buses and cycles.

1.2 Role of the trial in the MORE project

This trial forms part of Work Package 5: 'City corridor case studies: design brief, package generation, option appraisal and overall assessment', and forms part of Task 5.3.1 ('Technology and design trials) and Deliverable 5.6 ('Assessment of potential for new technologies').

In particular, the trials have been influenced by the outcomes of Work Package 3, in particular Deliverable 3.1 'Analysis of technological advances', which identifies, describes and assesses the contribution that new technological advances could make to the provision of the supply on main roads in cities. Within the deliverable, it was identified that the conveyance of information (for example LED road signs and lane markings) could be a key contributor of new technologies enhancing the use of road transport infrastructure.

More specifically, the trials aim to "test new dynamic signing and lining concepts – and the transitions from one 'plan' to another - based around LED technologies, in laboratory conditions with a wide range of street user groups".

1.3 Brief introduction to the PEARL laboratory and its capabilities

Developed by Professor Nick Tyler, PEARL (Person-Environment-Activity Research Laboratory) is a unique facility, designed to explore the ways in which people interact with their physical environment. It is a massive space (around 4,000m_2 in floor area and 10m high), in which UCL scientists can create life-sized environments – such as a railway station, a high street, or town square – so that they can examine how people interact with the environment and other people in these types of places, under controlled conditions.

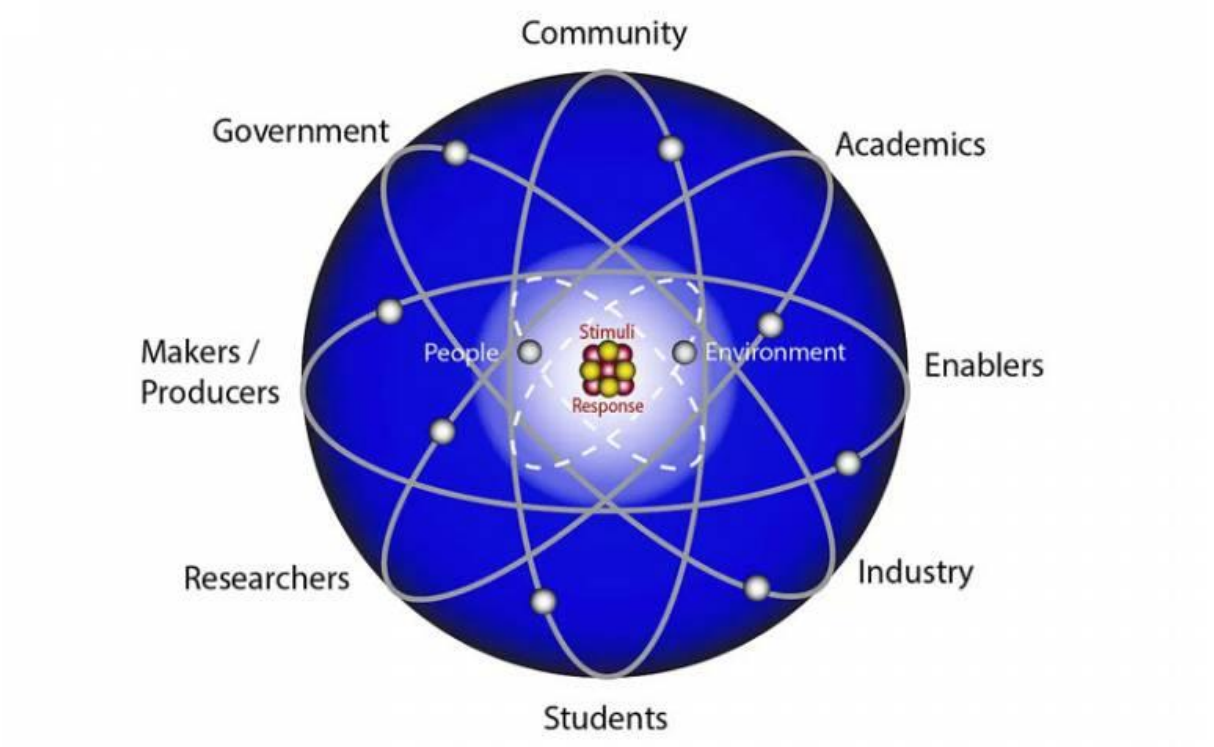
Much of our understanding about how cities work is based on assumptions about how people perceive, respond to, use and act in the physical environment. Many of these assumptions are based on practical experience over many years, but precise relationships cannot be established in the real world, as there are too many confounding variables. PEARL enables the scientific community to study in detail how people actually interact with the environment under controlled conditions, so that we can obtain rich insights that facilitate improved designs of real urban systems.

The laboratory allows for a change of profile, type and texture of material used on the floor area; it can simulate lighting of any colour and intensity, create sounds from the tiniest bird song to the most massive explosion, and includes other senses, such as smell - and much more.

PEARL's vision is to create a better world for a future in which people and the environment can thrive together in a mutually beneficial, safe, equitable and healthy way. It aims to improve the quality of life, health and wellbeing of all, within the context of a more sustainable environment.

PEARL is a dynamic, integrated and interdisciplinary organisation comprising Researchers, Academics, Makers, Producers, Enablers and Students, who together can make an important contribution to the study of People-and-Environment interactions.

Its organisational structure can thus be likened to that of an Atom: we are more than the sum of our individual parts, as we all work together towards the creation of a better world.



2 Planning the LED trials

Planning involved several stages:

1. Identifying issues to be addressed during the trials
2. Determining the sample (composition & size) of participants
3. Selecting stimulus materials and scenarios to be presented to participants
4. Obtaining UCL ethics approvals
5. Obtaining hardware to simulate LED traffic signs and road markings
6. Programming and testing the hardware and software
7. Conducting the trials
8. Analysis and writing up

The key issues that were to be addressed by the trials included:

- **Understanding of existing signs and markings**
  - What do they mean?
  - Do they make sense?
- **Reactions to new types of sign**
  - What do they mean?
  - Do they make sense?
- **LED vs conventional signs & markings**
  - How well do they compare under different lighting conditions?
  - Reactions to scope for flexibility
  - General reactions to use of LED?
- **LED road surfaces and transitions**
  - Methods of signalling transitions
  - Reactions to the idea?
- **Overall reflections?**

It was decided to carry out the trials with groups of motor vehicle drivers, rather than through individual interviews. Cyclists were not included as, in general, kerbside traffic regulations do not affect where they can stop and park. Since the topic was a novel one, it was felt that discussions among the group members would be a valuable part of the exercise.

Three groups of participants were planned:

Group 1: Younger car drivers (18 – 44)

- Age range; Male/female balance; Ethnic representation
- Infrequent car driver trips/low mileage vs Frequent car driver trips/high mileage

Group 2: Older car drivers (45+)

- Age range; Male/female balance; Ethnic representation
- Infrequent car driver trips/low mileage vs Frequent car driver trips/high mileage

Group 3: Professional passenger and freight vehicle drivers

- Taxis, Private hire, etc; buses and coaches
- Vans (delivery), vans (servicing – e.g. plumbers), medium goods, HGVs
- Age range; Male/female and ethnic representation

The recruitment and on-site greeting of the three groups were managed by Accent Marketing and Research. Participants were offered a financial incentive.

Considerable effort went into selecting stimulus materials and the scenarios to be presented to participants, as illustrated in Chapter 4. They comprised a variety of traffic sign layouts, road marking bay shapes and colours, and coloured carriageway surfaces to reserve space for specific types of vehicles.

The UCL ethics committee required a detailed description of the sample composition and sampling method, the questions to be asked/topics to be addressed, and the visual stimuli to be presented. Information sheets and consent forms were developed and approved by the committee, as shown in Annexes A1 and A2.

Two traffic signs were commissioned from RBLI of Aylesham, Kent via Simon Morgan at Buchanan Computing (a MORE partner). These depicted two ways of showing peak period stopping restrictions, with off-peak loading permitted; one showing the Red Route version of the signs and the other the standard UK version. LED strips and studs were obtained from commercial suppliers. Most LED signs were shown on high-quality monitors and high quality, ceiling-mounted data projectors were hired, to depict different coloured road surfaces.

Templates for the LED versions of existing traffic signs were provided by Buchanan Computing, using their SignPlot software. Grid Smarter Cities provided one of their their-sided traffic signs for the trials. Background lighting, the sequence of LED sign and marking displays, and the sequence of carriageway surfaces were programmed by the PEARL team.

A section of a footway and carriageway were constructed, so that LED markings could be embedded in the carriageway and the kerb.

Planning commenced in July 2021, with the discussion groups taking place in late October 2021. The original intention had been to run the trails in spring/summer 2021, with support from an MSc student, but due to COVID restrictions on group meetings, the work had to be delayed until the late summer/autumn.

3 Conducting the trials

The trials took place between the 26th – 28th October 2021. Each group session lasted 1.5 hours, and refreshments were provided. The groups were moderated by Peter Jones, with other CTS staff (Luciano Pana Tronca and Paulo Anciaes) assisting and taking notes. The activities were videoed and audio recorded.

The PEARL technical team managed the lights and projections. Two members of the technical crew were behind the cabin ensuring the correct functioning of the lights, while one crew member was on the platform listening to the discussion and communicating with the crew when it was time to display the next sequence

3.1 Participant profiles

Younger car drivers' group (Tuesday 26th October 2021)

Nine young car drivers were recruited. The average age was 34 years old. Five out of nine drove their cars for 5+ days a week; three drove their cars between 2 and 5 days a week and only one drove their car once a week or less. Six drivers used a small or medium sized car, two use a large car and one uses a 4-wheel drive vehicle. Four out of nine were female and five males.

Older car drivers' group (Wednesday 27th October 2021)

This group included nine participants. The average age was 57 years old. Older drivers in this group mostly used their cars between 2-4 days a week (6 participants), one used their car between 2-3 days a week, and two participants used their cars more than 5 days a week. Six participants drove a small or mid-sized car (not a 4-wheel drive vehicle), one used a large car, one a mid-size vehicle and one a small or mid-sized car. This group included 4 women and 5 men.

Professional drivers (Thursday 28th October 2021)

This group also included nine participants. The average age was 40 years old, with ages ranging between 27 and 68. Three participants drove either a taxi or private hire car, two drove buses, one drove a van, one a coach or funeral car and one drove a delivery or service van. Eight participants were male and one female.

