SMART MOTORWAYS

Safety: Design, Construction or Education?

HIGHWAYS AGENCY

Safe roads, reliable journeys, informed travellers

Safety: Design, Construction or Education?

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ABSTRACT

Since the success of the 2006 "Active Traffic Management" pilot on the M42 east of Birmingham, the Highways Agency has deployed over 50 km of smart motorways that combine the use of technology with the use of the hard shoulder to create additional capacity.

The experience from these schemes has been very positive - improved flow, reduced accidents, fewer emissions - all at a fraction of the cost and environmental impact of traditional widening. In fact, the performance of smart motorways has exceeded expectations, notably in terms of safety, and this has led the Highways Agency to consider how it can deliver the objectives of smart motorways at an even lower whole life cost.

This paper looks at the latest variant of smart motorway, known as 'all lane running' and describes the approach to design, construction and education to support the permanent conversion of the hard shoulder to a running lane.

The reader is referred to the follow publications for more detailed information on the smart motorway design discussed in this paper:

Highways Agency Interim Advice Note 161/13 – "Smart motorways All Lane Running", available at http://www.dft.gov.uk/ha/standards/ians/pdfs/ian161r1.pdf

Smart motorways all lane running – Concept of Operations (to accompany Ian 161/13), available at: http://www.dft.gov.uk/ha/standards/tech_info/files/ALR_Concept_of_Operations_v2_0.pdf

Smart motorways campaign material to support the introduction of 'all lane running', available at: http://www.highways.gov.uk/publications/smart-motorways-campaign-material/

1 SMART MOTORWAYS: BUILDING CAPACITY

The traditional method of adding highway capacity was to widen existing roads or build new ones. However, such projects are facing growing public opposition, fuelled by concerns about environmental impact, noise and air quality, and future impacts on land development patterns. Such opposition coupled with forecast traffic growth of around 44%[1] and annual congestion costs of around £2 billion, are forcing many public agencies to consider alternate approaches that are quicker and cheaper to build, but provide much needed congestion relief and support economic growth.

It is within this context that the Highways Agency (the authority responsible for all motorways and Trunk Roads in England) has embarked on an ambitious program of smart motorways to deliver improved highway performance by making better use of space within the current highway boundary and specifically the use of the hard shoulder as a running lane

2 DYNAMIC HARD HOULDER RUNNING

2.1 DYNAMIC HARD SHOULDER

The initial smart motorway design added extra capacity by opening the hard shoulder to traffic during periods of heavy traffic demand (a concept known as ‘dynamic hard shoulder running’ or DHS).

Figure 1: *Dynamic Hard Shoulder with Emergency Refuge Area*

[1] Road Transport Forecasts 2011 – Results from the Department for Transport’s national transport model, Department for Transport January 2012

The generic smart motorway DHS design features:

- “inter-visible” gantries (approximately every 800 m), containing overhead lane control / speed limit signals and a dynamic message sign (the “inter-visible” requirement means drivers can see the next gantry before fully passing the gantry that precedes it) and limits ‘*surfing*’ – speeding up and slowing down between successive gantries.
- Emergency Refuge Areas (ERAs), typically located immediately downstream of the gantry, providing a safe stopping area for vehicles in the event of a breakdown; each ERA is equipped with an emergency telephone, camera for viewing by the control centre and loops to detect vehicle entry and exist.
- automatic incident detection and queue protection, fed by loops every 500 metres in each lane
- full PTZ CCTV coverage
- a series of fixed “hard shoulder” CCTV cameras used by operators to verify that the hard shoulder is clear prior to opening
- automated enforcement of mandatory dynamic speed limits

On such MM-DHS schemes, motorists may only use the hard shoulder as a running lane when indicated by the overhead matrix sign.

Before the hard shoulder is opened, the highway is “conditioned”, a phase during which the speed limit is reduced to 60 mph in an effort to establish smooth traffic flow.

