MODELLING DRIVER BEHAVIOUR AT ROADWORKS

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1 INTRODUCTION

1.1 Background

SIAS Ltd (SIAS) has been commissioned via the Scottish Road Research Board (SRRB) to investigate the modelling of driver behaviour at road works.

The problem, simply stated, is that whilst the layout of many Traffic Management (TM) configurations does not significantly differ from "normal" layouts (for example, a merge from two lanes to one lane), the throughput observed can differ dramatically. The reasons for this appear to lie in driver behaviour. This study is about furthering an understanding of what factors are in play and how they can be better modelled.

1.2 Purpose

There has been very little practical information about how driver behaviour, and the resulting impact on traffic conditions, differs with TM in place. The purpose of this research is to try and address this shortfall by providing:

- an initial examination of the underlying issues involved in modelling driver behaviour at road works
- some initial ideas about how to positively influence driver behaviour at road works to improve traffic conditions
- guidance for the modelling of TM at road works, with a view to this guidance being adopted when examining such schemes on behalf of Transport Scotland

1.3 Modelling Roadworks

Traffic modelling is a valuable tool for predicting the impacts of any TM associated with road and structures maintenance and construction.

TM is provided at roadworks principally to protect contractors and plant operating on the site. Its secondary function is to control traffic through the road works. Advanced warning signage ahead of the roadworks informs drivers of the works ahead and any action to take.

Modelling provides information about potential delays prior to the implementation of TM at roadworks. This information can be relayed to the general public enabling drivers to make informed decisions about re-routeing to avoid the proposed works, changing mode, or not travelling at all. Modelling can also allow the proposed TM layout to be optimised prior to implementation to ensure that delays are minimal.

In order to accurately model the impacts of TM at roadworks it is critical to have an understanding of how driver behaviour may differ from "normal" circumstances.

The manner in which drivers perceive the TM situation, and the resulting behaviour differs from the behaviour observed in “normal” circumstances such as on approach to merge tapers at the end of D2AP or WS2+1 sections. The reasons for this apparent difference are not well understood despite the very great impact it can have on capacity, delays, safety and emissions.

2 DRIVER BEHAVIOUR AT ROADWORKS

2.1 Background

SIAS was commissioned by Transport Scotland (TS) to undertake traffic modelling to support the development of a major maintenance strategy for the structures on the M8 between Baillieston and Hillington. The modelling was carried out using the Clyde Strategic Microsimulation Model (CSMM), developed by Transport Scotland.

The development of the CSMM is detailed in the Clyde Strategic Microsimulation Model; Model Development Report (SIAS Ref; 73606, March 2011).

The CSMM is used as the platform for the testing of proposed roadworks scenarios in a number of future years. Before undertaking any testing, TS requested that the approach was ‘validated’ by using the system to model a previous works scenario (Arkleston Bridge Strengthening Works) and compare the resulting traffic flows and conditions with observed data. This validation exercise retrospectively examined the impact of the Arkleston Bridge Strengthening Works, comparing the observed impact with the modelled impact predicted using the CSMM.

More information about this validation exercise is detailed in Information Note 12: Maintenance Forecasting Verification (SIAS Ref; 73888, August 2011).

2.2 Traffic Management Details

The Arkleston Bridge Strengthening Works took place between 17th July and 8th September 2009. TM measures were implemented on the Whitecart Viaduct on both the eastbound and westbound carriageways for the duration, with full closures and associated diversions implemented where appropriate during night works.
The eastbound TM included:

- Temporary Speed limit of 40mph from J29 to approx. 500m east of J27 EB on slip
- Reduction of the main carriageway from 3 lanes to 2 lanes from approx. 300m west of J28 to approx. 500m east of J27 EB on slip.
- The westbound TM included:
- Temporary Speed Limit of 40mph from approx. 500m west of J26 WB on slip to approx. 350m west of J27 WB off slip
- Reduction of the main carriageway from 3 lanes to 2 lanes from approx. 500m east of J27 to approx. 350m east of J27 WB off slip
- Cylinders added to the J26 on ramp to prevent early merging – effective length of ramp reduced by around 2/3rds.

Figure 2.1 shows the TM on the Whitecart Viaduct during the Arkleston Bridge Strengthening Works.

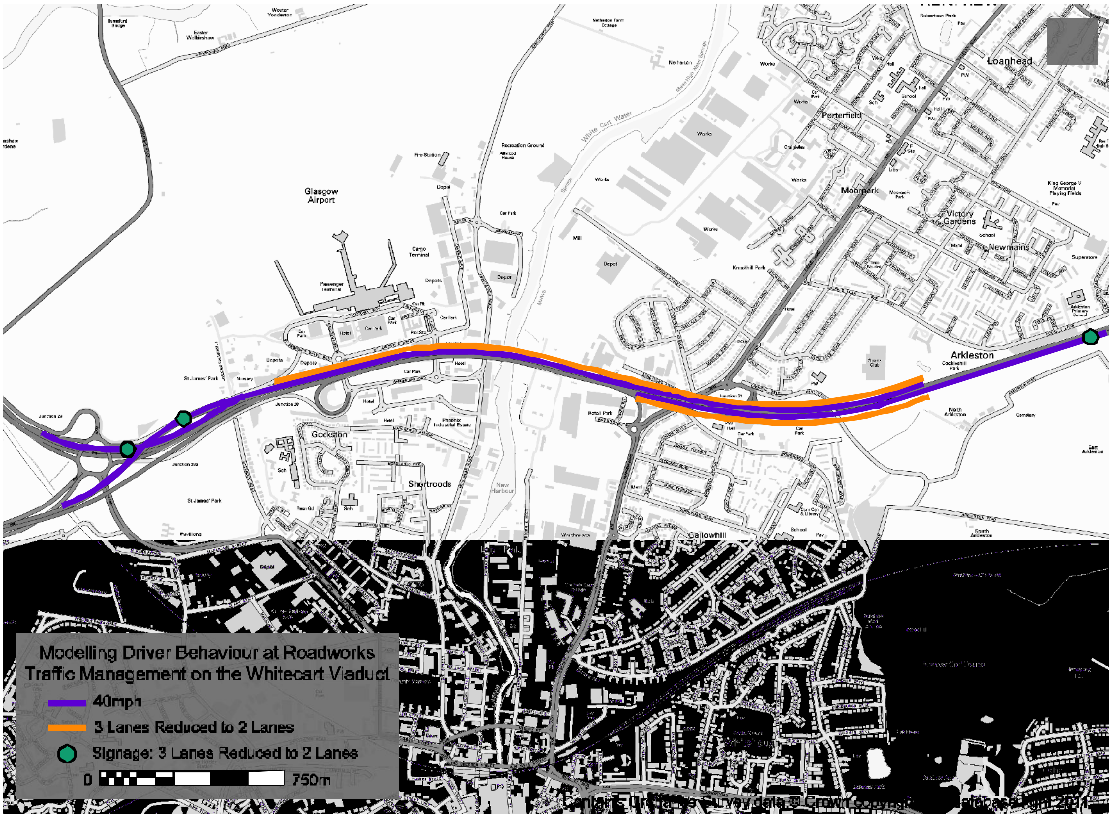

Figure 2.1 : Traffic Management on the Whitecart Viaduct

2.3 Traffic Management Impact

Count data from the permanent Automated Traffic Count (ATC) sites within the study area was provided from TS's Scottish Road Traffic Database (SRTDb). Data was provided for the period January 2006 to February 2009 where available. Further data was provided for the area local to the Arkleston Bridge Strengthening Works for the remainder of 2009.