3.2 Phases of the trials

Participants arrived at PEARL between 17:00-17:30hrs and were greeted by the Accent host. They were asked to read the information sheet (if they hadn't done so before) and to sign in and complete the consent form. They were provided with refreshments. A copy of the information sheet and consent form can be found in the annexes.

The trials consisted of four phases.

Phase 1 (seminar room):

Welcoming of participants, introductions around the table, overview of MORE and the LED trails, and an on-screen exercise involving exploring participants' comprehension of some existing traffic signs and markings.

Phase 2 (PEARL platform):

Participants were first shown four signs, two normal signs and their LED equivalents; lighting levels were then varied, to assess participants' reactions. They were then shown carriageway markings on the floor of the platform, both in painted and LED forms – and, in the latter case, in different colours; again, lighting levels were varied, to simulate day and night times. Finally, participants were presented with a dynamic parking sign, provided by Grid Smarter Cities.

Phase 3 (PEARL Floor area):

Participants were shown different projections onto a grey road surface, depicting different types of pedestrian crossings, plus cycle and bus lanes. In each case, issues around transitions were explored.

Phase 4 (seminar room):

Participants returned to the seminar room, for final around-the-table reflections on what they had seen and heard, before departing.

3.3 Acknowledgements

Most of the photographs shown in this report were extracted from the videos or from camera images taken by the PEARL crew; we thank and acknowledge, in particular, Joe Boxshall and Richard Burton for their help in setting up the trials and with follow up activities associated with this trial. Paulo Anciaes assisted with some of the groups and Grid Smarter Cities contributed several photographs used in this report

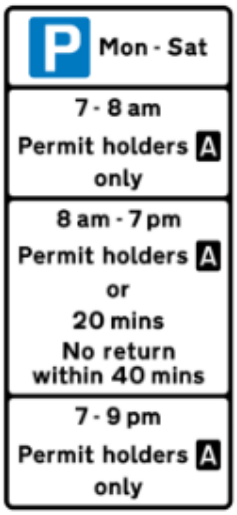
4 Key findings

This chapter displays what people were shown and then summarises their reactions.

NOTE that, in some cases, the digital camera images displayed here do not accurately capture lighting levels and the brightness of the LED road markings, in particular, due to a combination of the limited colour range of the camera chips and the tendency to auto-adjust to give the best exposure.

4.1 Phase 1 (existing signs/markings – seminar room)

4.1.1 Residential parking sign



It took participants some while to read and process the information provided in this sign.

Younger car drivers generally agreed the sign was confusing. In particular, they were not sure what happened on Sundays:

> *"Is it free to park after 7pm?"*

> *"There is too much information in one sign"*

Older car drivers agreed that the sign meant that vehicles owned by non-residents couldn't park at certain times, but there were different opinions about which times the sign referred to. In general, they agreed in a similar way as younger drivers, that the sign had too much information and it was somewhat complicated.

In contrast, the sign was clearly understood by professional drivers:

> *"Permit holders can park anytime" "Non-permit holders (can park) only for 20 minutes between 8-7".*

4.1.2 High street kerbside activity sign

The majority of younger drivers didn't understand this sign. They mentioned that it was confusing, in particular about the meaning of "No waiting", and whether that included "No stopping". Referring to the white section of the sign, participants said:

> *"It's free to load on Sundays*" and

> "*You can do anything after 5pm*".

In general, those participants felt that they could park there.

Older car drivers took some time to come to an understanding about the meaning of the sign. They agreed that the sign applied in areas where people are picked up by taxis. However, they mentioned the word "waiting" is ambiguous and raised doubts about the application of restrictions on every day of the week.

Again, most professional drivers had a good understanding of the sign:

> *"Taxis can't park between 11 to 5"*
>
> *"Taxis can't use it between 10-4pm"*
>
> *"Sunday is free to park"*

However, some felt it was not clear if the "no waiting" section was only from Monday to Saturday. Additionally, they raised the issue that mini cabs are not considered taxis.

4.1.3 High street kerbside activity sign – Red Route

Younger car drivers generally correctly understood this sign; however, they expressed reservations about stopping even during what they perceived to be permitted times, due to fears they could be fined (given a reputation for strong enforcement on Red Routes).

However, some were unsure whether the bottom part applies from Monday to Saturday, as the top part indicates, or if it applies every day. Additionally, a question was raised as to whether loading can only be carried out by lorries and vans, or could apply to private cats too.

For older drivers and professional drivers, the sign was generally easy to understand. Yet, some older drivers were not sure if they could stop between 4pm and 7am; this group also mentioned they would need to stop in order to read the sign, which meant "it's self-defeating".

4.1.4 Blue bus lane sign

Younger drivers identified the sign as being related to bus lanes; however, a few were not sure if the hours referred to the period when the bus lane was in operation or could be used by cars.

Some noted that other drivers did not read these signs and so did not use them during permitted hours – giving them an advantage.

Both older drivers and professional drivers had a good understanding of the sign. Older drivers also had the impression that cars rarely use the bus lanes outside the operating hours.

4.1.5 High street kerbside road markings

Younger drivers had a relatively poor understanding of the markings. In particular, they were unsure about the meaning of the dashed line. They didn't know if it was related to parking or loading [this would be evident from the accompanying traffic sign, not shown to participants] - and were unaware that the colours denoted hours of operation: red line – part of Red Route hours only; white line – throughout Red Route hours.

Older drivers also didn't understand the difference between the red and white dotted lines. Some professional drivers, but not all, knew about the difference between the red and white dotted lines.

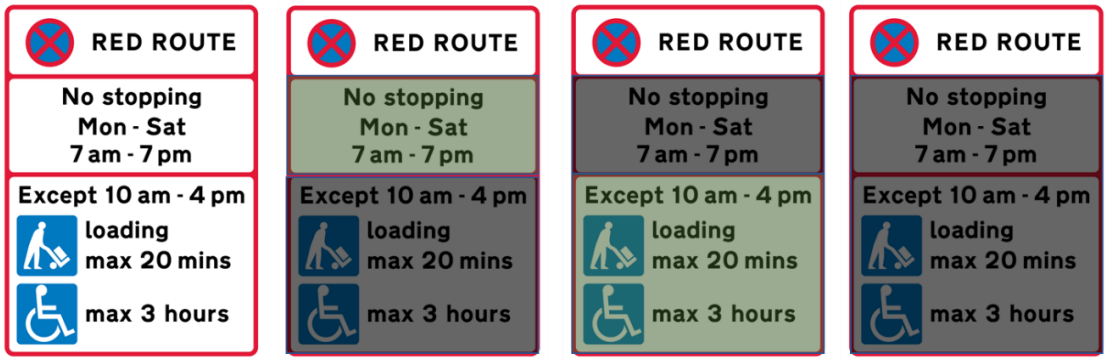
Younger drivers displayed a good understanding of the yellow lines (i.e. double yellow = no waiting/parking at any time; single yellow = restrictions apply during limited hours – see traffic sign). But they did not know about the meaning of the kerb 'blip' – which indicates that loading is not permitted at any time.

Older drivers had similar understandings concerning the double yellow lines and the single yellow line, however they were less clear about the rules for loading. Some recognised and understood the kerb 'blip', but most didn't.

The best comprehension was displayed by professional drivers, who generally understood the meaning of both the kerbside lines and the kerb blips. They recognised that the blip meant that you can't park, even with a disabled badge – although participants hadn't seen this marking very often.

Participants generally complained about a lack of training about the meaning of signs and markings, as these keep changing without proper communication.

4.1.6 Highlighting time-specific information on signs



This set of signs was designed to obtain reactions to the possibility of highlighting the regulations that applied at a specific time of day, on LED signs (grey = not applicable).

Younger drivers considered that "blacking out" the information that didn't apply could be helpful, in particular along Red Routes, as it is generally (incorrectly) understood that motorists can't park there. However, some participants raised the issue that all information should be visible, to enable drivers to plan ahead and be aware of regulations at different times of day. They also raised concerns about possible power failures or technical issues around incorrect displays on LED signs - which could result in them getting fined incorrectly.

Several older drivers worried about the cost: "*where will the money come from*". But, in general, participants liked the idea and regarded it as simple and less confusing to highlight what applies at that particular time of day. When considering the colour of the highlighted area, all said that using green was fine - but that this should be checked in related to colour blind people. They also suggested having a white light around the box that applies at the time.

The professional drivers all had a good understanding of the signs and supported the idea of using some form of highlighting. Some suggested that it should be clear when there are no restrictions in operation:

> *"Don't use different colours (for highlighting what is in operation), just white [showing what applies] and no colour [i.e. blank out the parts that don't apply]"*

4.1.7 Unconventional parking sign from the US

Among the younger drivers' group, only one person understood the sign. Most mentioned it could be dangerous to try to read it when driving.

Older drivers found the sign confusing too, and said that people might opt to ignore it. In particular they dislike "*too many symbols and colours*", and they were confused by the need for two different tables [representing different regulations in the two directions]. Some disagreed and were positive:

> *"I could get used to it, diagrams like this are better than words".*
>
> *"It's like a puzzle, I need to spend time understanding it, then it becomes obvious".*

Professional drivers really liked the sign:

> *"Once you get used to, its useful"*
>
> *"It's simpler"*
>
> *"I would understand something like this better*
>
> *Its self-explanatory"*
>
> *"It's one instruction without exceptions, so you find your slot and that's it"*