Figure 2: *Conditioning phase*

Once smooth flow is established and the hard shoulder has been checked for obstructions, the hard shoulder is then opened to traffic. This is indicated by the display of a speed limit over the hard shoulder, coupled with the display of speed limits over all other lanes (consistent with the Highways Agency's "all-on all-off signalling policy").

Figure 3: *Hard shoulder running*

2.2 RESULTS FORM THE INITIAL PILOT

In 2006, the Highways Agency piloted Dynamic Hard Shoulder running via a pilot scheme on a 17 km stretch of the M42 motorway near Birmingham, with impressive results:

- a reduction in personal injury accidents from 5.08 to 2.25 per month[2] and a notable a reduction in the "accident severity index from 0.16 to 0.07[3] (figures measured over the first 36 months of operation)
- a reduction in journey times during peak periods of 9% in the northbound carriageway and 24% in the southbound carriageway[4]
- a reduction of 22% in journey time variability[5]
- compliance with speed limits of 94% or better for speed limits between 50 and 70 mph[6]

[2] "M42 MM Monitoring and Evaluation – Three Year Safety Report". January 2011
[3] "M42 MM Monitoring and Evaluation – Three Year Safety Report". January 2011
[4] "M42 ATM Monitoring and Evaluation: Project Summary Report". November 2009, table 4.1
[5] "M42 ATM Monitoring and Evaluation: Project Summary Report". November 2009, table 4.1
[6] "M42 ATM Monitoring and Evaluation: Project Summary Report". November 2009, table 4.1

- reductions of approximately 4% in CO, HC, CO_2 and NOX and of 10% in particulate matter[7]
- a marked improvement in the perception of long distance users of the level of service of the highway.

2.3 IMPLEMENTING DYNAMIC HARD SHOULDER OPERATION

As a result of the success of this initial scheme, the Highways Agency embarked on a series of additional smart motorway deployment, as shown in the table below:

Table 1: *Dynamic Hard Shoulder Schemes*

Scheme	Status
M42 J3a-7 pilot (Birmingham area)	Operational
Birmingham Box Phase 1 (M40 j16-3a, M42 j7-9, M6 j4-5)	Operational
Birmingham Box Phase 2 (M6 j8-10a)	Operational
M1 J10 to 13 (near Luton)	Operational
Birmingham Box Phase 3 (M6 j5-8)	Operational
M4/M5 (near Bristol)	Operational
M1 j28-31 (east of Sheffield)	Operational
M62 J25-30 (near Leeds)	Operational

2.4 APPROACH TO OPERATION

2.4.1 Criticality of being able to open the hard shoulder

Once a smart motorway scheme featuring dynamic hard shoulder running is built, the ability to use the hard shoulder as a running lane becomes an integral part of the network. From a network capacity perspective, the ability to open the hard shoulder is equivalent to keeping a regular running lane open during periods of heavy demand. Any situation where the hard shoulder cannot be opened when needed is conceptually equivalent to closing a regular running lane.

2.4.2 Smoothing the traffic

To reduce the risk of incidents, the Highways Agency has a policy of reducing the speed limit to 60 mph in the period immediately prior to hard shoulder opening. This has the effect of smoothing the traffic, equalising speeds across lanes and preventing flow break down. Once the traffic is judged sufficiently smooth by the operator, the hard shoulder opening procedure is started.

[7] "M42 ATM Monitoring and Evaluation: Project Summary Report". November 2009, table 4.1

2.4.3 Checking the hard shoulder

In the MM DHS design, a dynamic hard shoulder cannot be opened to traffic until an operator has verified that the hard shoulder is clear. This is achieved through the use of a network of fixed (immobile) CCTV cameras, positioned to provide 100% coverage of the hard shoulder. Once the operator has confirmed that it is free of obstructions, the hard shoulder is opened in reverse flow order on a link by link basis, thus ensuring that no vehicle will encounter an obstacle after entering the motorway.