In order to establish the impact of the roadworks on traffic conditions, speeds from the ATC sites in the locality of the works were provided in addition to the count data.

The traffic counts showed that flows decreased significantly during the roadworks, most notably eastbound in the AM peak hour and westbound in the PM peak hour.

2.4 Observed and Modelled Flows and Speeds

Modelled flows and speeds at locations equivalent to the ATC sites in the scheme locality were extracted and compared with the observed data.

Table 2.1 and Table 2.2 show comparisons between observed and modelled flows for the AM (08:00-09:00) and PM (17:00-18:00) peak hours, at the locations included in Table 2.1 and Table 2.2.

Description	Observed	Modelled	Diff (abs)	GEH
Eastbound				
M8 Eb West of J29	1530	2230	699	16.1
A737 Nb to M8 Eb	1850	2316	466	10.2
M8 EB before J28	2778	4146	1368	23.3
M8 J27 off ramp Eb	299	629	330	15.3
M8 J27 on ramp Eb	729	490	-240	9.7
M8 Eb J27 - J26	4022	4308	286	4.4
Westbound				
M8 Wb J26 - J27	3527	3513	-14	0.2
M8 Wb J28 Off slip	647	875	228	8.3
M8 WB J28 - J29	2698	2754	56	1.1
M8 Wb to A737 Sb	900	826	-74	2.5
M8 Wb off slip to J29	473	482	9	0.4
M8 Wb through J29	1244	1407	163	4.5

Table 2.1 : Observed/Modelled Flow Comparisons; 08:00-09:00

Description	Observed	Modelled	Diff (abs)	GEH
Eastbound				
M8 Eb West of J29	2270	2207	-63	1.3
A737 Nb to M8 Eb	1032	1147	115	3.5
M8 EB before J28	2738	2836	98	1.9
M8 J27 off ramp Eb	565	513	-52	2.2
M8 J27 on ramp Eb	601	709	108	4.2
M8 Eb J27 - J26	3365	3517	152	2.6
Westbound				
M8 Wb J26 - J27	3488	4772	1283	20.0
M8 Wb J28 Off slip	410	596	186	8.3
M8 WB J28 - J29	3831	4587	756	11.7
M8 Wb to A737 Sb	2104	2354	250	5.3
M8 Wb off slip to J29	360	493	133	6.4
M8 Wb through J29	1290	1658	368	9.6

Table 2.2 : Observed/Modelled Flow Comparisons; 17:00-18:00

Figure 2.2 shows the observed and modelled flow on the M8 eastbound, west of J29.

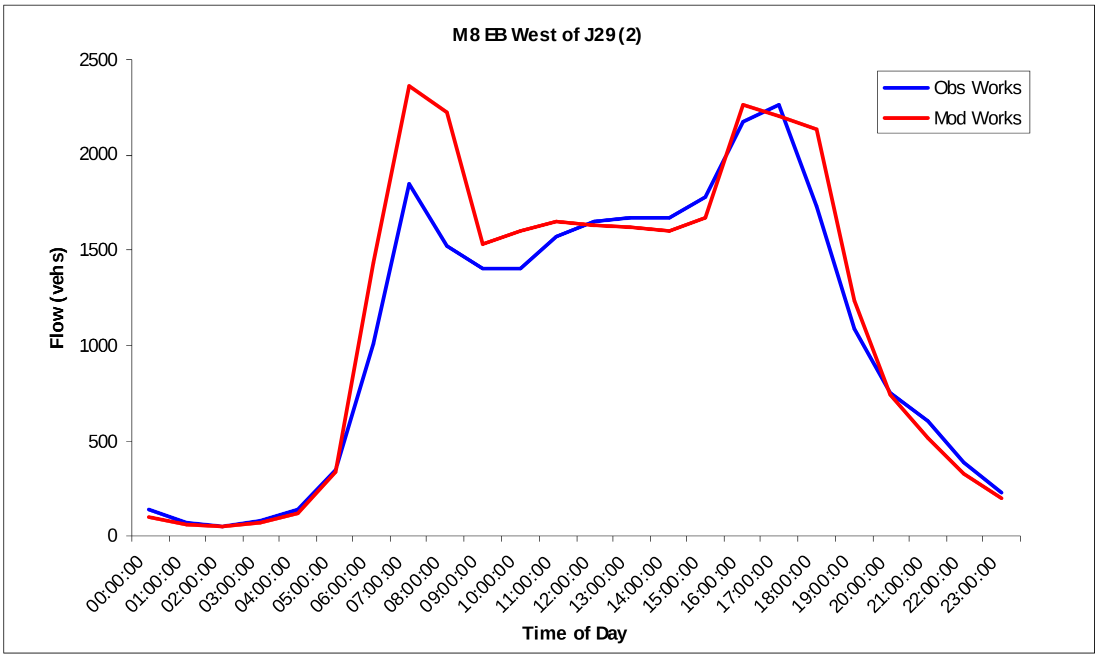

Figure 2.2 : Flow Comparison – M8 eastbound, west of J29

Figure 2.2 shows that in the IP and PM periods the modelled flows match well with the observed. In the AM period the modelled flows are significantly higher than the observed.

Figure 2.3 shows the observed and modelled flow on the M8 westbound between J26 and J27.

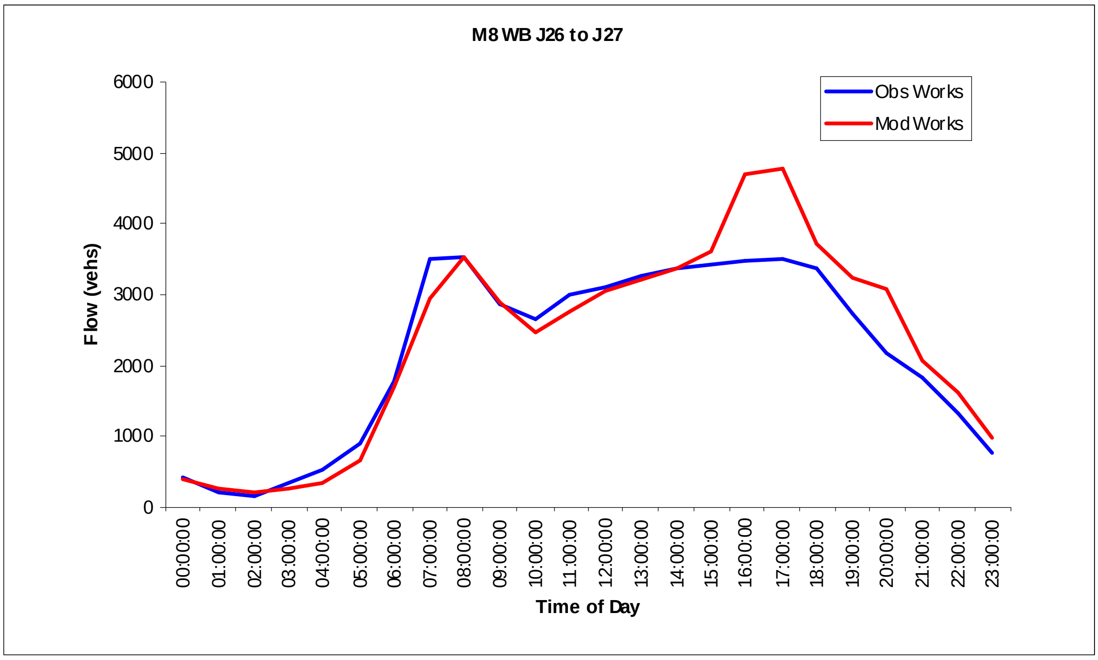

Figure 2.3 : Flow Comparison – M8 westbound between J26 and J27

Figure 2.3 shows that in the AM and IP periods the modelled flows match reasonably well with the observed flows. In the PM period the modelled flows are higher than the observed.

