WHITE PAPER

The Tortoise and The Hare

Modelling Road User Micro-Journeys to Determine Accurate Intergreen Times

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TRAFFIC GROUP SIGNALS

About this White Paper

This technical paper was produced by Traffic Group Signals to present a new method of applying intergreen times to temporary traffic signals.

The paper and trial data was been written by Traffic Group Technology, the Research & Development division of The Traffic Group.

For more information about Traffic Group Signals, please visit: **TrafficGroupSignals.com**

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QUESTIONS ABOUT THIS PAPER

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Glossary:

AG	AutoGreen® - a registered trademark
CAD	Computer Aided Design
DfT	Department for Transport
TGS	Traffic Group Signals
TSM	Traffic Signs Manual

WHITE PAPER

The Tortoise and The Hare

Modelling Road User Micro-Journeys to Determine Accurate Intergreen Times

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Abstract

The selection of appropriate intergreen times is an essential safety consideration for any traffic signal design. If the times chosen are too short, collisions or near-misses could result. Times that are too long impact efficiency and can cause a reduction in signal compliance.

The available intergreen guidance, being in the form of a lookup table, simplifies the problem significantly however in doing so, the way in which a specific road geometry affects each vehicle type is not taken into account.

Guidance states that the suitability of intergreen times should then be validated through on-site observation. But how effective really is this? Is it practical for the commissioning engineer on-street to observe every combination of road user type on the gaining and losing phases arriving with the appropriate timing in relation to the signals to genuinely validate the complete intergreen matrix?

A new method of calculating intergreen times is presented in this paper that aspires to address these shortcomings, create safe and efficient intergreen times for all users and remove the burden on both signalling scheme designers and commissioning engineers.

A Unique Signalling Environment

Any method that can define intergreen times quickly, accurately and with less error is of course something that could be of a benefit to all types of signal installation. As will be illustrated, there are however some specific reasons that drive a need for improved facilities in this area for use at temporary traffic signal installations.

Many thousands of traffic signals are deployed in the UK at any point in time on a temporary basis. Whether these are portable signals or temporary signals, the environment and culture in which they operate poses unique challenges when compared with permanent signals.

Where a permanent signalling deployment may take many months to design, test, deploy and commission, the equivalent processes in the temporary traffic management space often span just a few days or even hours. Temporary signalling has only a limited influence over the road layout, having to fit in around excavations, materials storage and existing permanent infrastructure. Temporary signals often span longer distances and incorporate shuttle working. Distances between signals of between 100m and 200m are common. Drivers too pose a challenge as they can find temporary layouts disorientating and frustrating. Some drivers even question whether compliance with signals at temporary installations is a legal requirement.

Managing this environment is difficult enough but to add to this, civil works often transition from one phase to another at pace, requiring the signalling to change sometimes every few days as the work progresses.

Historically, the Traffic Management industry has coped with these seemingly unmeetable demands using a 'Keep it Simple' formula. Specifically:

- Employ highly simplistic phase-based signalling that services just one phase at a time. This eliminates the vast majority of design decisions for the signalling because there are so few ways in which the signalling function can be varied.
- Employ easy-to-configure (but inefficient) red times based on clearance or datum times. These are sometimes specified on CAD-derived TM drawings but are regularly wrong and generally ignored by the operative putting the signals out anyway.
- Perform all signal configuration at the roadside with a few button presses to enter red and green timings.
- For everything else, send an operative to site. This could include long periods of time performing manual control.

This approach has provided a complete flexibility in the provision of Traffic Management services however, this has come at a cost:

- Signalling efficiency is often very poor.
- Costs are very high.

It should at this point be noted that some efforts to improve the efficiency of portable signals have been made and have achieved a level of relative improvement.

Traffic Group Signals developed a new method of control for portable signals called **AutoGreen Technology**, and this was presented at JCT in 2019. AutoGreen especially addressed some of the more significant weaknesses of signals deployed to 2-way shuttle working sites, where the signals can easily end up blocking the shuttle lane.

The issue remains however, that until portable and temporary signals can grow out of their simple 'phase-based' origins, they will always lag significantly behind stage-based permanent signals in terms of efficiency.

