Dynamic Dimming: The Future of Motorway Lighting?

Andy Collins, Tom Thurrell, Robert Pink and Dr. Jim Feather report on a recent lighting installation in north Lancashire involving new methods of dimming and control

Andy Collins is Principal Lighting Engineer, Lancashire County Council; Tom Thurrell is head of corporate marketing at WRTL Exterior Lighting; Robert Pink is national sales manager of Royce Thompson; Dr. Jim Feather is a researcher at the Department of Optometry & Neuroscience, UMIST

The M65 in Lancashire is one the country's lesser known motorways, carrying only a fraction of the traffic of the busy M6 which it joins close to Preston. Running eastwards towards Yorkshire, the M65 provides access and bypass for the towns of Blackburn and Burnley and ends at Colne, just beyond Nelson. At its eastern end, the seven-mile, two-lane stretch from junctions 10 to 14 is under the ownership and management of Lancashire County Council (LCC).

Pic 1: The M65 at dusk

However, this small and relatively insignificant part of the national motorway system is at the heart of a pilot project that may revolutionise the way all motorways are lit in the future. In collaboration with WRTL Exterior Lighting, Royce Thompson and Peak Traffic Management Systems, LCC's Street Lighting Group recently replaced the lanterns along this stretch of road with a dimmable lighting system controlled by traffic flow. The scheme, the first of its kind to be implemented in the UK, was installed by Lancashire County Council Engineering Services.

Running in parallel with this scheme, research is being undertaken by the Optometry and Neuroscience Department of the University of Manchester Institute of Science and Technology (UMIST) into ocular stress whilst driving at night. Measurements made on the M65, under different lighting levels, have produced important information on the relationship between ocular stress and motorway lighting.

Taken together, these developments are expected to produce significant energy savings for LCC, contribute towards Government targets in the reduction of CO2 emissions -- and lead ultimately to safer night-time driving conditions on UK motorways.

Historical Background

LCC maintains the largest number of street lighting installations of any Highway Authority in the UK. Its innovative policies in street lighting were established in the late '90s when the Street Lighting Group installed dimmable lighting on the A671 Whalley Eastern By-Pass. This was the first scheme in the UK to be so equipped, and the successful outcome of this project made an important contribution to the development of LCC's energy strategy at the time.

In 1998, LCC's Highways and Transportation Committee decided, as a matter of policy, that all traffic route schemes should incorporate dimming capability. It also authorised the use of new technology – e.g. electronic control gear within all new lighting equipment - – as and when it became available.

Energy Efficiency Leaders

LCC's leading role in lighting innovation and energy management was recognised in November 1999, when it became the first Highway Authority to achieve Energy Efficiency Accreditation Status. This award is conferred by the Institute of Energy and is recognised as the national benchmark standard in energy management. Subsequently, the Street Lighting Group won the Major Energy Users Council's 'Best Energy Strategy' Award at the Energy Awards in September 2000(1).

Energy Strategy and Management

Between 1997 and 2001, a number of events and developments contributed to demands for better energy management by major consumers, including local authorities. These included:

- The Kyoto Protocol and the subsequent Climate Change Levy introduced by the UK Government
- Load Research and Power Factor Measurements on Unmetered Supplies
- The introduction of 'Best Value'as a statutory obligation for all local authorities

All of these created pressure to reduce energy use, improve energy efficiency and encourage energy conservation(2). Due to these pressures, LCC entered discussions with electronic control gear manufacturers whose equipment was able to offer LCC a number of advantages, including a reduction of circuit wattage and the ability to achieve near unity power factor correction, thereby lowering energy consumption.

Technological Developments

The system chosen for this project was Royce Thompson's Elgadi electronic control gear, complete with power line modem, and the Horus street lighting control system. Elgadi incorporates a high frequency electronic ballast for high pressure sodium lamps from 50W to 250W. This means that it can offer reductions in gear losses, an improvement in power factor and longer lamp life. Dimmable down to 30%, the system requires no external igniter and maintains constant lamp power within a stable spectrum. Built-in features also include an intelligent controller and two-way remote communication facility.