2.6 Observed Driver Behaviour

One of the first questions which the discrepancy between observed and modelled flows and speeds on the Whitecart Viaduct during the Arkleston Bridge Strengthening Works poses is whether the observed driver behaviour is typical for this type of TM scenario.

Table 2.3 and Table 2.4 suggest that it is. Table 2.3 presents the mean open-lane capacities for different combinations of lane closure as taken from the Highway Capacity Manual 2004. Table 2.4 presents the mean open-lane capacity for the Arkleston Bridge Strengthening Works Case Study.

Table 2.3 : Mean open-lane capacities for different combinations of lane closure

No. of lanes				
Total	Open	% of total lanes available	Average capacity (vphpl)	% capacity reduction from notional 2000 vphpl
4	3	75%	1520	-24%
3	**2**	**66%**	**1490**	**-25%**
4	2	50%	1480	-26%
2	1	50%	1340	-33%
5	2	40%	1370	-31%
3	1	33%	1170	-41%

Table 2.4 : Mean open-lane capacity for Arkleston Bridge Strengthening Works Case Study

Total	Open	% of total lanes available	% capacity reduction from pre-works situation
3	**2**	**66%**	**-21.75% (Mean)**
			-55% (Max)*
			-5% (Min)**

** M8 J27 off ramp EB*
*** M8 Eb West of J29*

According to the Highway Capacity Manual 2004 the average capacity reduction with 2 lanes open from a total of 3 lanes is 25%.

The observed data from the Arkleston Bridge Strengthening Works Case Study shows an average capacity reduction with 2 lanes open from a total of 3 lanes as 21.75%.

This similarity between these average % decreases in capacity suggests that the impact on traffic flow of the TM during the Arkleston Bridge Strengthening Works is typical of the impact of the same TM in other locations.

The evidence above suggests that the traffic theories underlying existing models lead to over-estimates of capacity at roadworks. For example, when faced with a TM situation in which traffic is expected to merge into a reduced number of lanes, transportation engineering theory might predict that the available lanes will become fully occupied on an ‘All Or Nothing’ (AON) basis. Individual drivers will elect to travel in the lane that has the lowest cost to them in terms of various economic factors such as travel time. The individual driver, faced with a choice of lanes to travel in, will choose a different lane whenever the travel time (or other cost variable(s)) of remaining where they are become exceeded, and will continue to change lanes as long as cost is optimised. By these simple means the traffic stream will organise itself such that all available lanes will become maximally loaded.

As Table 2.3 indicates, this is not the case in practice. The effects observed in real-life situations are non-linear and strongly hint at other, more complex processes being in play. In particular, a simple approach to behaviour at road works does not take account of:

- The fact that drivers do not have complete information on cost variables such that they can make an optimum decision
- Even if they did have complete information, an optimum decision at an individual level will be guided by other motivations and objectives, and may not be optimal from a transportation engineering perspective
- The TM situation represents a change in the perceptual environment and this, in turn, interacts with driver's expectations, allocation of attention and decisions about expected and required behaviour
- Driver behaviour at the collective level of the total traffic stream effects how individual drivers will behave
- Behaviours taking place in a TM situation are culturally embedded (i.e. cars that are arranged in a line are in a queue and there are expected norms and standards of behaviour governing how people 'should' queue)

The following sections provide an initial exploration of these issues.

3 HUMAN FACTORS

3.1 Background

Human Factors is a well established scientific discipline that seeks to use knowledge on human capabilities and limitations to design artefacts, entities and entire infrastructures for human use. Research into driver behaviour forms a substantial part of the field.

The following review takes as its structure a form of timeline. It deals with the factors that influence driver behaviour before and on the approach to a Traffic Management (TM) situation as it is during these phases that the problem of reduced capacity seems to arise.

3.2 Driver Behaviour before Roadworks

3.2.1 Unwritten rules of the road

Driver behaviour is partly governed by so called 'norms' or collective expectations "that define the boundaries of appropriate social behaviour in particular settings" (Antony, Manstead & Semin, 1996). Collective similarities in driver behaviour are well established in the scientific literature: sounding the horn to communicate annoyance to other road users is more prevalent in Greece and Turkey than it is in Finland and Sweden (Warner et al., 2011), for example, or fewer 'aggressive violations' are performed by Finnish, British and Dutch drivers compared to those in Iran (Lajunen, Parker &

Summmala, 2004). The wider collection of norms that help to define the boundaries of social behaviour in all its aspects is referred to as culture. Culture is formally defined as:

"The system of information that codes the manner in which [drivers] in an organised group [traffic stream] interact with [other drivers] and [the road] environment" (Reber, 1995, p. 177).

3.2.2 Driving behaviours are contagious

Driving is a 'social' activity performed in close proximity to, and to varying degrees in close cooperation with, other drivers (Fleiter, Lennon & Watson, 2010; Stradling, 2007). In motorway driving in particular the presence of other drivers is very important. Research shows that a large component of driver situational awareness is devoted to the behaviour of other motorists (e.g. Walker, Stanton & Chowdhury, 2012;Paster, Tajero & Roca, 2006).

If other motorist's behaviour in this environment is important then so are the expectations and beliefs about how those 'other people' view 'your' behaviour. This has been shown to have an important inhibiting or amplifying effect on behavior referred to as conformity:

"the tendency to allow one's opinions, attitudes and actions and even perceptions to be affected by prevailing opinions, attitudes, actions and perceptions" (Reber, 1995, p. 152)

Conformity can be a more powerful determinate of driver behaviour than other environmental, engineering and even enforcement-based interventions (Havarneanu & Havarneau, 2012; Edwards, 1999). Conformity-based behaviours can be seen in numerous transport studies. Drivers behave differently approaching junctions when following, or being followed, by others; they tend to go faster and brake later (e.g. Sato & Akamatsu, 2007). On congested motorways, the influence of surrounding traffic gives rise to inadequate speed adaptations in poor weather because drivers 'feel under pressure from other drivers to keep up' (Edwards, 1999). Some forms of social pressure work in favourable inhibiting directions (e.g. people that the driver knows, such as passengers, tend to inhibit speed; Fleiter, Lennon & Watson, 2009) but in other situations, with 'anonymous other drivers', it has the reverse effect (e.g. early-merging in response to upcoming TM).