2.4.4 Impact of incidents

During busy periods, the dynamic hard shoulder will be open to traffic and hence any incident or breakdown during these periods that is unable to leave the network will block a live lane. Whilst this makes incidents relatively easy to detect (due to the resulting traffic queue), it means that it is particularly important to quickly move the incident off the network or to one of the Emergency Refuges Areas. Whilst this is clearly a challenge, experience has shown that incidents can generally be cleared sufficiently quickly so as not to unduly impact journey times and journey time reliability.

2.4.5 Responder access

Access for fire, ambulance, police, towing and other services ("Responders") was a major concern during the concept development of hard shoulder running, as Responders could no longer rely on the hard shoulder to provide rapid access to an incident. In reality, experience has shown that the combination of lane signals and individual driver behaviour has been effective at freeing up a path to the incident. So, whilst DHS requires far greater coordination between Responders and the control centre (which lane to close, from which point, etc), concerns about difficulties in reaching incidents have generally failed to materialize.

2.4.6 Maintenance

The density of infrastructure and technology, restricted access to the hard shoulder and normal challenges around road space booking makes maintenance a major issue on DHS schemes. Further, the critical role played by technology in the safe operation of the scheme means that many faults are considered "critical" and hence must be fixed quickly so as not to impede the ability of the hard shoulder to be opened.

In response to the above, the Highways Agency has undertaken a detailed review of the priorities of different types of maintenance as well as a review of the MM design to ensure that as much maintenance as possible can be carried out without the need for lane closures. The Agency also undertook a detailed review of which faults and combinations of faults should prevent the hard shoulder from opening. Whilst these actions have been effective, the level of effort associated with maintenance remains a concern.

2.4.7 Gaining compliance

The risk of non-compliance is a major issue on smart motorway, largely due to the loss of a "safety valve" of the hard shoulder and due to operational rules that dictate when the hard shoulder can be opened. Specific concerns include:

The potential for drivers to ignore variable mandatory speed limits, where traffic conditions enable them to drive faster than the posted limit (ie the posted limit does not appear credible, at least for a particular stretch of roadway)

'Red X' (stop) lane closure signals may be ignored if drivers cannot immediately see why they have been set

The potential for drivers to use the hard shoulder when it is closed, particularly when the hard shoulder remains closed at the time when it is habitually open (ie due to a broken down vehicle or technology fault that prevents the hard shoulder from being opened).

Use of the ERAs for non-emergency stops

In response to the above, the DHS design includes:

a large number of dynamic message signs which can be used to reinforce lane signals or provide background information as to why signals are set in a certain way (thus making the instructions to drivers more credible and raising compliance)

an array of enforcement locations from which automatic dynamic speed enforcement equipment can be installed to target specific non-compliance issues;

targeted driver education campaigns, mainly through VMS messages

In addition, each scheme is required to produce a 'compliance strategy', which must assess the potential for non-compliance with specific rules, identify safety hazards that would be affected by the non-compliance, and develop mitigation strategies.

3 THE 'NEXT GENERATION' SMART MOTORWAY

In 2010, the newly-elected coalition government announced a "Comprehensive Spending Review". Conscious of the need to improve the transport infrastructure to support economic growth, but also recognising the fiscal constraints facing the country, the Highways Agency was set a challenge which was to continue to deliver the benefits of Smart motorways, but at a significantly reduced cost.

The key aspects of the challenge laid down were:

- Reduce whole life costs (including capital and operating costs) by 30%;
- Reduce the timescale for construction by 20%;
- Ensure no reduction in the safety performance (no increase in accident rate, using the 'SWAFR' metric[8]);
- Ensure no reduction in the journey time benefits being delivered by the MM-DHS design concept;
- Support the government's policy on "Supporting economic growth in a low carbon world".