Pic 2: Royce Thompson's Elgadi control gear unit

Pic 3: The Horus control unit

Horus, named after the Egyptian God of sky and light, combines with Elgadi to provide a total street lighting management system. This allows for activated lighting, dimming control by time and traffic flow, with peak saving and tele-metering capabilities. Luminaires can be individually controlled, faults identified and maintenance data recorded to ensure complete and constant control of the lighting operation.

Lighting Design

With increasing environmental awareness, and conscious of the need to provide appropriate levels of lighting for its roads, LCC also turned its attention to lighting designs. This involved closer examination of lighting standards and classes by reference to the new, but as yet unpublished, CEN Road Lighting Standard prEN13201. Traditionally, the choice of lighting class has been based on peak hour traffic volumes, when the driver's visual task is most demanding. However what was considered appropriate during these periods may be excessive for lower traffic volumes. The use of changing technology provided the opportunity to select a lower, more appropriate lighting category, for which dimming was the obvious solution.

The M65 Project

The opportunity to put dynamic dimming into practice came with the requirement to renew the lighting on the two-lane Burnley-Colne stretch of the M65. Management of the scheme became the responsibility of Principal Lighting Engineer Andy Collins.

Pic 4: LCC Principal Lighting Engineer Andy Collins on the M65

The idea was originally conceived in Holland and published in the paper 'Dynamic Public Lighting' in 1999(3), which proposed the concept of optimising motorway lighting efficiency by means of dimmable

Lantern	Carriageway				Hard Shoulder			Slip Roads			
	L_{av}	U_0	U_L 1	U_L 2	L_{av}	U_0	U_L 1	L_{av}	U_0	U_L 1	U_L 2
180 w SOX LTI	2.64	0.49	0.85	0.88	1.17	0.76	0.88	2.08	0.46	0.88	0.79

Table 1: average lighting levels under the old lighting scheme

lighting controlled by traffic flow. The aim of the M65 project was to replace the existing luminaires and control system with equipment that would link the level of lighting to the traffic flow, reduce power consumption by the use of electronic control gear, improve the power factor and provide monitoring for lamp defects.

Previous dimming schemes had been based purely on switching controlled by darkness levels and time of day. While traffic flow measurement equipment was in place on the M65, it had not previously been used in connection with lighting level control.

The old lighting consisted of approximately 700 LTI luminaires, mounted at 12 metres on the main carriageway and 10 metres on the slip roads. These had reached the end of their useful life, although the columns and electricity supply network were sound. This arrangement provided the average lighting levels shown in ***Table 1***.

However, the light was not very well controlled, with TI in excess of 15%, so that a significant proportion of light fell outside the hard shoulders and beyond the highway boundary. The motorway is visible at night from a great distance and lies primarily within an unlit area. This significant proportion of upward light produced by the LTI luminaires contributed to a high level of light pollution in the locality.

The lighting was controlled by a photocell at each feeder pillar, with each section supplied by the pillar switching on and off through a contactor. The same lighting levels therefore applied constantly throughout the night.

Lighting Level on Renewal

LCC's policy required that the recommended lighting class be applied during the busier periods, and reduced to approximately 50% during periods when traffic volumes considerably lower. It also stipulated the use of full-cut-off (flat glass) luminaires, in order to reduce light pollution in all its forms. The selection of the lighting class was determined utilising the CEN prEN 13201-1, which provides more detailed guidance on selection than BS5489, through the use of various new parameters. One of these is traffic flow – and detailed information on this was available for the M65 from the permanently installed traffic counters.

The significant parameters and their values for the main carriageway of this road are:

Separation of carriageways	Yes
Interchanges	Yes – some less than 3km interval
Traffic flow both ways/ 24 hour average	More than 25000 vpd – on busiest section
Complexity of visual field	Normal
Difficulty of navigational task	Normal
Ambient brightness level	Low

These parameters lead to a range of classes [ME3a; ME2; ME1] with a final recommendation of Class ME2. This specifies the following technical requirements for road surface luminance:

Average Luminance = 1.5 cd/m² U_O = 0.4 U_L = 0.7

In choosing new lanterns, LCC instigated a tender process based on a points system, with 60% related to performance and 40% to price. Four different manufacturers' products were considered and the final choice was the 150w Vectra luminaire from WRTLExterior Lighting.