At a larger scale, conformity interacts with cognitive biases to create situations where maladaptive behaviours become 'contagious'. For example, research has shown that as roads become more congested the average amount of time individuals spend overtaking other motorists is less than the average time other motorists spend overtaking them (Walton & Bathurst, 1998; Redelmeier & Tibshirani, 1999),. This leads to the perception that other travel lanes are moving faster. Conformity sees drivers seeking to match their speed with others, which those 'others' also perceive, hence the entire traffic stream tends to speed up. Similar 'contagion effects' are evident for other driver behaviours such as blocking late mergers from joining a queue etc.

3.2.3 – Driving is an 'expressive' activity

At the root of contagion models of behaviour is the need to conform to what are perceived as acceptable standards of behaviour and to avoid the negative consequences of ‘social rejection’. In a transport context social rejection would take the form of a breakdown in cooperative behaviours: other drivers reject attempts to change lanes, will demonstrate negative feelings, become aggressive and so forth. Social rejection brings with it negative feelings of embarrassment and a mismanaged self-presentation in which other drivers will make ‘errors of attribution’. Attribution is defined as:

“A tendency of people observing the action of another to interpret those actions as a sign of or as resulting from an internal disposition or trait” (Reber, 1995, p. 68).

Because of attribution, drivers will follow large trucks at shorter headways based on “a popular belief that truck drivers (being professionals and having their livelihood depend on their driving, or more accurately, their accident avoiding skills) are less likely to misjudge any situation, anticipating and ‘reading’ the road far earlier and more accurately than any car driver.” (Brackstone, Waterson & McDonald, 2008, p. 140). Attribution also explains why the perceived status of the ‘horn honker’ (an attribution based on the vehicle being driven) determines the length and duration of the ‘honk’ (Doob & Gross, 1968) and why popular driving stereotypes based around the vehicle being driven exist.

Drivers actively seek to avoid aversive emotions such as embarrassment or aggression. To do this they seek to control the way other drivers perceive them by exhibiting some behaviours (i.e. conforming to what the rest of the traffic stream is doing) whilst suppressing others (i.e. ignoring instructions to do something different such as ‘late-merge’). This phenomenon is not well studied in the driving domain but it is certainly the case that the need to project a particular image of oneself through particular driving behaviours is undertaken to avoid failures in self presentation. This offers an explanation for the reluctance of drivers in TM situations to late-merge: they do not want to be perceived as ‘the type of driver’ who would do that.

3.3 Driver Behaviour on Approach to Roadworks

The approach to TM sites sees the various latent driver behaviour factors resident in the traffic stream become active. Driver’s situational awareness prepares them to take notice of what other traffic is doing (this being a major component of situational awareness in motorway settings), with norms and expected standards of behaviour encouraging some behaviours and inhibiting others. Driving style preferences towards greater (rather than lesser) speed influences the behaviour of other drivers, who ‘feel under pressure from others’ due to low levels of social resistance. Social norms that dictate acceptable behaviours in queuing situations also come into play with drivers trying to avoid ‘social exclusion’ and ‘attribution errors’. As a result, despite engineering interventions such as signs, and enforcement interventions such as speed cameras and police patrols, the typical situation is one where drivers move into a desired travel lane too early – the so-called ‘early merge’ phenomenon - thus reducing capacity and throughput significantly. This section provides psychological insights into why drivers do this.

3.3.1 Effects of congestion

TM typically creates congestion. This has the effect of placing more ‘other drivers’ in closer proximity, thus activating powerful social processes which affect behaviour. In addition, driver’s intentions to perform desired behaviours are increasingly limited by the proximity of other vehicles and a more crowded road-space which, psychological theory informs us, leads to elevated levels of frustration within the traffic stream (Baron & Richardson, 1994; Shinar, 1998). Anger and aggression in driving is common. When surveyed, in the region of 80-90% of drivers reported some form of aggressive behaviour, from sounding the horn through to chasing other drivers (e.g. Parker, Lajunen & Stradling, 1998; Underwood et al., 1999).). The second condition is referred to as ‘aversive arousal’ or the experience of negative emotions and the way this leads people to avoid or react to situations that give rise to them. One of the principle ways in which congestion and queuing at TM sites gives rise to ‘aversive arousal’ is in respect to elevated levels of anxiety, some key reasons for which are reviewed in the next section.

3.3.2 The psychology of queuing

Drivers are notoriously intolerant of having their intention to ‘drive’ (or move forward towards their destination) thwarted, despite showing high levels of ‘wait tolerance’ in other settings (Maister, 2005). This gives rise to marked peculiarities in preferences, such as drivers preferring a more congested (i.e. slower) mainline flow than a longer wait at a ramp meter (Levinson et al., 2006), or considering approximately two minutes to be the maximum acceptable waiting time at railway level crossings, with 18% of drivers willing to drive around the barriers after 15 minutes (Ellinghuas & Steinbrecher, 2006). Studies reveal that congestion and queuing leads to particular sources of driver frustration/anxiety which are highly relevant to TM situations (Maister, 2005):

1) Occupied time feels shorter than unoccupied time

Waiting in a traffic queue is ‘unoccupied time’ that cannot be easily filled with other useful or distracting activities. The perception of time is entirely subjective and influenced by emotional states such as frustration. An unoccupied wait in a traffic queue increases the onset of driver frustration and anxiety, an aversive emotional state that drivers will try to avoid and makes queing time feel longer.

2) Drivers want to get started

The early merge phenomenon leads to queues that are often longer than the overt signs of a TM site. This means that for waiting drivers the cause of the queue (i.e. the road works) is not evident and the experience of the TM site has not yet begun. Put another way, “pre-process waits are perceived as longer than in-process waits” (Maister, 2005, p. 4) meaning that waiting tolerance increases once drivers are actually ‘in’ the road works.

3) Anxiety makes waits seem longer

‘Choosing the right queue’ is a significant source of anxiety and a major factor in the early merge phenomenon. Drivers seek to avoid anxiety through a process of ‘anticipated regret’. They anticipate the negative consequences of late-merging and this serves as a disincentive to change their behaviour from an ‘early-merge’ strategy. This process is referred to specifically as ‘hyperbolic discounting’: drivers are willing to accept a lesser reward that arrives more quickly (i.e. immediate reduced anxiety arising from early-merging) rather than a bigger reward that will happen later (i.e. potentially faster journey times, but more anxiety through late-merging).

4) Uncertain waits are longer than known, finite waits
Another significant source of anxiety is how long the wait will be, and evidence suggests that drivers prefer longer definite waiting times (i.e. "delay of ten minutes") rather than vague queue information (i.e. "congestion ahead"). Creating an expectation, however, can be problematic when it is not met. Anxiety increases rapidly once the ten minutes of advertised wait time passes, for example.

5) Unexplained waits are longer than explained waits
Anxiety and frustration levels will be reduced if drivers can be made to understand the causes of their delay. "The lack of an explanation is one of the prime factors adding to a [driver's] uncertainty about the length of the wait" (Maister, 2005). Another key fact is simply that 'waiting is demoralising'; waiting in ignorance more so. Indeed, an important source of frustration is a driver having their status as 'a paying customer' diminished, with aggressive behaviours often being an attempt to re-establish this status.