4.2 Phase 2 (Comparing LED vs conventional sign and markings on the PEARL platform)

4.2.1 Conventional signs

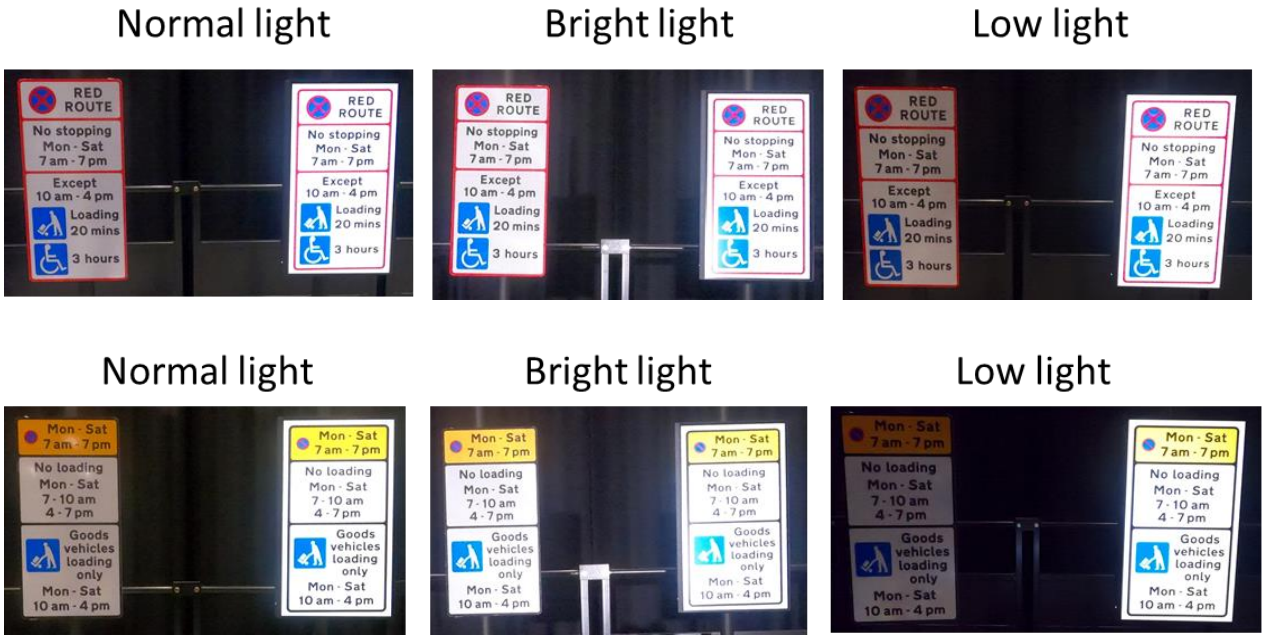
Participants were first shown two conventional kerbside regulation signs, one used on Red Routes (right hand sign) and the other on other roads, and asked to comment on/compare them (an extension of the Phase 1 exercise).

People generally understood both signs, that are largely different ways of conveying the same information (although the left-hand sign does not indicate the maximum loading duration). Younger drivers noted that the left-hand sign contained more information, and in that sense was more 'complete', but it took longer to grasp the meaning

4.2.2 Physical vs LED signs

For each of the above signs, in turn, participants were shown the conventional sign and an LED equivalent alongside, under different lighting conditions (NOTE the earlier caveat about the limited ability of digital cameras to capture lighting level differences).

Participants were first shown each set of designs, in turn, under normal lighting conditions. The background lighting was then lowered to simulate night time conditions, followed by right and left angle lighting and, finally, a strong front spotlight to simulate maximum sunlight face-on to the signs.



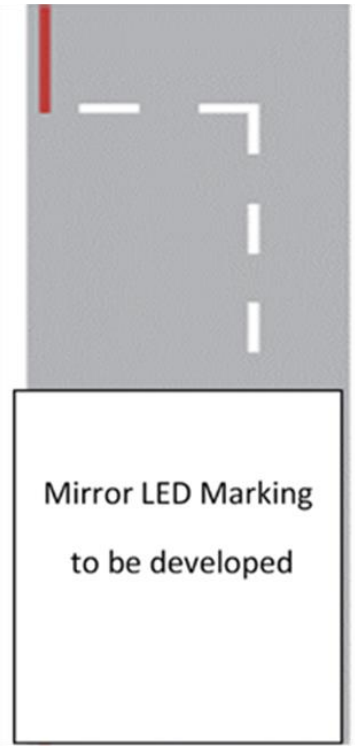
There were no major differences in the appreciation of the signs by the different groups. In general, all the groups considered the LED signs to be clearer and brighter than the conventional physical signs – and were pleasantly surprised by this. There was an exception, when the front spotlight was illuminating the signs, which showed that the LED signs couldn't cope with the strong, direct strong light and the glare. However, moving only a few degrees either way removed the problem.

On the negative side, participants raised issues around cost, maintenance, malfunctioning, vandalism and accessibility (colour blindness, dyslexia). Comments included:

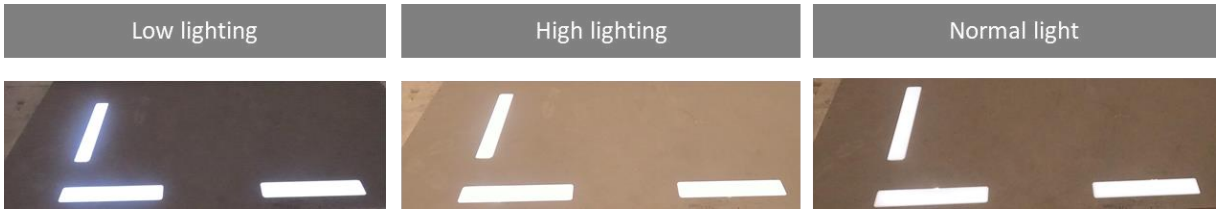
> *"In daylight it might be difficult but in night time is perfect".*
>
> *"I would be worry if there are not working"*
>
> *Low light: "Its brighter but better to see (the LED signs)"*
>
> *"Would the light annoy residents?"*
>
> *"My son has dyslexia, and he reads better with a non-white background"*

4.2.3 White bay dashed lines (Red Routes)

Participants were first shown a Red Route all-day parking/loading bay, with half the bay represented by a painted white dashed line and the other half using LED strips.



Under normal and strong lighting conditions, the LED and painted lines were largely indistinguishable, but under low lighting conditions the LED markings were much brighter and clearer.



Younger and older drivers raised concerns about the cost and funding for this measure. Younger drivers also didn't understand why this needed to change, as the painted lines worked fine – it was explained that this could allow for more flexibility.

Older drivers considered the LED better and clearer than the painted lines. They specifically mentioned that LED wouldn't wear out – unlike paint - and could be replaced when necessary.

Professional drivers considered the benefits of LED under different weather conditions, as they perform better, especially at night or under rainy conditions.

> *"It's a no brainer, the LED is much better. The normal signs wear out easily"*

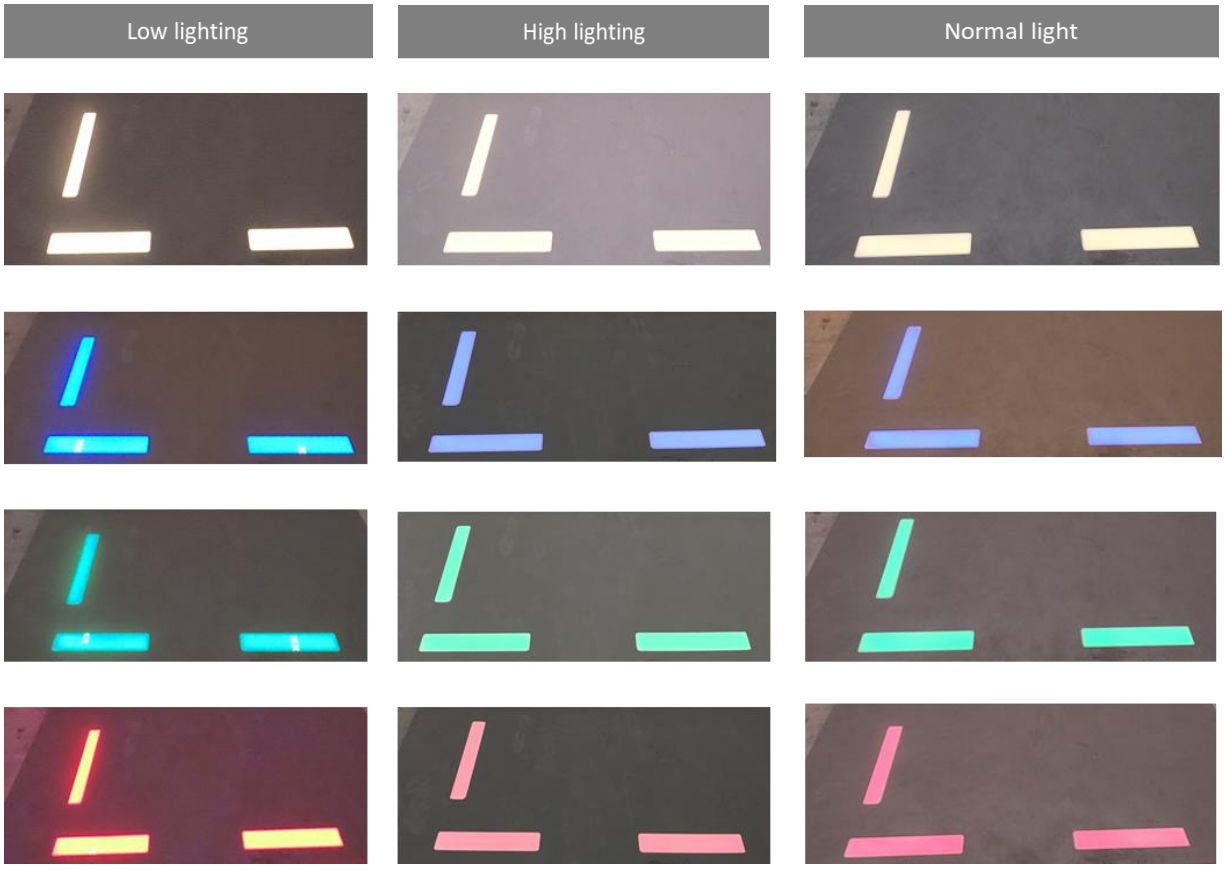
4.2.4 Scope for using other coloured dashed lines

The adoption of LED markings would provide for the possibility of using different colours on the same set of markings, to depict variations in regulations at different times of day. So, next participants discussed the benefits of using different coloured dashed lines, and their suitability under different lighting conditions.

Younger drivers considered that the LED lights and, in particular, the colours would work better at night. However, they were concerned that changes between colours (and the restrictions that would apply with each colour) would compromise advanced trip planning and provide no predictability, if applied dynamically:

> *"As long as you don't get so many colours, the traffic lights system works"*
>
> *"What about for colour blind drivers?" You would need some sign to show them it's changing"*
>
> *"The idea that you can change it from a laptop I like, it keeps the road moving – it's a smart way of going, [compared to] when things are statutory and you can't change them. Sometimes there are roads that are empty - you just waste space"*

Younger drivers also commented on the risk of malfunction. In terms of colour coding, they considered green and red better suited for general parking (showing permitted and non-permitted times, respectively) and blue for cars with blue badges; they did not see a value in using an amber colour – which was also the least clear under different lighting conditions.