[8] SWAFR = the Severity Weighted Accident Frequency Rate – a metric which considers not just the frequency of accidents but their relative severity: for example treating fatal accidents as more significant than those resulting in minor injuries

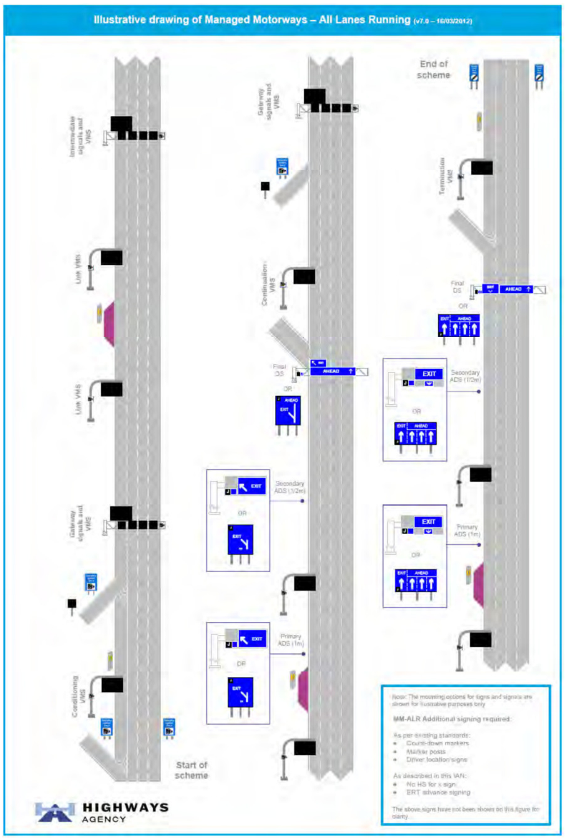
It was quickly realised that the dynamic nature of the hard shoulder was a source of significant additional cost (both capital and operating) and that meeting the above challenge required a fundamental rethink of whether a dynamic hard shoulder was truly required.

3.1 ALL LANE RUNNING DESIGN

Considerable knowledge has been gained from the construction and operation of smart motorways with DHS. This has allowed an evidence-based approach to the new design. The key feature of the ALR design is the permanent conversion of the hard shoulder to a running lane as opposed to the temporary conversion when conditions warrant under the old DHS design.

The generic Smart motorway All Lane Running (ALR) design features:

- cantilever signs every 1500m, which are designed to display the mandatory speed limit, lane blockage information as well as warnings or other driver information messages
- Emergency Refuge Areas, similarly equipped to those used on DHS, but at a maximum spacing of 2.5 km
- automatic incident detection and queue protection, fed by loops every 500 metres in each lane
- full PTZ CCTV coverage
- automated enforcement of mandatory dynamic speed limits



The 1500 metre spacing for Variable message signs and signalling (as compared to the 800m under the MM DHS design) was selected based on the results of simulation trials which showed that it would provide drivers with adequate guidance of the mandatory speed limits and lane availability.

Refuge areas, each equipped with an emergency roadside telephone, are included in the design requirements at up to 2.5km intervals. These refuge areas provide a place for vehicles to stop safely in emergency or breakdown. The 2.5km spacing is consistent with the frequency with which lay-bys are provided elsewhere on the all purpose trunk road network. Refuge areas can also be used to provide maintenance access, to commence the setting out of lane closures, or to assist with the recovery of vehicles or removal of debris during incident management.

Creating and preserving the controlled environment on ALR schemes will largely depend on the ability to achieve compliance with the posted speed restrictions and lane closures, and hence will depend on the development of an appropriate compliance and enforcement strategy.

Control room operators will have access to images from PTZ CCTV cameras, positioned to provide comprehensive coverage of the smart motorway sections of the network. Operators will be able to use the CCTV images to remotely confirm incidents, as well as conduct general observation of conditions on the network.