6) Unfair waits are longer than equitable waits
"The feeling that somebody has successfully 'cut in front' of you causes even the most patient customer to become furious" (Sasser, Olsen & Wycoff, 1979). This is a particular problem in motorway traffic streams. A powerful illusion is created due to the fact that drivers spend more time being overtaken than they do overtaking, thus giving rise to the faulty perception that other travel lanes are moving faster even though the 'average' speed across lanes is comparable (Redelmeier & Tibshirani, 1999). The design principle to be extracted from this is that "whatever priority rules apply, the service provider must make vigorous efforts to ensure that these rules match the [driver's] sense of equity, either by adjusting the rules or by actively convincing the [driver] that the rules are indeed appropriate" (Maister, 2005, p. 7).

7) The more valuable the 'service' the longer the driver will wait
Drivers will find waiting for something of little value, such as permission to continue on what will likely be a similarly congested and unsatisfying journey, to be particularly intolerable (Maister, 2005). In other words, the subsequent level of service often has low value to drivers and this is often reflected in the strategies drivers will employ in recurring situations like this. Studies reveal, for example, that drivers faced with congestion "will progress from lower-cost, short-term strategies to higher-cost, longer-term ones as dissatisfaction persists or recurs (Raney, Mokhtarian & Salomon, 2000, p. 141). This offers some insight into anecdotal observations that 'lane blocking behaviour' only emerges later in time, in response to high-cost strategies such as late merging becoming more popular among the queuing traffic.

For the reasons discussed above, advice aimed at increasing the efficiency of TM zones will not always be followed. This is not to say that drivers are unaware of signs and instructions (e.g. Bai, Finger & Li, 2010; Horberry, Anderson & Regan, 2006; Beacher, Fontaine & Garber, 2004 etc.) more that these social psychological factors intervene to significantly attenuate the desired response (Havarneanu & Havarneanu, 2012).

4 INFLUENCING DRIVER BEHAVIOUR AT ROAD WORKS

4.1 Background

At the outset this research aimed to provide some initial ideas about how to positively influence driver behaviour at road works to improve traffic conditions. This section of the report gives consideration to this.

4.2 Experiments in Early and Late Merging

A number of studies have been performed to analyse the relative benefits of different merging strategies in advance of TM sites. These strategies are defined broadly as follows:

- The Early Merge Strategy: This follows work performed by the Indiana Department of Transport and is a system which “encourages drivers to merge into the open lane sooner than they usually would and before arriving at the end of a queue” (Hossinger & Berger, 2012, p. 153). The rationale behind this strategy is that by organising the traffic stream well in advance of the lane-drop it avoids the problem of ‘disruptive flow’ caused by late merging, and the concomitant problems of accidents and driver frustration.

- The Late Merge Strategy: This follows work performed by various other US Departments of Transport (notably Pennsylvania and Minnesota) and is a system which “encourages drivers to stay on the open or dropping lane until the reach the merge point” (Hossinger & Berger, 2012, p. 153). The rationale behind this strategy is that more of the available road space can be used for ‘queue storage’, reducing queue length and driver frustration.

Neither of these strategies are ideal in all circumstances, and it is important to note that the studies are not based on UK motorways (with the associated norms, driving styles and behaviours therein). The Early Merge strategy reduces the number of traffic conflicts but reduces capacity by approximately 5% (McCoy & Pesti, 2001). The Late Merge strategy is more effective at peak times, but there is evidence that in off peak times drivers arrive at the lane-drop more quickly (which is potentially hazardous) and that the strategy is affected by the number of heavy goods vehicles in the traffic stream. It is for this reason that Austrian studies have tested the feasibility of a ‘Dynamic Late Merge Concept’ in which the strategies switch; early-merge during off peak times and late-merge in congested conditions. The important point to note is that for the social psychological reasons above, their effects when applied to a UK motorway context are far from assured. With that in mind the following key results from early/late/dynamic merge studies can be presented (drawn from Beacher, Fontaine & Garber, 2004):

Table 4.1 : Results of different merging strategies compared to the 'do nothing' option based on five empirical studies*

		Late Merge		Early Merge	
Factor	Control Condition	Static	Dynamic	Static	Dynamic
Capacity (pcph)	1390	1730	1820	No data	1540[1]
Forced Merges	20/hr	5/hr	No Data	Decreased	1/day
Lane Distribution	n/a	30% volume increase in closed lane	No Data	12.4% increase in open lane	20% increase in open lane
Mean Speed (vs. Control Condition	n/a	7mph decrease (uncongested) 32mph decrease (congested)	No Data	16.1mpg decrease (uncongested)	2mph decrease (uncongested)
Queue Length	n/a	Up to 50% decrease	No Data	No Data	No Data

1 – Conflicting data: 5% capacity reduction observed in one study.
** Table source: Beacher et al., 2004, based on data from Walters & Cooner, 2001; Bernhardt, Virkler & Shaik, 2001; McCoy, Pesti & Byrd, 1999; McCoy & Pesti, 2001; Tarko & Venugopal, 2001*

The body of evidence in favour of different merging strategies is far from resolved and is clearly highly contingent on contextual and wider social psychological factors of the sort discussed in this review. On the other hand, the headline is that every form of intervention is superior to the 'do nothing' option and that considerable gains can be achieved through a mixture of hard and soft engineering.

4.3 Summary and Initial Ideas

The findings of this research identify the strong influence that social psychological factors have on driver behaviour. The research also shows that TM scenarios tend to increase the strength and likelihood of these factors occurring. It is therefore important when considering how to influence driver behaviour at roadworks to take full cognisance of these social psychological factors.

Although the results of different merging strategies suggest that any form of intervention is superior to a 'do nothing' option this doesn't particularly help decision makers discern which intervention, whether that involves hard or soft engineering or a mixture of both, is most suitable for a specific TM scenario.

One line of enquiry which isn't expressed in the early and late merging experiments would be to focus attention on the causes of driver behaviour (the social psychological factors) rather than the symptoms (the behaviour itself).

Is it possible to influence a driver's attitudes or beliefs and therefore the behavioural outcome? Could the environment itself be modified in such a way that the optimum behaviour is the easiest and most natural? The following initial ideas point towards fruitful new areas of investigation:

Self-explaining roadworks

There is scope to revisit the design of TM interventions and infrastructure such that they are ‘cognitively compatible’ with drivers. In practice this means putting existing features (like cones or signs) in different positions based on a mixture of psychological and engineering theory. This is an active area of research under the heading of ‘Self Explaining Roads’ (e.g. Walker, Stanton & Chowdhury, 2012) that could, in future, be applied to Traffic Management.

Gantry signs and messages

There is also scope to consider the wording and content of gantry signs. Recent research shows that current messages (referring to checking fuel level or traffic conditions at very distant destinations) do not elicit particularly favourable reactions from drivers. The precise wording, language and tone of these gantry signs is an area for further research but the present review drives us towards considering the following alternatives:

- “it might not look like it, but all lanes are flowing at the same average speed”
- “stay in lane and have a quicker, more relaxing journey”
- “traffic moves faster if you allow merging”
- “drivers ahead are happy to let you merge (it’s not pushing in)”

Improving the queueing experience

The psychology of queueing discussed in Section 3.3.2 of this report highlighted the fact that congestion and queuing is a particular source of driver frustration and anxiety. Even if an intervention strategy didn’t affect the actual level of congestion or queueing it could be designed in such a way as to improve the queuing experience and thus reduce a driver’s sense of frustration and anxiety.