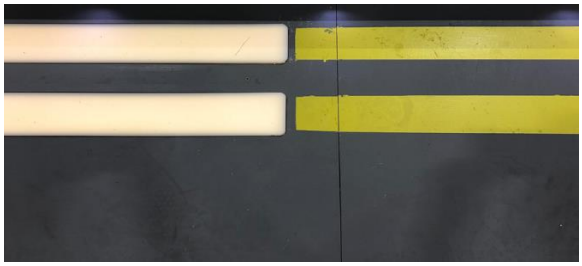
Older drivers agreed they didn't like the amber colour – what would it mean? - and preferred that the markings should be green and red only; although some participants found any mixing of colours confusing. They would prefer to stick to painted lines and using signing to indicate current conditions.

Professional drivers responded positively to flexible colour coding, and focused on situations that would provide the best use for the new technology:

> *"Something like this could be beneficial near Wembley" "For example, on match days you couldn't park [in some areas where] normally you would"*
>
> *"Blue use… "for electric vehicles"*

4.2.5 Kerbside yellow lines

As with the Red Route markings, participants were shown a section of single and double yellow line, contrasting pained and LED strip versions. Here the visual differences between the two media tended to be greater.



The main advantage of using LED line markings would be that they could be changed, by time of day, but younger drivers were very concerned about making such a transition:

> *"I feel there should be a sign that says 'In this road signage can be swap (referring to the yellow lines) for them to be aware'"*
>
> *"A lot of people plan ahead of their journey and (changing the lines) could be a problem, changing from a single to a double yellow line"*
>
> *"If you incorporate set times, then people would know"*

Older drivers considered that the LEDs looked better and stand out in low lighting. However, they were concerned the cost of installation and operation, and issues regarding any utilities under the road.

Professional drivers considered the yellow LED to be too pale, and were concerned about leaves covering the LEDs on rainy days.

4.2.6 Studs in the kerb upright

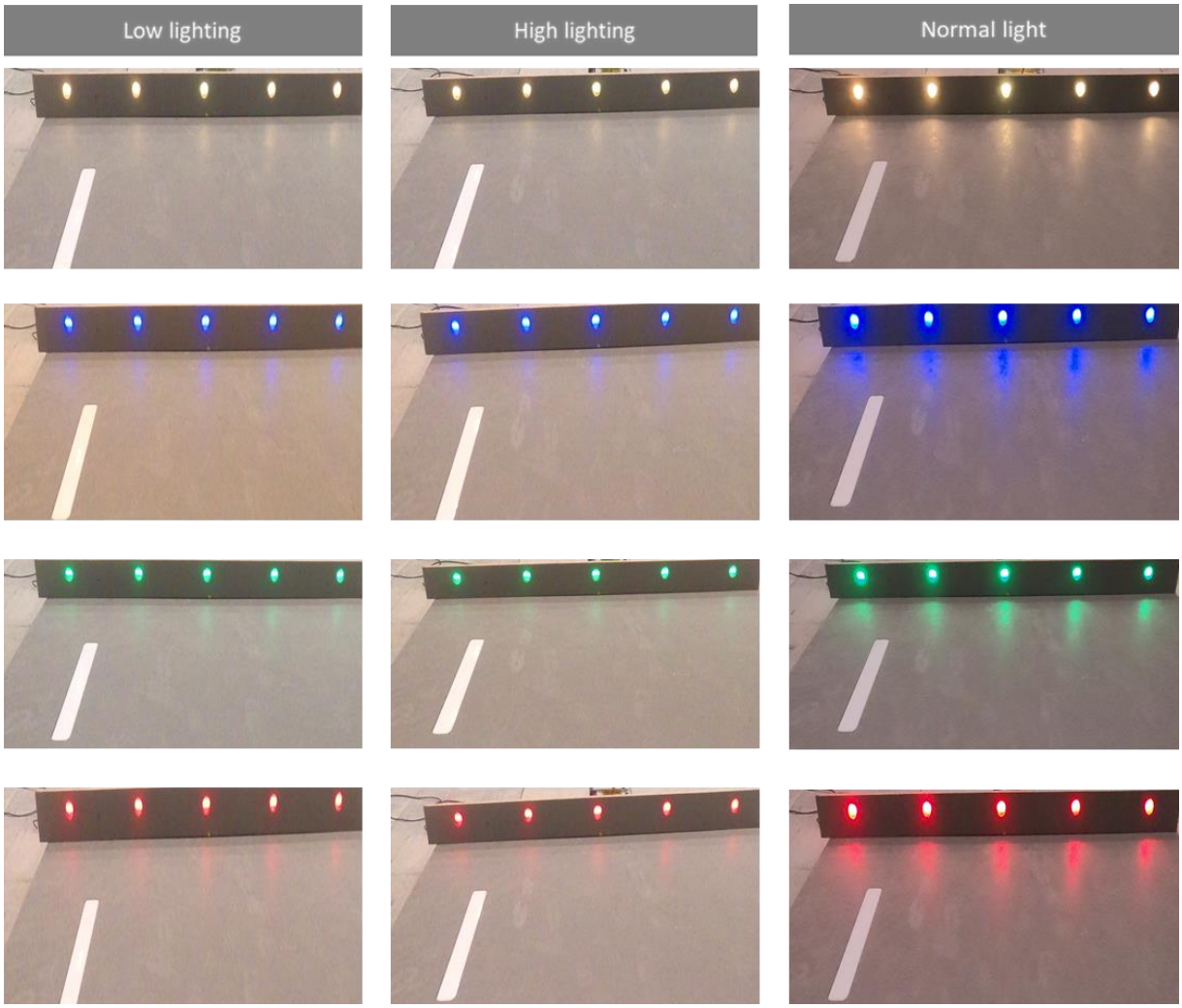
Using LED dashed lines in the carriageway would be expensive to install and would need to be very robust to take the weight of HGVs and well insulated to be protected from heavy rains. As an alternative, Simon Morgan (from Buchanan Computing) suggested using a white dashed line on the carriageway to demark a parking or loading bay, to show current regulations by using coloured studs located in the upright kerbstones – along with conventional traffic signs.

The same range of colours was shown, as for the dashed lines described above.

There were very mixed views among the younger driver group. They thought that the studs were clear, but questioned the need for them. Views on colours were similar to the dashed LEDs: yellow/amber is seen as confusing; they preferred red/green and maybe blue for police or ambulance.

There was also a concern that drivers might be distracted from concentrating on the road:

> *"You would have to look at the kerb to actually see the lights"*
>
> *"I like the way it looks, but I agree that you might not be able to see it (the lights)"*
>
> *"I'm not convinced by these lights"*



On the other hand, older drivers were very positive; they felt that you wouldn't need to slow down to understand the regulations and that it was generally easy to understand. However, they considered potential problems such as maintenance (rubbish, leaves), vandalism and big vehicles such as lorries parked on the road and obstructing the light. As regards colours, older drivers said that amber was not needed and that people associate green with "go" and red with "don't go". The issue of colour blindness was brought up.

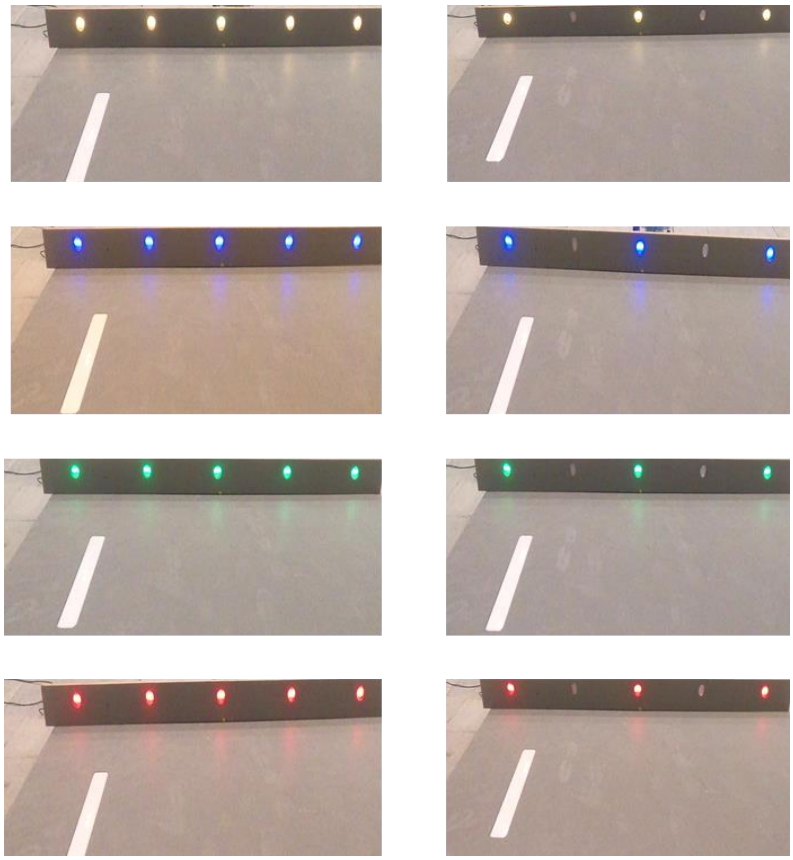
Professional drivers again discussed specific uses for the lights. They mentioned in particular that red could work for stadiums on match days. Amber had no clear connotation, although it could work in a specific area with a specific rule. Green was considered for ambulances or to denote where someone could park. One participant mentioned that blue could be for electric vehicles. In general, they considered this type of technology to be very practical and the next step forward, and related the kerb lights to the sorts of signing on smart motorways.

Professional drivers were also more positive about the cost, noting that in-kerb studs would be cheaper than the in-carriageway dashed lines, and have less possibility of being damaged as they are not installed in the carriageway.