It is for this reason that TGS set out four years ago with the objective of developing new portable and temporary signalling products that achieve the following objectives:

- The adoption of core signalling technology from permanent signals including stages, an intergreen matrix and many other key elements.
- Implementation of remote monitoring and management facilities that can eradicate the need for manual control even at the most challenging and complex sites.

Moving to a Full Intergreen Matrix

In 2021, TGS launched the Metro and Evo1 products, both of which support stage-based signalling with a full intergreen matrix.

Evo®1

Metro

The use of an intergreen matrix replaces the use of 'clearance' red times where each phase is configured with a red time that clears traffic through the entire roadworks site or, 'datum' red times. Datum red times require the operative to configure the signals with red times spanning distances from each phase to a common datum position within the junction.

Both methods were conceived decades ago as a method of simplifying the specification of red times to a point where they could be entered by a traffic management operative at the roadside. Much greater efficiency is possible by using a full intergreen matrix however, such a move brings with it a number of challenges as follows:

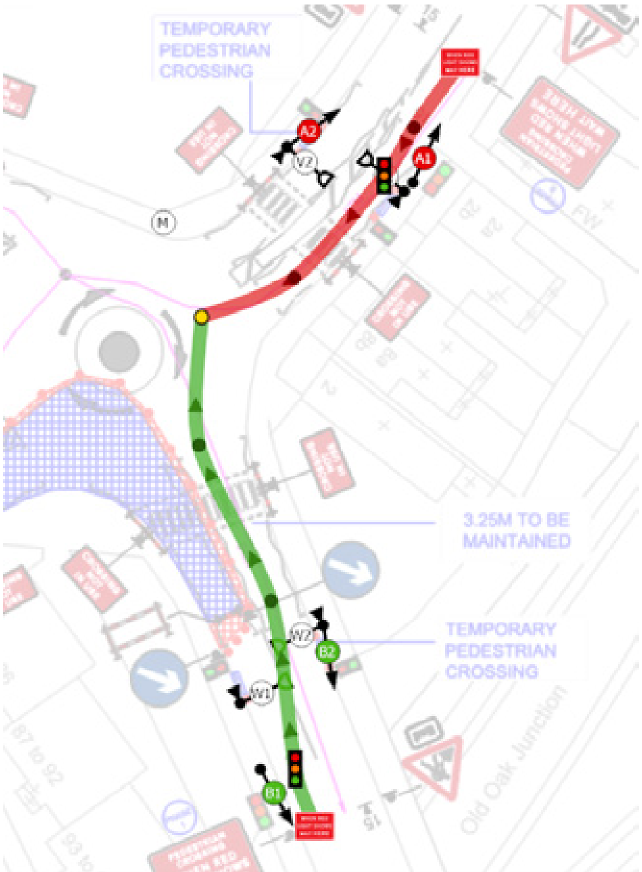
- Traffic management operatives are neither qualified or equipped for the task of modifying an intergreen matrix.
- An intergreen matrix can contain quite a lot of individual entries, each of which needs to be accurately specified within the very tight timescales of the Temporary Traffic Management environment and in a safe manner that has been subject to independent review.
- The geometry of many temporary signalling schemes can be challenging in terms of determining intergreen times. Distances can be longer than are experienced at permanent signal sites and there can be numerous bends for traffic to negotiate as they travel through the works.
- The guidance for setting red times at temporary works assumes that only clearance or datum red times are employed and that the geometry of such sites is very simple. This left TGS initially falling back on guidance from Chapter 6 of Traffic Signs Manual however, as will be covered later in the paper, this guidance also starts to unravel when applied in this environment.

Signal Studio

The temporary traffic management environment requires that signalling schemes can be configured very quickly. TGS has achieved this through the development of a bespoke end-to-end design software application called Signal Studio.

Signal Studio allows a signalling scheme to be fully designed and configured, simulated then deployed directly to hardware over 4G for an operative on site to load with a couple of button presses.

A graphical intergreen measurement tool is provided in the software along with facilities for calibrating traffic management drawings.



Intergreen Measurement Tool

The Intergreen measurement tool allows the user to draw the vehicle paths for each specific entry in the intergreen matrix. The software measures distances for these vehicle paths and performs a look-up of these against guidance to provide an intergreen time value for the matrix. The software saves each drawn line with the rest of the scheme data, allowing an independent review of intergreen times to be performed.