Manipulating driver’s perception of time in roadworks

There is scope to go further and design queuing interventions designed to manipulate driver’s perception of time, in effect, making the same queue ‘feel’ shorter. Although highly innovative and unusual, an evidence-base exists from which to proceed with experiments and trials.

These initial ideas are novel, innovative and possibly unusual. Faced with a situation where, in effect, an extra lane of capacity is being lost in TM situations due entirely to driver behaviour factors one extreme option is to provide, at great cost, more travel lanes. Clearly this is not feasible. The alternative approach is to regain that lost lane of capacity through small, clever, highly cost-effective Human Factors solutions, with the potential to deliver disproportionately beneficial outcomes. At the very least, knowledge on driver behaviour will allow these perplexing phenomenon to be better modelled and understood.

5 GUIDANCE FOR MODELLING

5.1 Background

One of the aims of this study was to provide guidance for the modelling of TM at roadworks, with a view to this guidance being adopted when examining such schemes on behalf of Transport Scotland.

5.2 Driver Response to TM Signage

This study highlights the fact that traffic does not always react as expected to a given signage strategy, and may behave differently within TM than in ‘normal’ circumstances. Simply coding the TM layout and signage has not in the case of the Arkleston Bridge Strengthening Works resulted in as robust representation of the driver behaviour as it might.

The comparison between observed and modelled flows during the Arkleston Bridge Strengthening Works shows two important findings:

- In uncongested conditions the comparison between observed and modelled flows shows a close match
- In congested conditions modelled flows exceed observed flows considerably

The reason for these two findings is that modelled drivers do not differentiate between a TM layout and the same layout in ‘normal’ circumstances whereas drivers in real-life do make this distinction. It seems that there is a level of congestion that, in behavioural terms, represents a threshold beyond which the queue becomes more important than the TM signage in influencing driver behaviour.

It’s important that we understand how modelled drivers do behave before considering ways to amend that behaviour in a TM scenario.

In S-Paramics each change in the network (e.g. a reduction in the no. of lanes available to drivers) is projected upstream. Drivers therefore become aware of a change and are able to react to it before they reach it. The distance a change can be projected upstream can be defined by the user (known as the signposting distance in S-Paramics). When a driver becomes aware of a change in the network they make a decision about what they want to do. In the case of the Arkleston Bridge Strengthening Works if a driver is in the outside lane and becomes aware that this lane will close further downstream they will decide to move into an open lane on the inside. In uncongested conditions this manoeuvre is relatively straightforward as there is plenty of road space for the driver to move into. In congested conditions a driver may be unable to find the road space which enables them to move to an inside line. This is when the critical difference between the modelled behaviour and observed behaviour during TM occurs. In the model, if the driver is unable to move from the outside lane to an inside lane they will carry on in the outside lane and continue to assess whether their desired manoeuvre is possible. This will last until the driver reaches the closed lane and has no choice but to move into an inside lane.

In real-life, as a result of the social psychological factors discussed in this paper, a driver will tend to stop and wait for another driver in the inside lane to let them in. This illustrates that the reason for the difference between observed and modelled driver behaviour is not primarily to do with a driver's awareness of the TM (and therefore not primarily to do with the TM signage itself).

We've acknowledged that the reason for the difference between observed and modelled driver behaviour is not primarily to do with a driver's awareness of the TM. The findings of the literature review and the differences between the observed and modelled flows and speeds approaching the Arkleston Bridge Strengthening Works both strongly suggest that in congested conditions drivers get into lane significantly in advance of any signs informing them of lane closures. In other words the awareness of the TM in congested conditions may come via the observed queue rather than the signage.

One way to represent this behaviour in the model would be to assume that drivers were aware of the roadworks before they reached the TM signage. This could be achieved in S-Paramics by increasing the signposting distance beyond the distance specified in the TM design. This would result in drivers being aware of the TM earlier but would not necessarily result in a change in their behaviour (as discussed above).

5.3 Option 1 – Predetermining a Modelled Flow

The findings of the literature review and the differences between the observed and modelled flows approaching the Arkleston Bridge Strengthening Works suggest that there is a correlation between the reduction in flow per lane and the reduction in the no. of lanes as a result of TM. One approach to modelling this would be to focus on the reduction in flow and use appropriate modelling techniques to represent this reduction. Instead of modelling all the social psychological complexity the focus would instead be on the outcomes.

For example, a modeller could assume a flow reduction of 25% per lane per hour at peak times and ensure that this reduction was achieved. This method, although crude, would not involve any further software development.

This approach was implemented at the Kessock Bridge works which are currently underway. Previous roadworks on the Kessock Bridge showed an average traffic flow at peak times of approximately 1300 vehicles per lane per hour. This was similar to observations at the roadworks on the Forth Road Bridge - 1200 vehicles per lane per hour.

The Kessock Bridge microsimulation model was therefore developed to accommodate 1300 vehicles per lane per hour through the TM site thus providing a robust representation of the likely congestion and queueing which would occur.

The drawback to this approach is that it would shut off opportunities to predict more complex or diverse situations.

5.4 Option 2 – Amending Modelled Driver Behaviour

An improvement on predetermining a modelled flow would be to represent in a simple form the observed driver behaviour in congested conditions at a TM site. This method would require some software development but at a relatively basic level.

The impact of this in modelling terms would be if a driver is unable to find the road space which enables them to move to an inside line they would wait for the opportunity to do so rather than carry on in the outside lane and continue to assess whether their desired manoeuvre is possible.

This behaviour is likely to represent a significant proportion of drivers in a TM situation and may be sufficient to robustly represent the likely levels of queueing and congestion with a model.

5.5 Option 3 – Modelling the Social Psychological Factors

The ideal approach to modelling driver behaviour at roadworks would be to robustly represent the social psychological factors discussed in this paper. This method would require significant software development.

Certain driver behaviours could be contingent on the level of congestion and the behaviour of the queue. For example, blocking behaviours could be contagious and time dependent (more common as time progresses etc).

Driving style parameters could be embedded into the modelled driver population e.g. the most aggressive drivers would display a certain behaviour and the least aggressive a different behaviour. There could be defined mapping between formal driving style concepts and driver aggression in the model.

6 REFERENCES

Allpress, J.A., & Leland, L.S. (2010). Reducing traffic speed within roadwork sites using obtrusive perceptual countermeasures. Accident; analysis and prevention, 42(2), 377–83. doi:10.1016/j.aap.2009.08.014

Bai, Y., Finger, K., & Li, Y. (2010). Analyzing motorists' responses to temporary signage in highway work zones. Safety Science, 48(2), 215–221. doi:10.1016/j.ssci.2009.08.005

Beacher, A. G., Fontaine, M. D. & Garber, N. J. (2004). Evaluation of the late merge work zone traffic control strategy. Charlottesville, VA: Virginia Transportation Research Council.