“Maybe (with the studs) you don’t even need the signs”

“That’s more affordable” “I would me more visible when driving” (studs kerb)

4.2.7 Frequency of studs

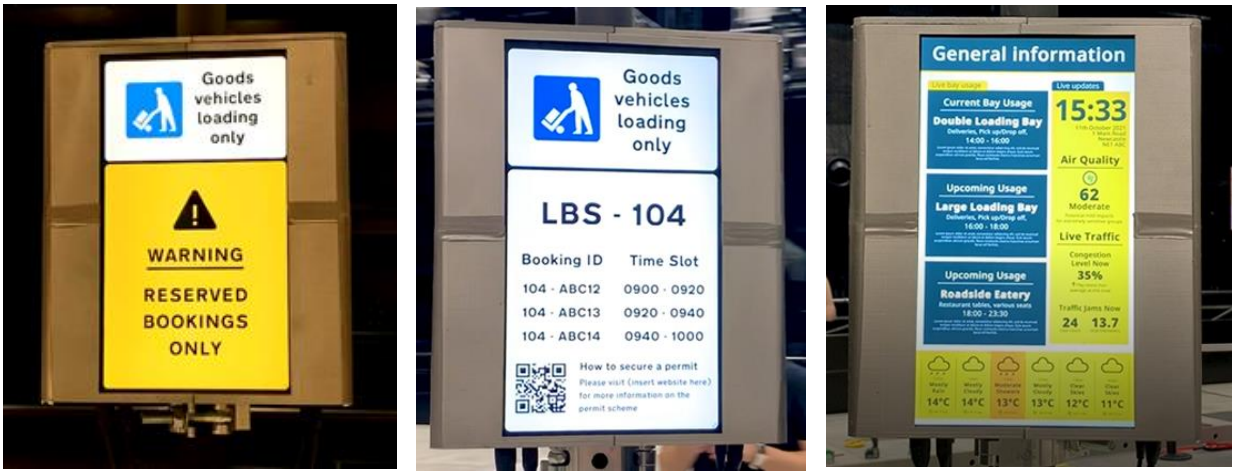


The cost of installation and maintenance would be reduced if studs were installed less densely. In the examples shown on the left alongside, studs were installed at 0.5m frequency. Next, alternate studs were switched off, to simulate a 1.0 metre spacing, and participants were asked if they thought that this would be sufficient.

All the groups considered that installing this reduced frequency of lights would still work effectively:

“You don’t need as many” (talking about reducing the frequency)

4.2.8 Dynamic kerbside loading reservations: a triangular LED sign



Drivers were shown an experimental three-sided LED sign, under development by Grid Smarter City, to be used in conjunction with their dynamic loading booking system. The first sign face warns drivers that this section of the kerbside is reserved for drivers with bookings only. The second face records details of each booking (i.e. booking reference and time slot booked), while the third face is used for public service information, such as weather conditions, or local public events.

This part of the exercise generated much interest and many comments and questions.

Younger drivers asked how someone could extend their time, if they arrived a bit late or underestimated how long they would need. They raised concerns that the system is not flexible enough.:

> *"The problem is extending your time, I find when I rented and extend its already booked by someone else and you need to move. It's not flexible enough for me, its stuck on that time"*
>
> *"There is no guarantee"*

Some also mentioned that general information would better suit bus stops, not parking.

> *"I think that should be on a bus stop, it would be good to have them (there)"*
>
> *"It's not needed, maybe in a busy area for tourists"*

Older drivers asked:

> "*What if there are delays and I can't use the booked space?"*

They were concerned that large companies could make block bookings for long periods of time – just in case it is need – and leaving booked, but unused, space for much of the time.

Older drivers would prefer a larger sign, to be readable when driving. The community information was considered useful. Using the sign to display commercial adverts was seen as a solution to offset costs. They advised that bays should be numbered in order to be better identifiable. They also asked what would happen if you arrive late.

> *"Good idea but some details don't work"*

Professional drivers were particularly interested in time management:

> *"How do you manage the time….?"*

As previously, professional drivers explored the potential practical uses of the technology. They mentioned it could work if spaces are reserved only for loading bookings (in comparison with many normal loading bays, where disabled people can also park) in busy areas. Some people would like to be able to use it for parking, for example when going to the theatre. Discussing the type of deliveries, they felt it would work for freight deliveries on busy streets, but not in residential areas

As regards the "local information" displayed on one face, they asked what kind of information was shown and whether advertising could be included. They suggested that it would be useful

to display local traffic updates. To mitigate the risk of malfunctioning, they proposed the installation of a physical QR code on the post, to be read if the screen was not working:

> *"I would be game changing, you won't even need the LED signs"*
>
> *"I think for business purposes this would work, but for personal purposes it won't"*
>
> *"This is probably for those business who have massive deliveries, but not for deliveries in residential areas"*

4.3 Phase 3: Modifying the carriageway

Participants next moved to the edge of the raised PEARL platform, to view various projections from overhead data projectors, displayed on the grey floor surface, alongside.

In this section of the report, we show the images that were input to the data projectors and some examples of them as they appeared when projected onto the floor.

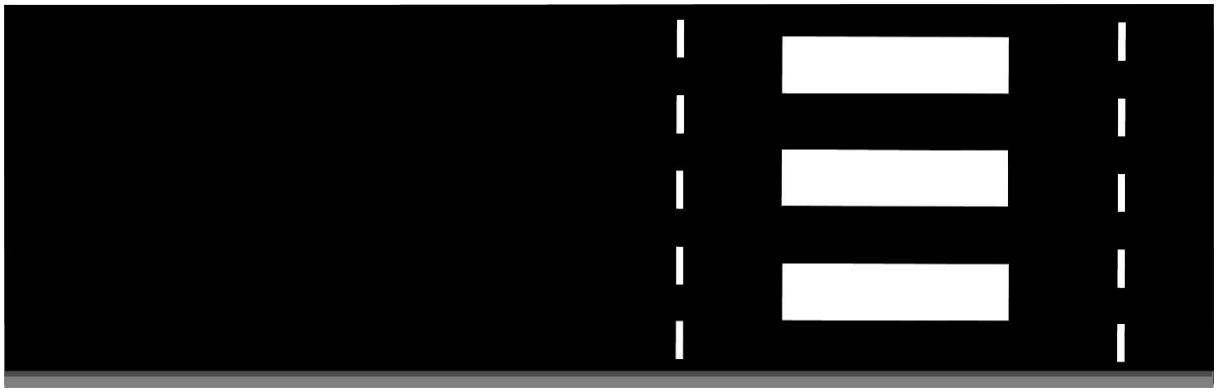
4.3.1 Pearl floor

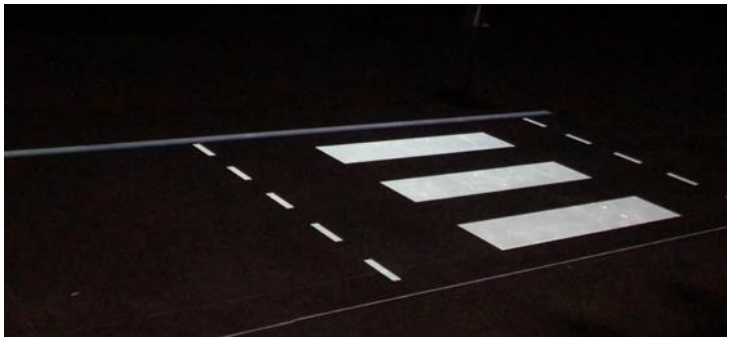
First, for orientation purposes, participants were shown a simple representation of part of a carriageway, with a double yellow line next to the kerb and a single dashed line at a distance of 3 metres, to represent a single traffic lane for general traffic.

This was well recognised by all the road user groups.

4.3.2 Pedestrain crossing: Zebra crossing

A simplified zebra crossing was projected onto the floor, showing the zebra markings and the dashed while line demarcating the edge of the crossing area.





The lighting of the zebra markings was then lowered and raised, with the suggestion that the lights would be intensified when a pedestrian approached the crossing, to alert drivers to their presence.

Some younger drivers felt that it would be dangerous to change the lighting levels, as drivers might not know what it means. They also questioned what would be the appropriate timing/distance between a person about to cross the road and the lights turning brighter – and, could you be sure that they were about to cross the road?

But, others thought changing the colour intensity could be beneficial:

> *"If it's possible to make it whiter when (the pedestrian) is approaching"*

Older drivers mentioned that having the lights increasing in intensity when pedestrians are crossing would be confusing for them as:

> *"Drivers learn the roads. Like this, it's always changing".*

It could also mean drivers would come rely on the lights and might not notice if something else is happening on or around the crossing area. They raised the issue that the LED markings would have a 'glass' top which could be a danger for cyclists riding over them.

Professional drivers said it could be useful in the evenings, when light levels are low, but if it malfunctioned and people had come to rely on it, then this situation could be dangerous.

> *"It's good if there is a sensor and the lights get brighter. Depends on the speed limit and how much time to react the driver will have"*