Pic 5: the Vectra lantern from WRTL

Design calculations incorporating the Vectra produced the following results summarised in ***Table 2***.

These show clear benefits in comparison with Table 1. The previous installed load of 153.4kW has been reduced to 116.6kw, a 24% reduction, which will be further enhanced when the control gear is operating at its full potential.

Lantern	Carriageway				Hard Shoulder			Slip Roads			
	L_{av}	U_0	U_L 1	U_L 2	L_{av}	U_0	U_L 1	L_{av}	U_0	U_L 1	U_L 2
WRTL Vectra 150w SONP/T Flat Glass	1.49	0.62	0.82	0.85	0.83	0.73	0.89	1.45	0.62	0.73	0.77

Table 2: lighting levels with the new lighting scheme

Dynamic Lighting

The data from the traffic counters is relayed to each of the seven feeder pillars, incorporating the Horus control system and hence to the Elgadi electronic ballast complete with a power line modem in each lantern. Therefore traffic flow is being continuously monitored and the lighting level is adjusted to preset levels, depending on the flow. The traffic flow is determined for the busiest section of the Motorway, namely junctions 11-12, with the lighting level applied to the complete section (i.e. junctions 10-14).

There are three lighting levels based on traffic flow: full brightness and two dimming stages according to the average number of vehicles passing over a half-hour period.

Vehicles per Hour	**Lighting Level**
>3000	100%
3000-1500	75%
<1500	50%

The system incorporates 'soft' switching when reducing from one level to another, so that light variation is gradually adjusted to the lower level without sudden changes.

Having planned and installed dimmable lighting based on traffic flow primarily for the purposes of energy conservation and environmental improvement, it was decided to examine the new system from the perspective of the driving experience and road safety.

Driver Comfort and Safety

In 1999 research began in the Department of Optometry and Neuroscience at UMIST into the eye's response to glare from bright lights. Initial funding for the work was provided jointly by WRTL and the UK Government under the LINK scheme. When this ended, WRTL funded further work into the effects of motorway lighting on the eye(4) [a summary of some of this research can be found in ***Lighting Journal***, July-August 2002, page 20].

An instrument to measure ocular stress was developed, the UMIST Ocular Stress Monitor (OSM). This measures the electrical activity (EMG) of the orbicularis muscle, a large muscle which surrounds the eye. This muscle, together with the pupil, reacts to changes in the light level falling on the eye, to ensure that the amount of light entering the eye is as constant as possible. The OSM is portable and can be used on location.

There is no doubt that lighting a motorway improves driver comfort. It has, however, been shown (Murray et al, 2002) that the flickering or strobing effect of overhead lights on the driver's eyes as he travels at high speed along a lit motorway contributes to ocular stress. This phenomenon has been termed Dynamic Discomfort Glare. Higher levels of ocular stress make driving more uncomfortable, which in turn is likely to impact directly on road safety.

Trials to investigate the effect of this flicker at different road lighting levels were undertaken on the M65. Measurements of ocular stress were made with the OSM over the same stretch of road, with the lighting set at three different levels (100%, 70% and 50%). A further test was made (at 100%) with the vehicle's sun visor lowered, to shield the driver's eyes from the overhead lights. Measurements of vertical illuminance on the driver's face were made with a calibrated photo-diode. Traffic volume was very light and the effect of glare from oncoming car headlights was therefore discounted. Each reading shows the difference in EMG between the muscle's resting state and that measured during each journey. The results are shown in ***Table 3***.

Light Level	EMG Difference (travelling – resting)	Reduction
100%	5.11	
70%	4.38	- 14%
50%	3.96	- 23%
100% (visor down)	1.36	- 73%

Table 3: difference in EMG under different lighting states

This data demonstrates that, on a quiet motorway, reducing the luminance of the overhead lights results in a measurable reduction in ocular stress, as recorded by the EMG of the orbicularis. A 30% reduction in the lighting level caused a 14% reduction in the EMG value, while a 50% reduction in lighting level gave a 23% reduction in the EMG. Driver comfort is therefore improved with each reduction of lighting level. Lowering the sun visor produced the biggest improvement, a massive 73% fall in EMG.