Beacher, A., Fontaine, M., & Garber, N. (2004). Evaluation of the late merge work zone traffic control strategy. Report VTRC-05-R6 Virginia Transportation Council, (August).
Bener, A., Al Maadid, M. G. a., Özkan, T., Al-Bast, D. a. E., Diyab, K. N., & Lajunen, T. (2008). The impact of four-wheel drive on risky driver behaviours and road traffic accidents. Transportation Research Part F: Traffic Psychology and Behaviour, 11(5), 324–333. doi:10.1016/j.trf.2008.02.001

Bernhardt, K.L.S., M.R. Virkler, and N.M. Shaik (2001). Evaluation of Supplementary Traffic Control Measures for Freeway Work-zone Approaches. Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

Borowsky, A., Oron-Gilad, T., & Parmet, Y. (2009). Age and skill differences in classifying hazardous traffic scenes. Transportation Research Part F: Traffic Psychology and Behaviour, 12(4), 277–287. doi:10.1016/j.trf.2009.02.001

Brackstone, M., Sultan, B., & McDonald, M. (2002). Motorway driver behaviour: studies on car following. Transportation Research Part F: Traffic Psychology and Behaviour, 5(1), 31–46. doi:10.1016/S1369-8478(02)00004-9

Brackstone, M., Waterson, B., & McDonald, M. (2009). Determinants of following headway in congested traffic. Transportation Research Part F: Traffic Psychology and Behaviour, 12(2), 131–142. doi:10.1016/j.trf.2008.09.003

De Waard, D., Van den Bold, T. G. M. P. R., & Lewis-Evans, B. (2010). Driver hand position on the steering wheel while merging into motorway traffic. Transportation Research Part F: Traffic Psychology and Behaviour, 13(2), 129–140. doi:10.1016/j.trf.2009.12.003

Dogan, E., Steg, L., & Delhomme, P. (2011). The influence of multiple goals on driving behavior: the case of safety, time saving, and fuel saving. Accident; analysis and prevention, 43(5), 1635–43. doi:10.1016/j.aap.2011.03.002

Doob, A. N., & Gross, A. E. (1968). Status of frustrator as an inhibitor of horn-honking responses. The Journal of Social Psychology, 76, 213-218.

Edquist, J., Rudin-Brown, C. M., & Lenné, M. G. (2012). The effects of on-street parking and road environment visual complexity on travel speed and reaction time. Accident; analysis and prevention, 45, 759–65. doi:10.1016/j.aap.2011.10.001

Edwards, J. (1999). Speed adjustment of motorway commuter traffic to inclement weather. Research Part F: Traffic Psychology and Behaviour, 2 (1), 1-14.

Elliott, M.A., Armitage, C.J., & Baughan, C.J. (2005). Exploring the beliefs underpinning drivers' intentions to comply with speed limits. Transportation Research Part F: Traffic Psychology and Behaviour, 8(6), 459–479. doi:10.1016/j.trf.2005.08.002

Engström, J., Johansson, E., & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. Transportation Research Part F: Traffic Psychology and Behaviour, 8(2), 97–120. doi:10.1016/j.trf.2005.04.012

Fleiter, J. J., Lennon, A., & Watson, B. (2010). How do other people influence your driving speed? Exploring the "who" and the "how" of social influences on speeding from a qualitative perspective. Transportation Research Part F: Traffic Psychology and Behaviour, 13(1), 49–62. doi:10.1016/j.trf.2009.10.002

French, D. J., West, R. J., Elander, J. & Wilding, J. M. (1993). Decision-making style, driving style, and self-reported involvement in road traffic accidents. Ergonomics, 36(6), 627-644.

González-Iglesias, B., Gómez-Fraguela, J.A., & Luengo-Martín, M.Á. (2012). Driving anger and traffic violations: Gender differences. Transportation Research Part F: Traffic Psychology and Behaviour, 15(4), 404–412. doi:10.1016/j.trf.2012.03.002

Havârneanu, G.M., & Havârneanu, C.E. (2012). When norms turn perverse: Contextual irrationality vs. rational traffic violations. Transportation Research Part F: Traffic Psychology and Behaviour, 15(2), 144–151. doi:10.1016/j.trf.2011.12.003

Heaslip, K., Collura, J., & Jr, M. K. (2009). Evaluation of Work-Zone Design Features to Aid Older Drivers. Transportation Research Board 88th Annual Meeting, January 11-15, 2009, 36–41. Retrieved from http://trid.trb.org/view.aspx?id=881575

Highways Agency. (2009). Network Maintenance Manual. Retrieved January 16, 2012, from http://www.dft.gov.uk/ha/standards/nmm_rwsc/index.htm

Horberry, T., Anderson, J., & Regan, M. a. (2006). The possible safety benefits of enhanced road markings: A driving simulator evaluation. Transportation Research Part F: Traffic Psychology and Behaviour, 9(1), 77–87. doi:10.1016/j.trf.2005.09.002

Hössinger, R., & Berger, W. J. (2012). Comprehension of new instructions for car drivers in merging areas. Transportation Research Part F: Traffic Psychology and Behaviour, 15(2), 152–161. doi:10.1016/j.trf.2011.12.009

Huang, Q., & Shi, J. (2008). Optimizing work zones for two-lane urban road maintenance projects. Tsinghua Science & Technology, 13(5), 644–650.

Hurwitz, D.S., Wang, H., Knodler, M.A., Ni, D., & Moore, D. (2012). Fuzzy sets to describe driver behavior in the dilemma zone of high-speed signalized intersections. Transportation Research Part F: Traffic Psychology and Behaviour, 15(2), 132–143. doi:10.1016/j.trf.2011.11.003

Jin, T.G., Saito, M., & Eggett, D.L. (2008). Statistical comparisons of the crash characteristics on highways between construction time and non-construction time. Accident; analysis and prevention, 40(6), 2015–23. doi:10.1016/j.aap.2008.08.024

Khattak, A.J., Khattak, A.J., & Council, F.M. (2002). Effects of work zone presence on injury and non-injury crashes. Accident; analysis and prevention, 34(1), 19–29.

Lajunen, T., Parker, D., & Summala, H. (1999). Does traffic congestion increase driver aggression? Transportation Research Part F: Traffic Psychology and Behaviour, 2, 225–236.

Lee, H.-Y. (2009). Optimizing schedule for improving the traffic impact of work zone on roads. Automation in Construction, 18(8), 1034–1044. doi:10.1016/j.autcon.2009.05.004

Lepert, P., & Brillet, F. (2009). The overall effects of road works on global warming gas emissions. Transportation Research Part D: Transport and Environment, 14(8), 576–584. doi:10.1016/j.trd.2009.08.002

Levinson, D., Harder, K., Bloomfield, J., & Carlson, K. (2006). Waiting tolerance: Ramp delay vs. freeway congestion. Transportation Research Part F: Traffic Psychology and Behaviour, 9(1), 1–13. doi:10.1016/j.trf.2005.08.003

Li, Y., & Bai, Y. (2008). Development of crash-severity-index models for the measurement of work zone risk levels. Accident; analysis and prevention, 40(5), 1724–31. doi:10.1016/j.aap.2008.06.012

Long, S., Gentry, L., & Bham, G.H. (2012). Driver perceptions and sources of user dissatisfaction in the implementation of variable speed limit systems. Transport Policy, 23, 1–7. doi:10.1016/j.tranpol.2012.05.007

Mann, L. (1970). The psychology of waiting lines. American Scientist, 58, 390-398

Martens, M. H., & Fox, M. (2007). Does road familiarity change eye fixations? A comparison between watching a video and real driving. Transportation Research Part F: Traffic Psychology and Behaviour, 10(1), 33–47. doi:10.1016/j.trf.2006.03.002

McCoy, P.T., and G. Pesti (2000). Dynamic Late Merge Control Concept for Work Zones on Rural Interstate Highways. Paper presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

McCoy, P.T., G. Pesti, and P.S. Byrd (1999). Alternative Information to Alleviate Work Zone-Related Delays. SPR-PL-1(35)P513. University of Nebraska, Lincoln.