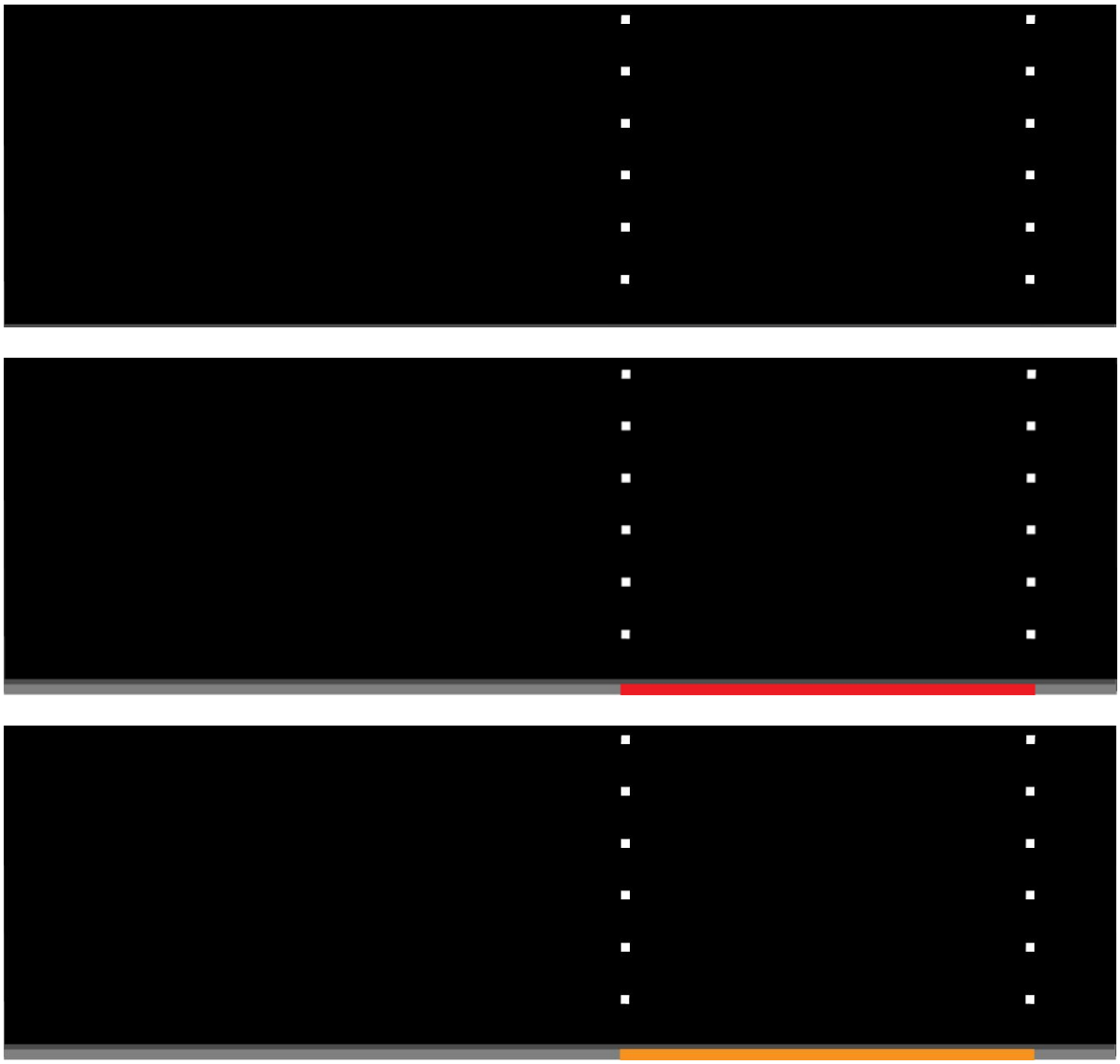
"At the moment lots of zebra crossings are fading down"

"It would work only at night "If it doesn't work and people get used to and all of the sudden, someone crosses…"

4.3.3 Pedestrain crossing: Signalised crossing

The surface studs showing the limits of the carriageway crossing area were projected onto the floor, along with a grey line representation of the kerb line.

Then, a colour was added to the kerb within the crossing area, successively showing red (indicating don't cross), amber (prepare to cross) and green (safe to cross). The traffic signal head was not represented.



Younger drivers had mixed views. They wondered whether people would look down, or be able to see the coloured kerb if they were not at the front of the queue? Several preferred the TfL 'countdown' display.

Older drivers saw it as a good, extra safety measure. However, they were concerned that, if pedestrians were texting, they wouldn't see the red line it would be less effective. They mentioned this as adding cost to providing crossings, as the pedestrian traffic signals already serve this purpose. They considered including amber to not be a good option as people:

"….*push their luck, take risks with amber".*

Some professional drivers had seen a similar approach in New York, where a red line on the footway flashes when the green period for pedestrians is coming to an end. In particular, they said it was:

"*Fantastic for children.*

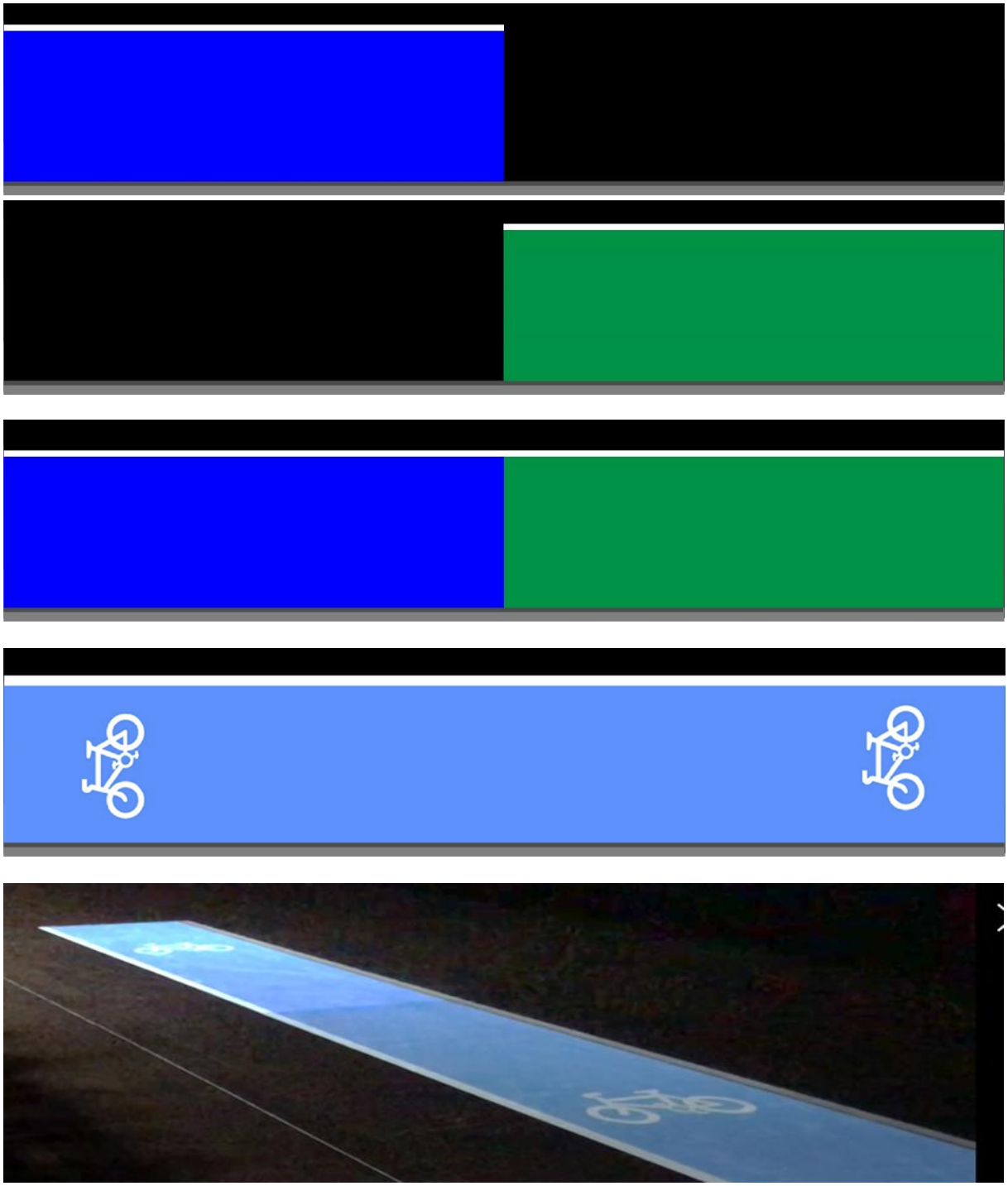
They also suggested that the red line on the kerb should be linked to the dots on either side of the crossing, so that when the kerb colour turns green, then the dots should change colour to red.

4.3.4 Depicting a cycle lane

Participants were shown two colours depicting a cycle lane - a blue lane and a green lane, both with a white line edge marking on the far side from the kerb – and asked which colour they preferred. As the TfL super cycle highways are denoted by a blue surface, then most motorists opted for that colour.

Professional drivers also preferred blue, and not everyone recognised green as an existing option. They proposed that there should be one standard colour for all priority cycle lanes and not two, as is currently the case in the UK.

A standard cycle image was ten projected onto the surface of a blue cycle lane. Most drivers thought that adding the cycled symbol aided comprehension of the marking and an awareness of cyclists.

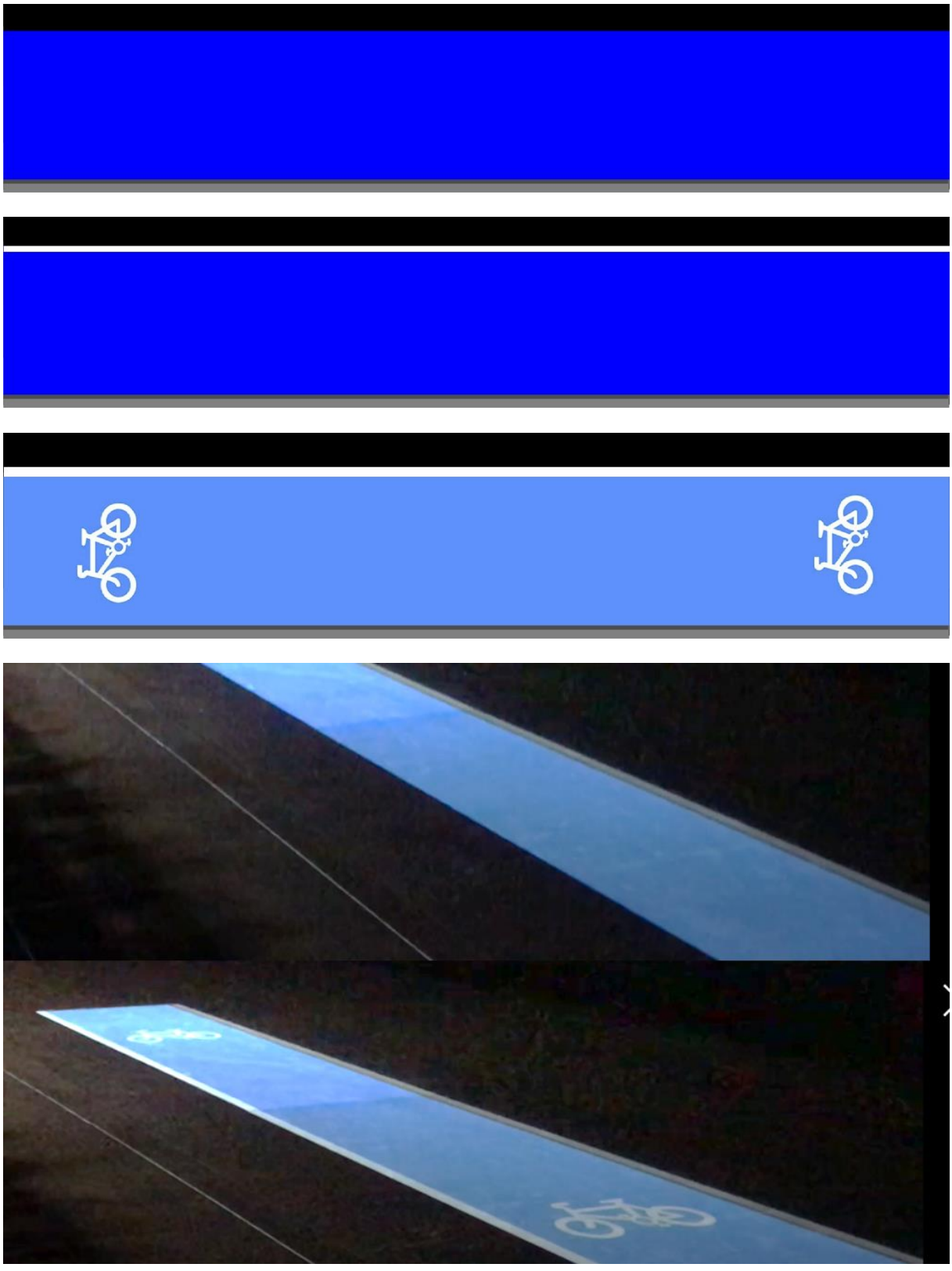


4.3.5 Cycle lane transition

In cases where a cycle lane does not operate for 24 hours per day, then the question would arise of how to mark the transition from the starting and ending of the period of operation.