A key feature with the tool was the ability to support generating red times using either the Chapter 8 guidance (Pink Book) or using the collision point style calculation from Chapter 6. Typically schemes employ a mix of the two.

The Guidance

Getting to this point solved many of the previously identified challenges with defining a full intergreen matrix for temporary works, but not all. As TGS deployed more schemes, it became apparent that times derived from the guidance often required manual modification. The requirement to add additional intergreen time was common under the following conditions:

- Sites with distances greater than 70m.
- Sites where traffic has to negotiate one or more bends through a shuttle.
- Shuttle working sites with heavy use by cyclists.
- Shuttle working sites with any form of gradient.

The expectation that timings will need to be modified on-site is noted in TSM Chapter 6:

> **The method set out here has been found to give a good basis for the initial settings, but on-site observation once the installation is in operation is essential, and adjustments should be made if necessary.**

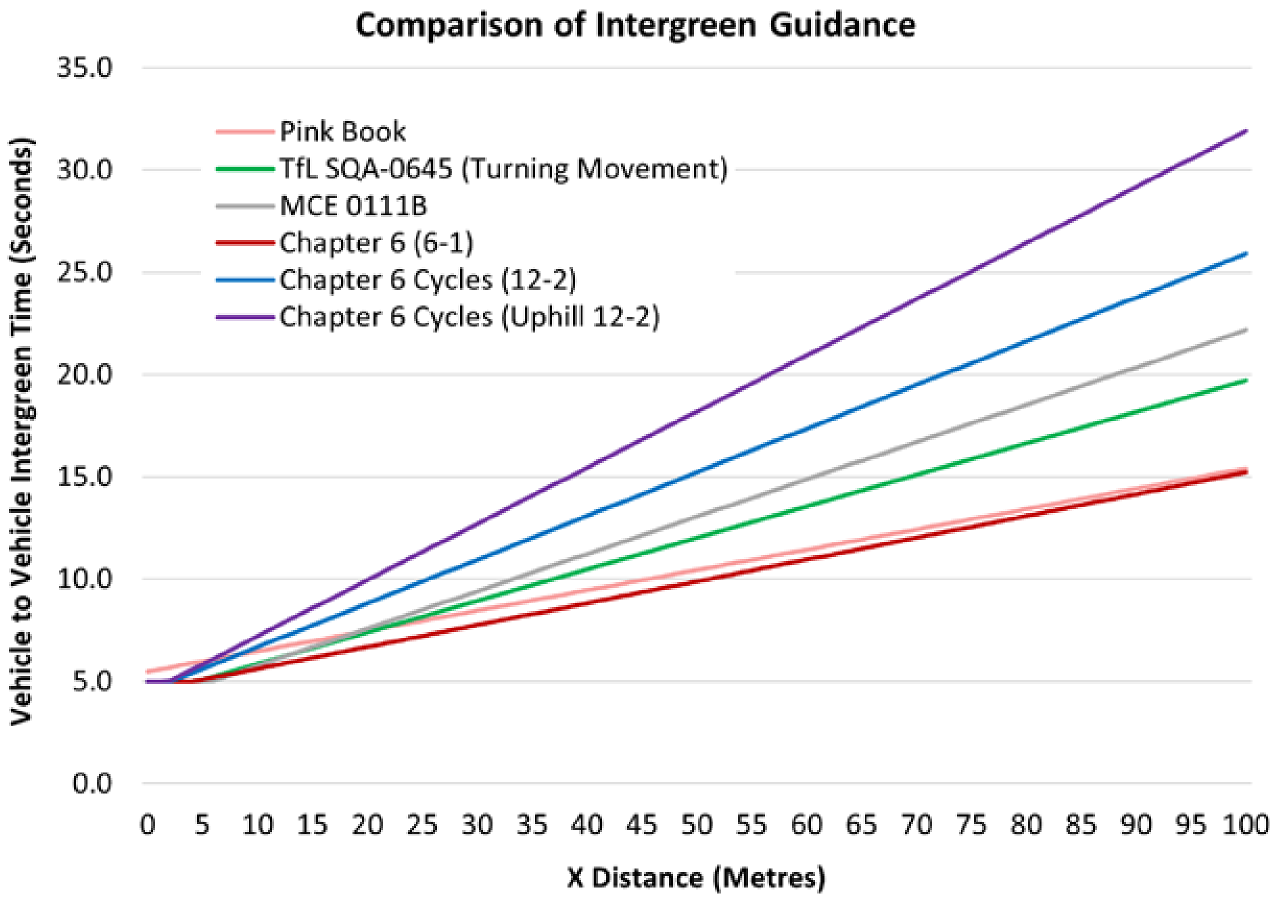
Also:

> **The intergreens suggested in Table 6-1 take no account of factors such as vehicle speeds, the vehicular mix of traffic or site conditions such as gradients. It may therefore be necessary to make adjustments to the intergreen once the site is operational.**

Chapter 6 also provides useful details regarding design speed and acceleration for cycle traffic.

One of the problems is which guidance to follow. The Pink Book is intended to be the definitive guidance for portable signals. Chapter 6 provides guidance on intergreen times in table 6-1 but also provides separate guidance on intergreens that are suitable for cycles in table 12-2. Exactly how does the scheme designer determine which guidance to follow? Surely cyclists ride most routes therefore, intergreens should be derived from table 12-2 in Chapter 6? Ultimately, the challenge is that accommodating cyclists costs efficiency. Where should designers strike the balance?

To illustrate this issue, the graph below shows a direct comparison of a range of sources of guidance. The graph was generated by using linear regression to fit a straight line to the published guidance figures. This was then linearly interpolated this to provide continuous values in a common range. Note, few of these guidance sources are actually published with figures the span up to 100m yet, these are distances at which temporary works often require intergreen calculations.



At an X value of 100m, the guidance itself ranges from 15s to 32s. Determining which guidance to follow is potentially a time-consuming distraction for the designer and one that is prone to human error.

The Objective

The objective of the work presented in this paper is to further improve the accuracy of intergreen times generated on the desktop at the design stage such that less modification is required on street.

Whilst a period of on-site validation will always be required, reducing the scale of this activity makes works more agile, more cost-efficient and ultimately safer with less scope for human error. Other benefits also arise:

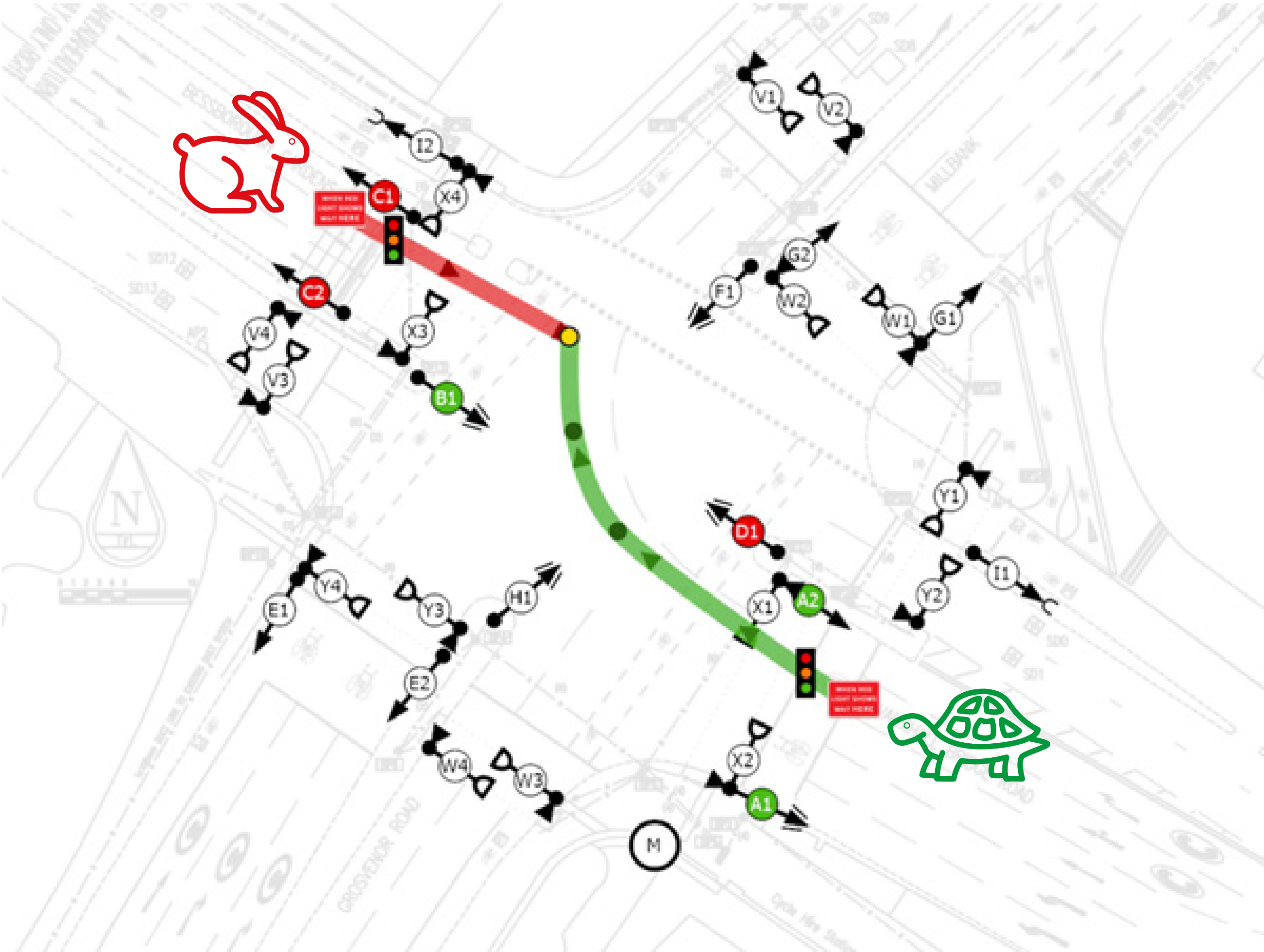
- Any case where intergreen times require modification on-site exposes traffic to a non-optimal intergreen time for as long as it takes for the requirement to modify a specific intergreen time to be actioned. Temporary signals are often deployed at night where traffic levels are too light to perform all of the necessary intergreen observations which inherently increases the time it takes to spot a necessary correction.
- Where the order of stages has been optimised to reduce the total overall interstage time, this optimisation can be invalidated if intergreen times in the scheme are modified after deployment, where the ordering of stages usually would not be changed.
- Early identification of unsatisfactorily long intergreen times in a scheme can prompt the designer to consider employing additional detection hardware in the scheme as required to dynamically extend intergreen times (for example, to pickup slower cyclists). This can be then designed in before the signals are deployed rather than being a retrospective addition.

The Physics Model

The core subject of this paper is the creation of a physics-based model that essentially 'drives' (or 'rides') vehicles through the works in order to determine how much time they take to do this. Two 'micro-journey' times are estimated by the model:

- Time taken for a vehicle passing through a phase that is losing right of way to travel from it's stop line (or wait here sign) to a defined collision point. This vehicle is the 'tortoise'.
- Time taken for a vehicle waiting at a phase that is gaining right of way to travel from it's stop line (or wait here sign) to a defined collision point. This vehicle is the 'hare'.

These micro-journeys are defined by the lines drawn by the user in Signal Studio onto the calibrated traffic management drawing as below, with the losing phase shown in green and the gaining phase shown in red.



These intergreen lines define the conditions for a race between a losing-phase vehicle and a gaining-phase vehicle. For convenience, these are named as the tortoise and hare in this paper as a reminder that for the losing phase the intergreen time needs to be sufficient to suit the slowest vehicle type making this micro-journey. Equally, the gaining phase must suit the fastest vehicle type making this micro-journey.

The intergreen period essentially defines a 'head start' period of time that attempts to ensure that the tortoise always reaches the conflict point before the hare.

Nature of the Model

The model calculates micro-journey times for each specific class of vehicle independently based on a set of physical characteristics that have been defined for each vehicle class.