It should be noted that other factors, in addition to vertical illuminance at the driver's face, are likely to influence ocular stress. UMIST's continuing research programme, supported by WRTL, aims to measure horizontal illuminance and road luminance, to further improve the understanding of the relationship between road lighting and ocular stress of a driver.

Lighting	CO_2 Emissions (tonnes)	Carbon (tonnes)
Old Scheme	274	75.7
Lantern Change Only	208	56.7
Traffic-Flow Profile Applied	129	35.1

Table 4: estimated reduction in CO_2 emissions and carbon using the new scheme

Summary

The use of electronic control gear on the M65 project has proved the most effective way of achieving multiple lighting levels. It also reduces electricity consumption compared with conventional control gear at all levels, maintains consumption at the same level throughout life, consistently provides close to unity power factor, and provides extended lamp-life.

Lantern changes have reduced the installed load by 20%. By linking lighting level to traffic flow, it is estimated that the load will reduce by a further 25-30%. The combination of appropriate lighting levels and the use of the latest technology offers a significant reduction in energy usage, and the related reduction in greenhouse gas emissions.

In terms of measurement of electricity consumption, the assessment method, using notional circuit watts and operating hours, is no longer possible with a 'dynamic lighting' system. Following consultation between United Utilities Metering and LCC's Energy Consultant, meters will be installed in each of the seven feeder pillars on the M65 scheme in order give true consumption readings.

Benefits

The M65 project will result in a number of benefits for Lancashire County Council, its residents and council tax payers, and all motorists who use the road in the future.

- Reduction in Energy Consumption
  The effect on annual energy consumption will be a reduction from 637,377kWh per annum to 484,581kwh – a saving of 24%.

However, if the traffic-flow profile is now applied at the three lighting levels to the load characteristic of the Elgadi ballast, the annual consumption estimate falls to 300,000kWh, representing a reduction in excess of 50%.

- **Cost Savings**
  Based on a unit cost of 4.2p/kWh (energy + use of system cost) the estimated energy cost for the relevant section of the M65 with the old lighting system was £26,769 per annum. It is now £12,600 with the traffic flow profile applied.

- **Environmental Benefits**
  The reduction in energy consumption on the M65 is an important part of LCC's contribution to the achievement of Government targets in the reduction of CO_2 emissions. Longer lamp life also helps to conserve other resources in the longer term; and dimmed lighting assists in lowering light pollution levels.

Table 4 illustrates the environmental benefits of the scheme.

- **Driver Comfort and Safety**
  The research by UMIST indicates that significant improvements in driver comfort are obtained where dimmable lighting is installed. While not specifically measurable, it is likely that general road safety is improved by reducing ocular stress, enabling motorists to remain more alert and reduce the risk of accidents.

Conclusion

As the first motorway in the UK to incorporate traffic-controlled dimming, the M65 project represents both a pioneering achievement and a model for future motorway lighting development. With ever-increasing pressure on public bodies to save energy and limit environmental damage, it is likely that dimmable lighting will become a much more common feature of our motorways in the future. Further developments in both lantern and control gear technology can be expected to bring increasing refinements in motorway lighting systems, while ongoing research into the comfort and safety aspects of motorway lighting should eventually contribute to improved road safety.

References:

1 ***A.Collins/K.Postlethwaite: 'Lancashire Strategy Wins Major Award',*** Lighting Journal***, November/December 2000***
2 ***A.Collins/K.Postlethwaite: 'Energy Strategies for Street Lighting – Creating Better Value?',*** Lighting Journal***, May/June 2000***
3 ***'Dynamic Public Lighting', Ministerie van Verkeer en Waterstaat, March 1999.***
4 ***'Measurement of Ocular Stress on the M65 Motorway', UMIST 2002***

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