To indicate the commencement of operation of the cycle lane, respondents were shown a sequence of events, starting with a grey carriageway:

- Blue carriageway shading appears, to denote the area of the cycle lane
- A white edge line is added
- Completed by the appearance of cycle symbols at regular intervals.



This led to a - sometimes heated – debate about whether cycle lanes should be time limited, or only operate on a 24-hour basis.

Young drivers in particular considered that:

> *"(Changing the cycle lanes) could endanger the cyclists"*

Older drivers were divided on the issue. Some thought cycle lanes should be 24 hours:

> *Should be either a cycle lane or a parking"*
>
> *"(Part-time cycle lane) puts cyclists' lives at risk";*
>
> *"it's safer not to have a cycle lane at all (than a part-time one)"*

But others were OK with the idea of a part-time cycle lane. Some considered that bicycles should be on pavement, not on the road – but cyclists and pedestrians sharing space is also dangerous.

Professional drivers also considered a part-time cycle lane to be problematic for cyclists; however, at quiet times it could be more beneficial to allocate the kerbside space for parking and loading, or even general traffic, when no one is using the cycle lane.

Given the majority prefererence for 24 hour cycle lanes, most were not interested in the transition process, although one participant noted that:

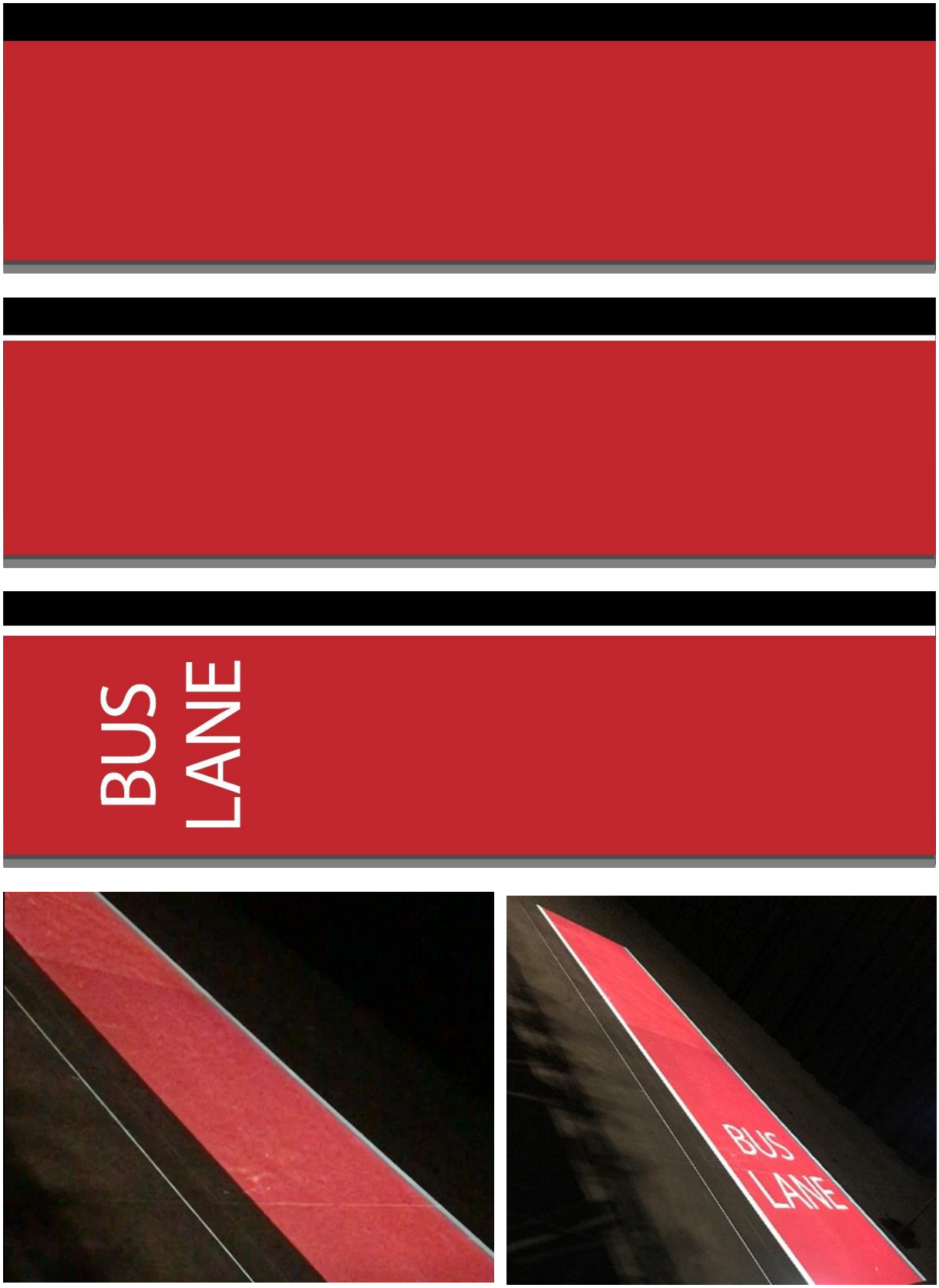
> *"If I'm cycling in the lane, if I see there is a change as a cyclist I could be more careful and understand that there is no more special lane".*

4.3.6 Depicting a bus lane

In a similar way to the depiction of a cycle lane, participants were first shown a red area projected onto the grey road surface, followed by a white edge line on the side away from the kerb, and the addition of wording saying 'BUS LANE'. There was also an LED sign depicting a standard bus lane operation sign, but with no hours of operation indicated. When the lane was not in operation, a red diagonal line appeared across the sign.

Everyone understood what was being represented and was comfortable with it. When the issue of a limited-hours bus lane was introduced, most people were much more supportive of this than a limited hours cycle lane.

For example, older drivers were in agreement that bus lanes should not be in operation 24 hours a day (since they do not face the same safety risks as with cycle lanes) and that their use should depend on the different requirements on that road at different times of day. They thought also that that colouring the bus lane only during its periods of operation might encourage more cars to use bus lanes outside their operating hours.



As regards adding a red diagonal line through the LED sign when the bus lane is not in operation, some participants suggested that it should be thicker but not everyone liked the addition of a line. Some thought it would be better to switch the sign off all together outside the hours of operation – but others pointed out that drivers could not be certain whether the bus lane was not operating, or that the LED sign had failed.

Professional drivers thought it was better to have the red line, specially until people understand that the bus lanes can be turned on and off. They stressed that people will need to time to get used to the idea that bus lanes might vary, by time of day. Some suggested that the hours of operation should be displayed on the carriageway surface too.

4.3.7 Bus lane transition

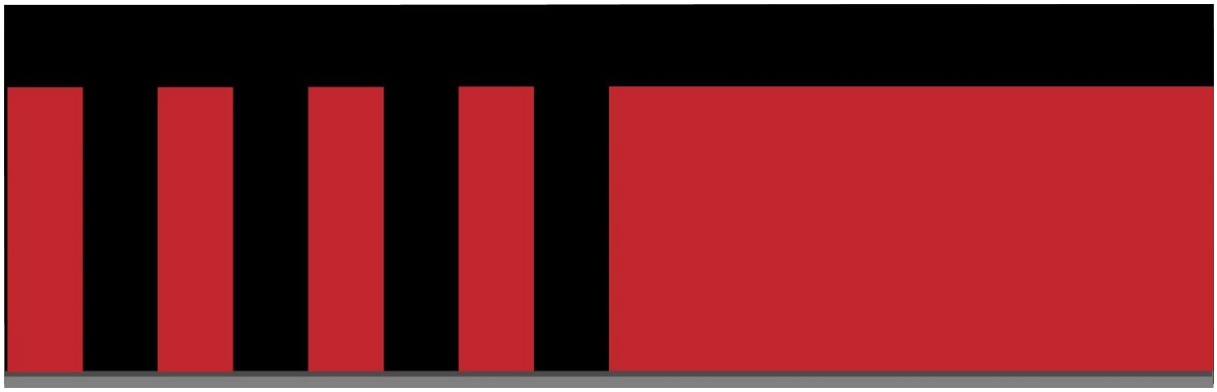
Two types of transition were demonstrated. First, a simple fading in and fading out of the bus lane, as described above, namely:

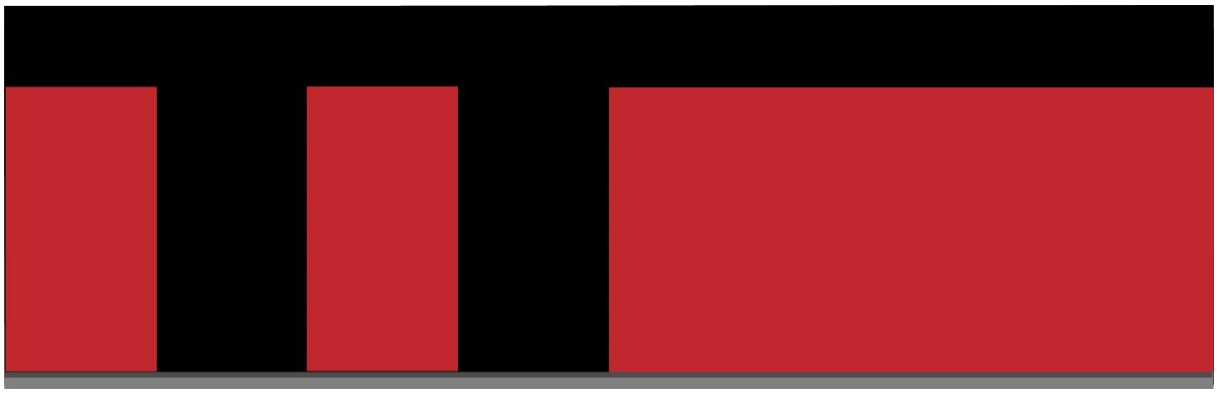
- First, the full bus lane with a white line and the words “BUS LANE”
- Removing the white line and wording and reducing the red light by 50%.
- Finally, all light was removed, revealing the grey carriageway

Many participants were concerned about phasing in and phasing out lighting levels, as their visibility would vary by weather and lighting conditions. Didn’t like change in colour intensity – would prefer to rely on the sign. They were also concerned about the cost of this type of system.