For phases losing right of way, the model calculates a micro-journey time for each of the following vehicle types and then from these selects the slowest:

- Cycles
- eScooters
- Buses
- HGVs
- Cars

For phases gaining right of way, the model identifies the fastest micro-journey time among the following vehicle types:

- Mopeds
- Motorbikes
- Cars

Note that the car model used for the gaining phase differs from the car model applied to the losing phase whereby the former represents a more aggressive driving style than the latter.

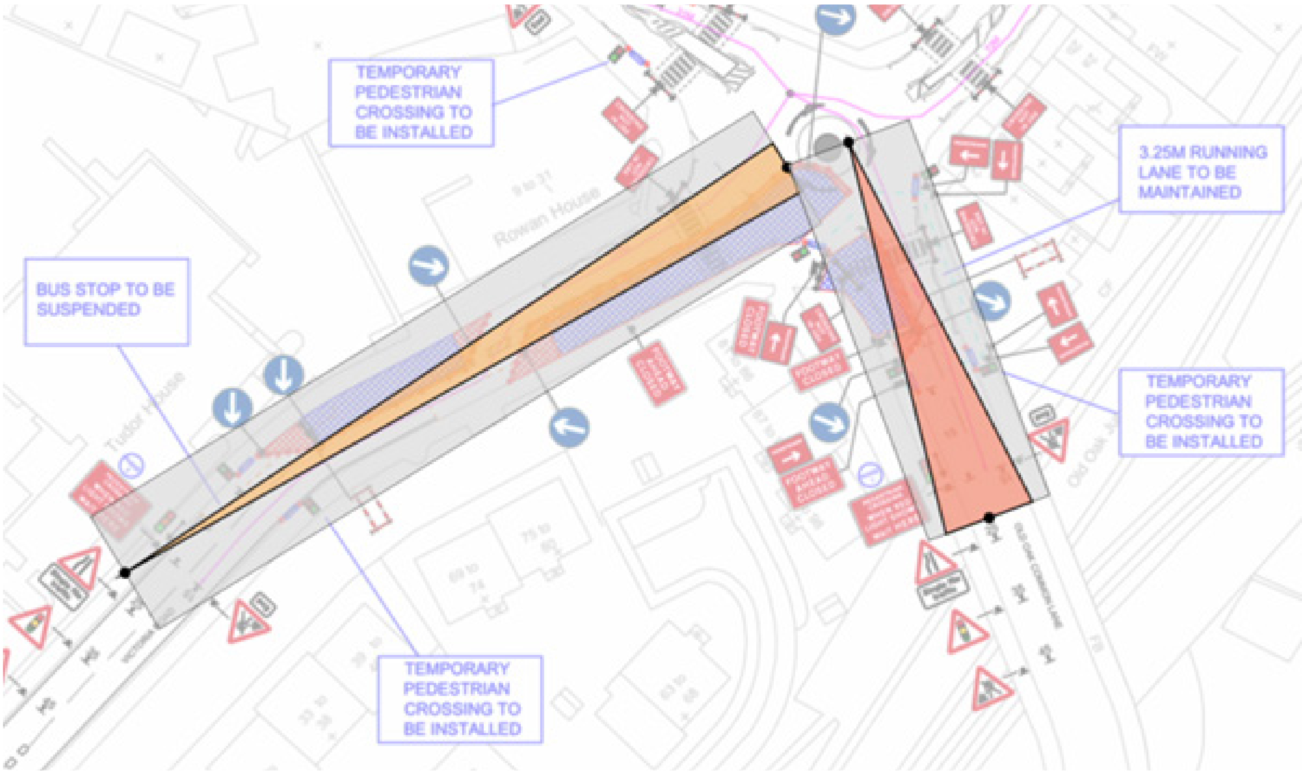
In order to generate realistic micro-journey times, the physics model builds a speed profile for the vehicle throughout the journey that respects the following physical characteristics of that vehicle.

- Maximum attainable speed.
- Typical rate of acceleration (longitudinal acceleration)
- Typical rate of braking (longitudinal deceleration)
- Cornering characteristics (lateral acceleration)
- Jerk (rate of change of acceleration)

The manner in which the model generates the required speed profile is similar to the model described in the paper 'Jerk-limited time-optimal speed planning for arbitrary paths' by Antonio Artunedo, Jorge Villagra, Jorge Godoy. The model also takes account of the speed limit for the site.