The permanent removal of the hard shoulder is expected to impact the management of incidents to some degree, as it will affect the ability to move broken down or damaged vehicles from the live traffic lane into a dedicated hard shoulder, or to use the hard shoulder as an emergency access route. Maintenance vehicle stops on the carriageway will now occur in live traffic lanes and will require appropriate Temporary Traffic Management (TTM).

Eliminating the dynamic hard shoulder element will serve to reduce any potential confusion over whether or not it is available as a running lane at a particular time, and will therefore eradicate hard shoulder abuse/misuse within the scheme (since there will no longer be a hard shoulder).

Figure 5: *Gantry mounted signalling arrangement*

Figure 6: *Verge mounted signalling arrangement*

3.2 SAFETY CONSIDERATIONS

3.2.1 Theoretical review

A key design criterion for ALR was to ensure that the safety performance the scheme after ALR implementation was no worse than the pre-existing safety record.

The Highways Agency undertook a qualitative review[9] to test the safety of the new ALR design. In particular, the Agency reviewed known 'existing' motorway hazards as well as 'new' hazards introduced by the ALR design. The review concluded that the ALR design is likely to meet the safety objective for all road users:

Although three of the twenty highest scoring existing motorway hazards increase in risk, there was a reduction in risk for a significant number (15) of them, due to a controlled environment being provided through a combination of regularly spaced mandatory (enforced) speed signals, and comprehensive CCTV coverage;

Only one new high scoring hazard was identified (recovering a vehicle from an emergency refuge area).

Calculations show that the total 'after' score represents a reduction of approximately 15% when compared with the safety baseline.

3.2.2 Driver simulation

Many of the assumed safety benefits of an ALR scheme are linked to the provision of a controlled, compliant driving environment, achieved through the use of regularly spaced variable signs and signals. However, this control is dependent on the ability of drivers to recognise, understand and respond to the information being provided.

The Highways Agency conducted a driver simulator study (see Figure) to test driver behaviour and response in an ALR environment and to see how this compared to a DHS environment (for which there was significant empirical evidence available)[10].

Of all the assessment measures used to study behaviour within the simulated environments, there was found to be no practical or statistically significant difference in behaviour between participants driving in the 'MM-DHS' route or the 'ALR' route.11

The evidence from this simulator work has been used to provide a level of assurance that the design will perform as expected, and that it will provide the adequate guidance needed to deliver a controlled and compliant environment.

[9] "Smart motorways All Lanes Running – Demonstration of Meeting Safety Objective Report" – March 2012.
[10] TRL Report: "Future Smart motorways Concept Development | Task 1: Design Comparison Simulator Study" – March 2012.
[11] With one exception – in one section of the route, mean speeds were found to be higher in one configuration by approximately 1 mph. While statistically significant, it is thought to have little practical significance.

Figure 7 – Participant in the driving simulator study

3.3 COST CONSIDERATIONS

3.3.1 Capital expenditure

The ALR design should be significantly cheaper than MM-DHS. This will be achieved in part through the reduced provision of technology assets, as well as completely eliminating the requirement for dedicated hard shoulder monitoring CCTV cameras, and their associated control systems. There will also be a corresponding drop in civil infrastructure expenditure due to reduced gantry provision, less dedicated refuge areas, and reduced requirements for near side vehicle restraint barriers.

3.3.2 Operational expenditure

The ALR design will significantly reduce operational costs, mainly due to the elimination of the need to check the hard shoulder prior to opening and to contact vehicles in ERAs.

3.3.3 Maintenance

With the majority of driver information now being provided through verge-mounted signing and signalling (as opposed to solely through overhead gantries), both the frequency of traffic management associated with offside lane closures, and the challenges of conducting routine repair and maintenance of infrastructure positioned above live lanes are expected to reduce significantly. Conversely, there is some risk of increased maintenance cost due to the loss of a hard shoulder to perform a certain number of maintenance activities.