Morgan, J. F., Duley, a R., & Hancock, P. a. (2010). Driver responses to differing urban work zone configurations. Accident; analysis and prevention, 42(3), 978–85. doi:10.1016/j.aap.2009.12.021

Özkan, T., Lajunen, T., Chliaoutakis, J. E., Parker, D., & Summala, H. (2006). Cross-cultural differences in driving behaviours: A comparison of six countries. Transportation Research Part F: Traffic Psychology and Behaviour, 9(3), 227–242. doi:10.1016/j.trf.2006.01.002

Palat, B., & Delhomme, P. (2012). What factors can predict why drivers go through yellow traffic lights? An approach based on an extended Theory of Planned Behavior. Safety Science, 50(3), 408–417. doi:10.1016/j.ssci.2011.09.020

Paris, H., and Van den Broucke, S. (2008). Measuring cognitive determinants of speeding: An application of the theory of planned behaviour. Transportation Research Part F: Traffic Psychology and Behaviour, 11(3), 168–180. doi:10.1016/j.trf.2007.09.002

Pastor, G., Tejero, P., Chóliz, M., & Roca, J. (2006). Rear-view mirror use, driver alertness and road type: An empirical study using EEG measures. Transportation Research Part F: Traffic Psychology and Behaviour, 9(4), 286–297. doi:10.1016/j.trf.2006.01.007

Phillips, R.O., Ulleberg, P., & Vaa, T. (2011). Meta-analysis of the effect of road safety campaigns on accidents. Accident; analysis and prevention, 43(3), 1204–18. doi:10.1016/j.aap.2011.01.002

Raney, E. A., Mokhtarian, P.L., & Salomon, I. (2000). Modeling individuals' consideration of strategies to cope with congestion. Transportation Research Part F: Traffic Psychology and Behaviour, 3(3), 141–165. doi:10.1016/S1369-8478(00)00022-X

Ranney, T. (1999). Psychological factors that influence car-following and car-following model development. Transportation Research Part F: Traffic Psychology and Behaviour, 2, 213–219.

Redelmeier, D.A, & Tibshirani, R.J. (1999). Why cars in the next lane seem to go faster. Nature, 401(6748), 35. doi:10.1038/43360

Sato, T., & Akamatsu, M. (2007). Influence of traffic conditions on driver behavior before making a right turn at an intersection: Analysis of driver behavior based on measured data on an actual road. Transportation Research Part F: Traffic Psychology and Behaviour, 10(5), 397–413. doi:10.1016/j.trf.2007.03.001

Schmidt-Daffy, M. (2013). Fear and anxiety while driving: Differential impact of task demands, speed and motivation. Transportation Research Part F: Traffic Psychology and Behaviour, 16, 14–28. doi:10.1016/j.trf.2012.07.002

Sivak, M. (2002). How common sense fails us on the road: contribution of bounded rationality to the annual worldwide toll of one million traffic fatalities. Transportation Research Part F: Traffic Psychology and Behaviour, 5(4), 259–269. doi:10.1016/S1369-8478(03)00003-2

Sorock, G.S., Ranney, T.A, & Lehto, M.R. (1996). Motor vehicle crashes in roadway construction workzones: an analysis using narrative text from insurance claims. Accident; analysis and prevention, 28(1), 131–8.

Tarko, A., and S. Venugopal (2001). Safety and Capacity Evaluation of the Indiana Lane Merge System. FHWA/IN/JTRP-2000/19. Purdue University, West Lafayette, Ind.
Transportation Research Board (2000). Highway Capacity Manual 2000. Washington, D.C.

Velichkovsky, B.M., Dornhoefer, S.M., Kopf, M., Helmert, J., & Joos, M. (2002). Change detection and occlusion modes in road-traffic scenarios. Transportation Research Part F: Traffic Psychology and Behaviour, 5(2), 99–109. doi:10.1016/S1369-8478(02)00009-8

Walters, C.H., and S.A. Cooner (2001). Understanding Road Rage: Evaluation of Promising Mitigation Measures. Report 4945-2. Texas Transportation Institute, College Station.

Wang, C., Quddus, M.A, & Ison, S.G. (2009). Impact of traffic congestion on road accidents: a spatial analysis of the M25 motorway in England. Accident; analysis and prevention, 41(4), 798–808. doi:10.1016/j.aap.2009.04.002

Warner, H. W., Özkan, T., Lajunen, T., & Tzamalouka, G. (2011). Cross-cultural comparison of drivers' tendency to commit different aberrant driving behaviours. Transportation Research Part F: Traffic Psychology and Behaviour, 14(5), 390–399. doi:10.1016/j.trf.2011.04.006

Weng, J., & Meng, Q. (2011). Analysis of driver casualty risk for different work zone types. Accident; analysis and prevention, 43(5), 1811–7. doi:10.1016/j.aap.2011.04.016

Weng, J., & Meng, Q. (2012). Effects of environment, vehicle and driver characteristics on risky driving behavior at work zones. Safety Science, 50(4), 1034–1042. doi:10.1016/j.ssci.2011.12.005

Werneke, J., & Vollrath, M. (2012). What does the driver look at? The influence of intersection characteristics on attention allocation and driving behavior. Accident; analysis and prevention, 45, 610–9. doi:10.1016/j.aap.2011.09.048

Whitmire, J., Morgan, J. F., Oron-Gilad, T., & Hancock, P. a. (2011). The effect of in-vehicle warning systems on speed compliance in work zones. Transportation Research Part F: Traffic Psychology and Behaviour, 14(5), 331–340. doi:10.1016/j.trf.2011.04.001

Wu, J., McDonald, M., & Chatterjee, K. (2007). A detailed evaluation of ramp metering impacts on driver behaviour. Transportation Research Part F: Traffic Psychology and Behaviour, 10(1), 61–75. doi:10.1016/j.trf.2006.06.003

Yousif, S., & Al-Obaedi, J. (2011). Close following behavior: Testing visual angle car following models using various sets of data. Transportation Research Part F: Traffic Psychology and Behaviour, 14(2), 96–110. doi:10.1016/j.trf.2010.11.001

Zhang, K., Batterman, S., & Dion, F. (2011). Vehicle emissions in congestion: Comparison of work zone, rush hour and free-flow conditions. Atmospheric Environment, 45(11), 1929–1939. doi:10.1016/j.atmosenv.2011.01.030