Second, a more incremental transition at the start of a bus lane was illustrated, comprising:

- First, a grey road surface
- Next, the fading in a set of narrow red stripes
- Then increasing to double-sized red stripes and
- Finally, the full bus lane surface covered in red light, with the white edge line and the words “BUS LANE” added.






BUS
LANE

Younger drivers said: *"Having the transition is confusing"*

A few participants found it confusing and asked themselves if this would encourage speeding. But most younger drivers liked the idea of building up blocks, but just at the start of the bus lane; although they were concerned about the expensive and would be happy to rely on the sign

Older drivers agreed that if the transition hours change from day to day, this would cause uncertainty. They were concerned about the surface material and the impact it might have on surfaces and on cyclists' and motorcyclists' safety.

Professional drivers liked the idea of having a pre-warning and asked about the possibility of having an interaction between the bus lane and the stud kerb lights (shown in the previous phase) to enhance the transition. They preferred the 'stepped' introduction of the part-time bus lane, over a transition based on a change in lighting intensity, as the former would be more robust to different ambient lighting conditions.

4.4 Phase 4 (Reflections and conclusions – seminar room)

Finally, participants were escorted back to the room where the session began, and were asked about their overall impressions about what they had seen, and any implications for future traffic management and signing.

When asked about their overall impressions, younger drivers were succinct in their responses. They recognised the advantages of introducing greater flexibility in the ways in which busier streets are designed, managed and operated. They also agreed that LED signs and markings could help to achieve this greater flexibility and dynamism, while improving legibility and comprehension. But they were concerned about the costs of installation and operation of LED systems, and the risk of malfunctions: could there be a physical sign behind the LED that would act as a fall-back?

Older drivers concluded that the new signs and markings could be useful, especially in busy areas. Safety might improve, because signs/markings are lit and so highly visible, especially on overcast days. They considered LED signs as 'the future' and were excited to participate in the trials. They regarded this new technology as a "young baby" that will grow up and mature. They saw it as complementing new forms of in-car information – so supporting, not substitute information.

As regards potential downsides, they mentioned costs, vandalism (vandals could destroy LEDs, but not metal) and the need to take into account colour-blindness.

Colours should be used in a simple and self-evident way, with green (go/available) and red (stop/not authorised) preferred over amber and other shades. They stressed the need to simplify parking restrictions, and standardize signs, so that they are easy to see by moving vehicles. This would reduce delays caused by hesitant drivers and increase safety.

Finally, older drivers put a greater emphasis on the signs, with the marking providing supporting information. In general, they wanted simplicity, standardisation and certainty – so need to be careful when introducing any dynamic element: people need to know what to expect

Professional drivers very much liked the use of LED lighting (both signs and road markings), being especially bright at night and under poor weather conditions – although the glare issue in bright sunshine requires more attention. The embedded kerb lights, used in conjunction with standard painted bay markings, were considered a 'game changer', enabling them to spot at a glance empty bays where they would be eligible to load or park.

In general, they were less concerned about costs: they agreed that it doesn't matter how much it costs, that costs will drop over time as schemes are rolled out, and that change that supports future demands and aspirations always happens. Vandalism and malfunctions are also issues that would need addressing.

They generally supported 24-hour cycle lanes, but only peak period bus lanes.

5 Conclusions and recommendations

All participants were fully engaged in the discussion groups and the displays presented to respondents in the PEARL laboratory setting provided an ideal stimulus for exploring the future potential of LED traffic signing and road markings.

Everyone was impressed by the brightness, sharpness and general visibility of the LED displays, in all but the strongest glare under head-on lighting conditions. They addressed concerns about the existing fading of signs and road markings, and provided opportunities to make signs both more comprehensive – highlighting the applicable regulations at a specific time – flexible and responsive to changing conditions.

Some of the displays were seen as being more attractive and realisable than others. The LED signs were generally well received, including the Grid Smarter Cities triangular sign. While participants were generally impressed with the LED dashed road markings, in terms of clarity and versatility, many questioned the need for a wide range of colours, which could confuse drivers; and questioned the cost of installation within the road surface and the robustness needed to withstand the weight of the heaviest vehicles. In contrast, the use of coloured LED studs built into the kerbsides was seen as a 'game changer', being very versatile and adaptable, while giving a clear and easily recognisable message to motorists while driving, in conjunction with adjacent LED traffic signs.

While the main application of these technologies is likely to be on our busiest urban streets, some specialist applications were suggested, such as around major football stadia and other major occasional trip attractors, where kerbside regulations are very different on certain days.

All groups brought up the cost of installing and maintaining such new technologies, but it was the younger and older car drivers that were more concerned about this, while professional drivers saw the cost as an investment. All groups expressed some concern about potential vandalism and malfunction of the LEDs; but most participant regarded what they saw as being 'the future'; several saw the technology as being beneficial on busy, mixed up urban streets, and used as an analogy the introduction of 'smart' motorways on the national road network.

The last two years during the Covid-19 pandemic was mentioned (particularly by professional drivers) as a time when many, quite radical changes were introduced very quickly – with very little warning and information about those changes. If more flexible and dynamic management of roadspace is to become more common, then it is vital that the signing and markings accurately display current information. But there was a warning in all the groups that drivers often plan ahead and so there is a desire for stability and regularity; at least providing some information on conditions at other times of day.

Professional drivers took a distinctive approach when looking at the LED displays as a form of innovation. They tried to see how to adapt the technology to their needs, personally or professionally, while young and older drivers were much more focused on looking for problems.

Annexes

A.1 Participant information sheet for adults

A.2 Consent form for adults in research studies

PARTICIPANT INFORMATION SHEET FOR ADULTS

UCL Research Ethics Committee Approval ID Number: 0718/001
YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET
Title of Study: Dynamic LED road signs and markings
Department: Civil, Environmental and Geomatic Engineering

Name and Contact Details of the Researcher(s): Professor Peter Jones: peter.jones@ucl.ac.uk
Name and Contact Details of the Principal Researcher: As above

You are being invited to take part in a research project. Before you decided it is important for you to understand why the research us being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

1. What is the project's purpose?

The objective of this study is to explore how we can vary the displays of traffic signs and road markings to manage traffic at different times of the day. To do that, we would need to replace fixed signs and painted road markings with LED versions. We are inviting you to join in a discussion, to share your thoughts on the ways in which we might use traffic signs and road markings to better inform drivers about the regulations.

2. Why have I been chosen?

We are inviting a random sample of drivers to take part in a series of discussion groups, each with around eight to ten participants. Across the groups, we are aiming to reflect the diversity of people who drive, both for personal and business purposes

3. Do I have to take part?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form.

4. What will happen to me if I take part?

You will join a group of other drivers, in a discussion lasting about 90 minutes, during which refreshments will be provided. You can leave at any time, should you wish to do so. You will be paid an incentive, to cover travel and other costs. The discussion will be audio and video recorded and transcribed. No personal data will be held on the transcription and this will be stored on a password protected file and computer at UCL**.**

5. Will I be recorded and how will the recorded media be used?

The audio recordings of the discussion and the video recording of the signs and markings you will be shown will be used only for analysis. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

6. What are the possible disadvantages and risks of taking part?

We do not foresee any risks being involved in this research**.**

7. What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will help to improve traffic signing for drivers in the future.

8. If you feel you wish to make a complaint to an independent person please contact Chair of the UCL Research Ethics Committee – ethics@ucl.ac.uk

9. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any ensuing reports or publications.

10. Limits to confidentiality

Confidentiality will be respected subject to legal constraints and professional guidelines.

11. What will happen to the results of the research project?

Following the discussion groups, a report will be written to summarise the various views expressed, illustrating the various signs and road markings that people will have commented on. This will be published in February 2022.

12. Who is organising and funding the research?
This research is being conducted by UCL with funding from the European Commission.

13. Contact for further information
Please contact Peter Jones: peter.jones@ucl.ac.uk

Notice:
The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk
This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice. For participants in research studies, click here

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices.

The lawful basis that will be used to process your personal data are: 'Public task' for personal data.

Your personal data will be processed so long as it is required for the research project. We will anonymise or pseudonymise the personal data you provide and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Thank you for reading this information sheet and for considering taking part in this research study.

CONSENT FORM FOR ADULTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: Dynamic LED road signs and markings

Department: Civil, Environmental and Geomatic Engineering

Name and Contact Details of the Researcher(s): Professor Peter Jones: peter.jones@ucl.ac.uk

Name and Contact Details of the Principal Researcher: As above

This study has been approved by the UCL Research Ethics Committee Project ID number: 0718/001

Thank you for considering taking part in this research. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study.

		Tick Box
	I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction. I am happy to be involved in an individual interview.	☐
	I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified. I understand that my data gathered in this study will be stored anonymously and securely. It will not be possible to identify me in any publications.	☐
	I understand the direct/indirect benefits of participating.	☐
	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	☐
	I understand that the information I have submitted will be published as a report.	☐
	I consent to the discussion being audio recorded and the signs we are being shown being videoed, and understand that the recordings will be stored anonymously, using password-protected software and will be used for specific research purposes	☐
	I voluntarily agree to take part in this study.	☐

Name of participant Date Signature