3.4 DRIVER EDUCATION

3.4.1 The need for driver information

There are various safety risks on the motorway. For all-lane running, we have tackled some of these through design, and others can be reduced through driver behaviour. In fact, some of the top hazards we have identified on sections of all-lane running are the same as those on other sections of motorway – those stemming from driver behaviour such as fatigue, speeding, tailgating, etc.

In 2012 the Highways Agency recorded that 11,200 people broke down on the motorway because they ran out of fuel; 38,700 people broke down because their tyres failed. If these breakdowns were eliminated through good preparation and maintenance, all roads – not just all-lane running schemes – could be made safer.

3.4.2 Building driver awareness

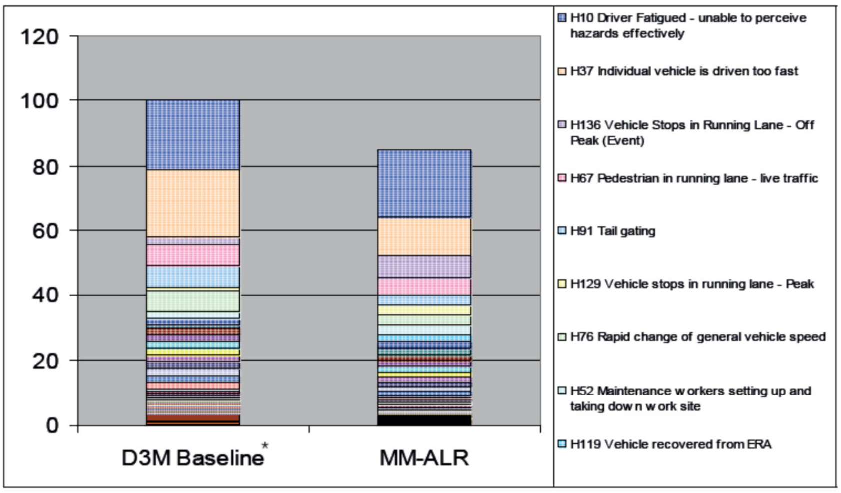
All lane running introduces a new style of 'smart motorway'. In order to try and eliminate and reduce the risks, a new driver awareness campaign was developed for all-lane running, building on concepts previously deployed for other campaigns such as 'make time for winter'. The campaign's aim was to help drivers understand how to drive on different types of smart motorways, understand the environment and know what to do if they broke down. Key areas of the campaign are in Table 2:

Table 2: *Campaign key areas*

Red X	Understanding and complying with signs such as Red X
What You'll See	Features of managed motorways, with links to individual scheme pages
Incidents	Management, traffic officers, emergency services, setting signs
Facts	Facts regarding safety, congestion
Hard Shoulder	Messages about hard shoulder abuse and safety
If you breakdown	Advice for drivers in the event of a breakdown . . . what do I do?
Your vehicle	Advice, how to avoid breakdowns, planning journeys

This last element is about drivers being prepared for their journey and ensuring that their vehicle is regularly serviced so that they are less likely to break down. The Highways Agency is working closely with our partners to ensure consistency and make the most of opportunities to join-up activity. We will be making a toolkit of information and materials available to partners to use when talking about smart motorways to their audiences throughout 2013-14, and onwards.

The following diagram shows how the top hazards for our motorways build up the risk profile for the baseline of a dual three-lane motorway (D3M) and for smart motorways all-lanes running (ALR). The size of each hazard represents the size of the risk.



*D3M = dual three-lane motorway, with hard shoulder

Figure 8: How the risk stacks up

The hazards above were those that a driver information campaign was considered able to influence, for example through:

- Advising drivers to take regular breaks on a long journey to prevent fatigue;
- Reducing speed related risk by reminding drivers about compliance with mandatory speed limits;
- Reminding drivers to avoid stopping their vehicle in live lanes and to use the emergency refuge areas;
- Reminding drivers only to use a refuge area for emergency stops;
- Explaining to drivers the risks faced by our maintenance workers and asking them to take care when workers are setting up and taking down works sites.

