Managed Motorways - Experience from the UK

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1 Abstract

Since the success of the 2004 “Advanced Traffic Management” pilot on the M42 east of Birmingham, the UK Highways Agency has deployed over 50 km of managed motorways (dynamic hard shoulder running, variable speed limits, lane signalling, etc).

The experience from these deployments 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 managed motorways has exceeded expectations, notably in terms of safety, and this has led the Highways Agency to consider how to deliver the objectives of managed motorways at an even lower cost.

This paper traces the history of managed motorways in the UK and describes currently thinking around the new “All Lane Running” design that features permanent conversion of the hard shoulder to a running lane. The paper concludes with a discussion about the potential implications of such innovative thinking for highway authorities in North America.

2 Introduction

Similar to most countries, congestion is a major issue in the United Kingdom where it is considered a drag on economic growth, an impediment to economic competitiveness, a contributor to air pollution, and a major public inconvenience.

Whilst the underlying causes of congestion are complex (urban form and land use patterns, transportation pricing and fuel taxation policies, cultural habits and working patterns, etc), the superficial problem remains that demand for road space outstrips supply. The true solution to the congestion problem therefore requires a combination of structural changes to influence the demand for private motorised transport but also short term policies to better match supply and demand during congested periods of the day.

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 restrictions on government spending are forcing many public agencies to consider alternate approaches that are less expensive to build and maintain and which respond to the aforementioned public concerns.

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 programme of managed 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.

3 The Managed Motorways Dynamic Hard Shoulder Running

3.1 The MM Dynamic Hard Shoulder Design

The initial Managed 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 - MM-DHS with Emergency Refuge Area

The generic Managed 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 next gantry before fully passing the gantry that precedes it)
- 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
- 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

On such MM-DHS schemes, motorists may 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- During the conditioning phase, the speed limit on open lanes is set to 60 mph and a "Red X" is shown over the hard shoulder to reinforce the fact that it remains closed to traffic.

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 – Once the hard shoulder is open, the speed limit is set to 60 mph (the default speed limit on UK motorways being 70 mph) or to a lower limit should conditions warrant

3.2 The Initial DHS Pilot and Results

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[1] and a notable a reduction in the "accident severity index from 0.16 to 0.07[2] (figures measured over the first 36 months of operation)
- a reduction of between in journey times during peak periods of 9% in the northbound carriageway and 24% in the southbound carriageway[3]
- a reduction of 22% in journey time variability[4]
- compliance with speed limits of 94% or better for speed limits between 50 and 70 mph[5]
- reductions of approximately 4% in CO, HC, CO_2 and NOX and of 10% in particulate matter[6]
- a marked improvement in the perception of long distance users of the level of service of the highway

3.3 DHS Deployments

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

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
Birmingham Box Phase 3 (M6 j5-8)	Under construction
M4/M5 (near Bristol)	Under construction
M1 J10 to 13 (near ??)	Under construction
M1 j28-31 (near ??)	Under construction
M62 J25-30	Under construction

3.4 DHS Operational Processes and Considerations

Criticality of being able to Open the Hard Shoulder

Once a managed 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.

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 and equalising speeds across lanes. Once the traffic is judged sufficiently smooth by the operator, the hard shoulder opening procedure is started.

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

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.

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 incident can generally be cleared sufficiently quickly so as not to unduly impact journey times and journey time reliability.

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.

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.

Ensuring Compliance

The risk of non-compliance is a major issue on managed 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)
- automatic dynamic speed enforcement equipment on selected gantries, backed up by mock enforcement cameras at other locations
- 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.

4 The "next generation" of Managed Motorways

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 Managed Motorways, but at a significantly reduced cost.

The key aspects of the challenge laid down were:

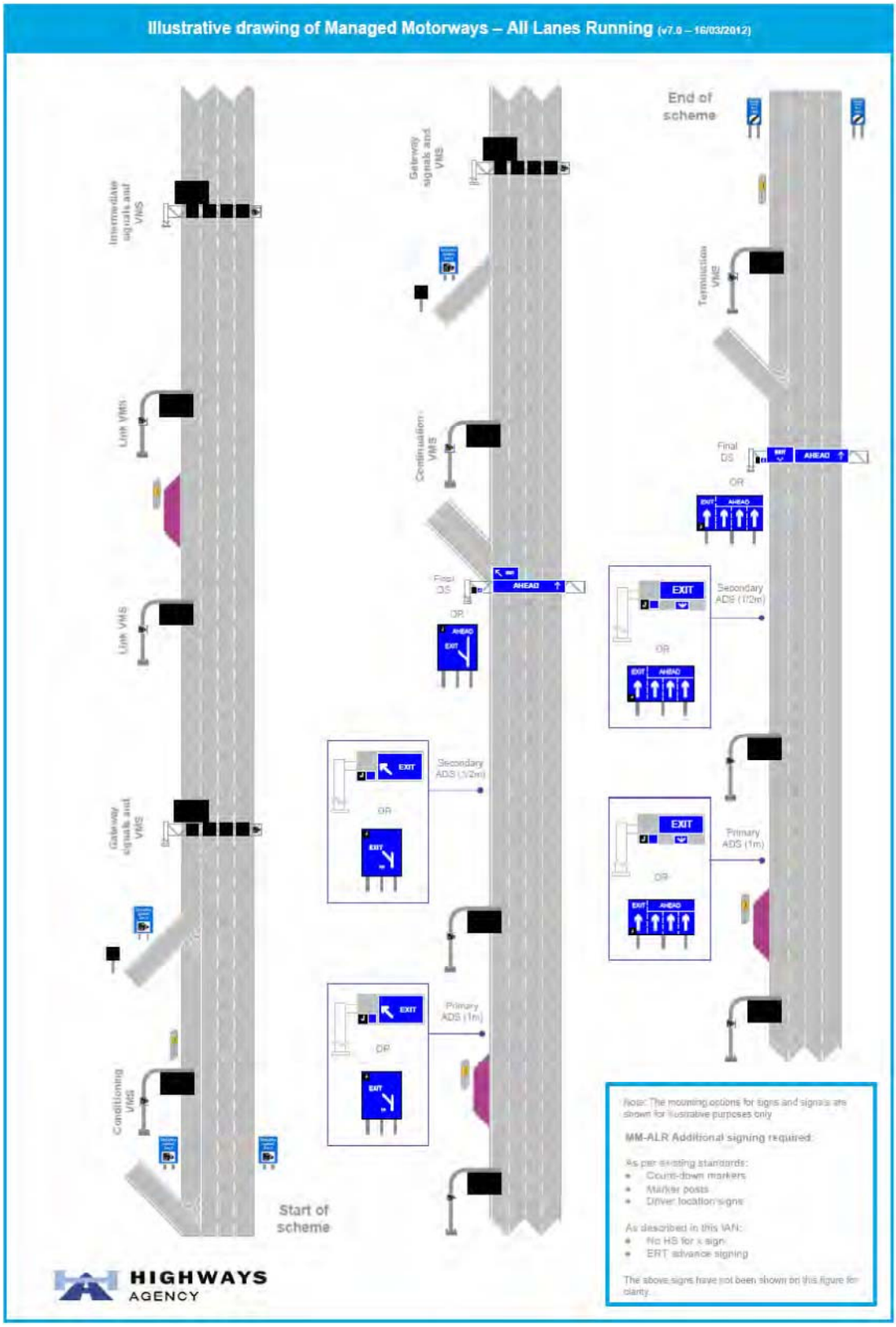
- Reduce whole life costs (including capital and operating costs) by 30%;
- Reduce the timescale for construction by 20%;
- Ensure no reduction in the safety performance (no increase in accident rate, using the 'SWAFR' metric[7]);
- Ensure no reduction in the journey time benefits being delivered by the MM-DHS design concept;
- Support the government's policy on "Supporting economic growth in a low carbon world".

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.

4.1 The Managed Motorways All Lanes Running Design

The key feature of the MM-ALR design is the permanent conversion of the hard shoulder to a running lane as opposed to the part time conversion of the hard shoulder under the old DHS design.

[7] 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



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 Traffic Management, or to assist with the recovery of vehicles or removal of debris during incident management.

The MM-ALR design includes variable message signs and signalling, at an approximately density of 1500 m (as compared to the 800 m under the MM DHS design), with the majority of the signs being cantilever mounted. This density of signing 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.

Creating and preserving the controlled environment on MM-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 managed 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).

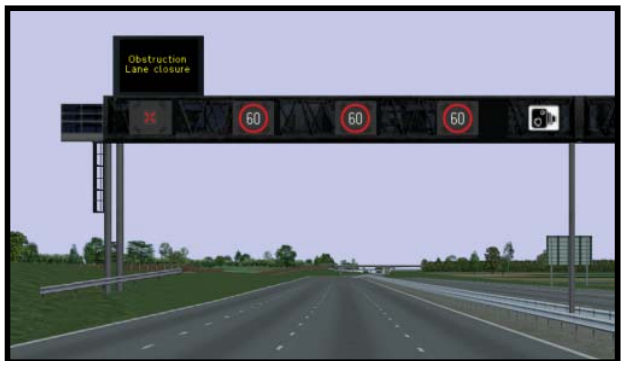


Figure 4 - MM-ALR Gantry mounted signalling arrangement

Figure 5 - MM-ALR Verge mounted signalling arrangement

4.2 Safety Considerations

Theoretical Review

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

The Highways Agency undertook a qualitative review[8] to test the safety of the new MM-ALR design. In particular, the Agency reviewed known 'existing' motorway hazards as well as 'new' hazards introduced by the MM-ALR design. The review concluded that the MM-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.

Driver Simulation

Many of the assumed safety benefits of an MM-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 6*) to test driver behaviour and response in an MM-ALR environment and to see how this compared to a DHS environment (for which there was significant empirical evidence available)[9].

[8] "Managed Motorways All Lanes Running – Demonstration of Meeting Safety Objective Report" – March 2012.
[9] TRL Report: "Future Managed Motorways Concept Development | Task 1: Design Comparison Simulator Study" – March 2012.

Figure 6 – Participant in the driving simulator study

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 'MM-ALR' route.[10]

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.

4.3 Cost Considerations

Capital Expenditure

The MM-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.

Operational Expenditure

The MM-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.

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.

[10] 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.

4.4 The MM ALR Programme

In November 2011 the Highways Agency announced that work will commence on a further twelve managed motorways schemes, with construction due before March 2015. These schemes are expected to be built to the MM ALR design.

5 Conclusion

The Highways Agency's Managed Motorway initiative represents a fundamental rethink about how to provide additional highway capacity in a world of growing public opposition to new highways and major widening and fiscal constraints that limit public agencies' ability to undertake such projects.

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 jurisdictions 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 jurisdictions. With its new Managed 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. Theoretical 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.

If the actual results match expectations, the MM-ALR design could become commonplace in many jurisdictions as a solution to the ongoing challenges off adding capacity in a fiscally constrained environment.