Through the information campaign, the aim was that drivers would understand and appreciate the safety benefits of the controlled environment. Correctly interpreting the information provided through a combination of regularly spaced mandatory speed signals, speed enforcement, and comprehensive CCTV coverage, the risks should be reduced.

4 THE CURRENT PROGRAMME

Following the Spending Review in October 2010, the Government announced plans to invest £1.4 billion on Major Road improvements through to the end of financial year 2014/15. Included within the programme were 11 Smart motorways schemes.

In November 2011 the UK Government committed to invest a further £1 billion to tackle areas of congestion and improve the national road network. This additional investment included funding for a further six schemes, and allowed the delivery of two planned schemes to be brought forward.

Table 2: *MM schemes currently in operation:*

Scheme	Type	Length (km)	Operational start date
M42 J3a to J7 (Pilot)	DHS	17.5	2006
M6 J4 to J5	DHS	8.0	2009
M6 J8 to J10a	DHS	11.5	2011
M1 J25 to J28	DHS	24.5	2011

Table 3: *MM schemes under construction:*

Scheme	Type	Carriageway Length (km)	Planned completion
M1 J10 to J13	DHS	24.0	2013/14
M4 J19 to J20	DHS	5.5	2013/14
M5 J15 to J17	DHS	5.0	2013/14
M62 J25 to J30	DHS	24.5	2013/14
M6 J5 to J8	DHS	14.5	2012/13
M25 J5 to J7	ALR	19.5	2013/14
M25 J23 to J27	ALR	25.5	2013/14

Table 4: *MM schemes in the design phase:*

Scheme	Type	Carriageway Length (km)	Construction start date
M1 J32 to J35a	ALR	16.0	2013/14
M1 J28 to J31	ALR	29.5	2013/14
M3 J2 to J4a	ALR	21.0	2013/14
M1 J39 to J42	ALR	9.5	2014/15
M6 J10a to J13	ALR	16.0	2014/15
M60 J8 to J12	ALR	7.5	2014/15
M60 J12 to J15	ALR	5.0	2014/15
M62 J18 to J20	ALR	12.0	2014/15

As a result, the total English smart motorway programme encompasses 136 km of Dynamic Hard Shoulder either in operation or under construction plus an additional 161 km of All Lane Running, the first sections of which are due to go live in late April 2014.

5 CONCLUSION

The Highways Agency's Smart motorway initiative represents a fundamental rethink about how to provide additional highway capacity in a world where traffic levels continue adding to congestion and where there is growing public opposition to new highways and major widening.

Evidence from dynamic hard shoulder projects, both in the UK and elsewhere, has shown that they deliver demonstrable benefits in terms of safely and capacity of the network at significantly lower costs than widening. For these reasons, more and more road authorities are looking at hard shoulder running as a response to the need for more highway capacity whilst taking account of fiscal constraints and public opposition to road construction.

The complexity arising from a dynamic hard shoulder (driver understanding, density of technology, operational costs) has been a barrier to the deployment of dynamic hard shoulder running in certain countries. With its new Smart motorways All Lane Running design (whereby the hard shoulder is permanently converted to a running lane), the Highways Agency is taking the bold step of fundamentally rethinking the requirement for a hard shoulder within a managed road environment. Work completed to date suggests that such roads can safely deliver significant operational benefits at a fraction of the costs of widening and at a significantly reduced cost compared to dynamic hard shoulders.

Design and construction are essential elements to the success of a smart motorway scheme, but more fundamental is the consideration of how such sections will be operated and maintained. Designs should only start once there is a true operational understanding.

Essential to any change in the way a road operates is to communicate with drivers and road users to help them understand what to expect and what is expected of them. There is only so much that a design can do to eliminate or mitigate risk, the rest is down to influencing driver behaviour.

If the actual results match expectations, the ALR design could become commonplace in many countries as a solution to the ongoing challenges of reducing congestion in a cost efficient and environmentally acceptable manner.