The model employs a number of passes through the data that represent the journey, processing it both in a forwards and backwards direction to create a speed profile for the complete journey that represents a realistic journey for the vehicle type that remains within the physical characteristics of the vehicle type. This means the model will automatically slow down for corners, then accelerate afterwards.

These parameters of the model also vary depending on the gradient of the road, as this can significantly impact on vehicle performance. A tool within Signal Studio allows road gradient to be drawn onto a TM drawing as shown below:



Once a gradient is drawn onto the map, the physics model automatically takes this into account, slowing down or speeding up any affected vehicles.

In order to calculate an intergreen time, the micro-journey time for the fastest gaining vehicle is subtracted from the micro-journey time for the slowest losing vehicle.

The model assumes a worst-case scenario where the losing phase vehicle passes through amber at the very last moment before red is displayed. Equally, the gaining phase vehicle is assumed to have an instant response time to the display of red/amber and then proceeds with the maximum available acceleration right up to the collision point.

Sourcing of Vehicle Characteristics Parameter Data

In order for the physics model to provide realistic intergreen times, it is essential that the parameters being used to model the physical characteristics of each vehicle type are realistic. The model parameters cannot really be defined as 'accurate' or 'inaccurate' because they simply define the assumptions upon which the intergreen calculation will be made. The authors have attempted to select parameters for vehicles on the losing phase that represent a slower-than-average driving style. Similarly, vehicles on the gaining phase have been modelled to represent vehicles moving much faster than average.

In seeking out parameters for the model, preference was given towards official guidance that relates specifically to traffic signal timings. For example, DfT LTN1/20 is a key input to the model in terms of the characteristics of cyclists.

Unfortunately however, the model requires parameters that are less commonly published. What is a reasonable assumption of cyclist speed up a 5% incline for example? How much lateral acceleration can a cyclist comfortably handle? To fill in these gaps, data values have been brought together from a wide range of sources. These include:

- DfT Traffic Signs Manual, Chapters 6 and 8
- Cycle infrastructure design (DfT LTN 1/20)
- Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal, John Parkin & Jonathon Rotheram
- In-Depth Investigation of E-Scooter Performance, TRL 2022
- Honda PCX 125 Acceleration Tests (Popular Delivery Rider Moped!)
- Analysis of longitudinal and lateral acceleration and speed data from our own Racelogic recordings

The parameter set has undergone a number of iterations and will continue to iterate as we develop further real-world experience using the model.

The model will automatically find the slowest losing phase vehicle and the fastest gaining phase vehicle for use in the calculation. Commonly (but not always) the two vehicles that define the intergreen are a cyclist on the losing phase and a moped on the gaining phase.

Cyclists

Cyclists move slowly compared to other vehicle types and are particularly affected by gradients. Prior work by John Parkin & Jonathon Rotheram has been useful in characterising the effect of gradient on cycle speeds. One advantage cyclists do have is their ability to corner with more lateral acceleration than other slow vehicle types such as buses. This is the reason why it isn't always a cyclist in the role of 'tortoise'. A winding route can cause a bus to be slower.

Mopeds

Mopeds are an interesting case. They are small enough to work their way to the front of the queue at the gaining phase, so are often the first vehicle to move off when signals change. They have good acceleration and their riders are often financially motivated to make rapid progress (e.g. food deliveries). Observing any shuttle working site, it is very common to see a scooter gain a number of seconds gap from the vehicles behind it as they pull away at a gaining phase.

Research into the specific acceleration characteristics of mopeds was difficult to find. Figures in the model are based on acceleration tests for a Honda PCX 125 moped where the vehicle was repeatedly accelerated from 0 to 60kph and the time taken to achieve this speed recorded. An average figure of 0 to 60kph in 6.7s has been employed in the model. This is surprisingly quick and also surprisingly easy to achieve on the vehicle, which is fully automatic and simply requires a twist of the throttle.

Validation

Extensive validation of the model is required prior to it being used to generate intergreen times for deployment on street. This process is ongoing. A further backstop to this validation is the fact that Signal Studio has been configured to never provide an intergreen time value that is shorter than would have been provided by the main chapter 6 guidance (Table 6-1).

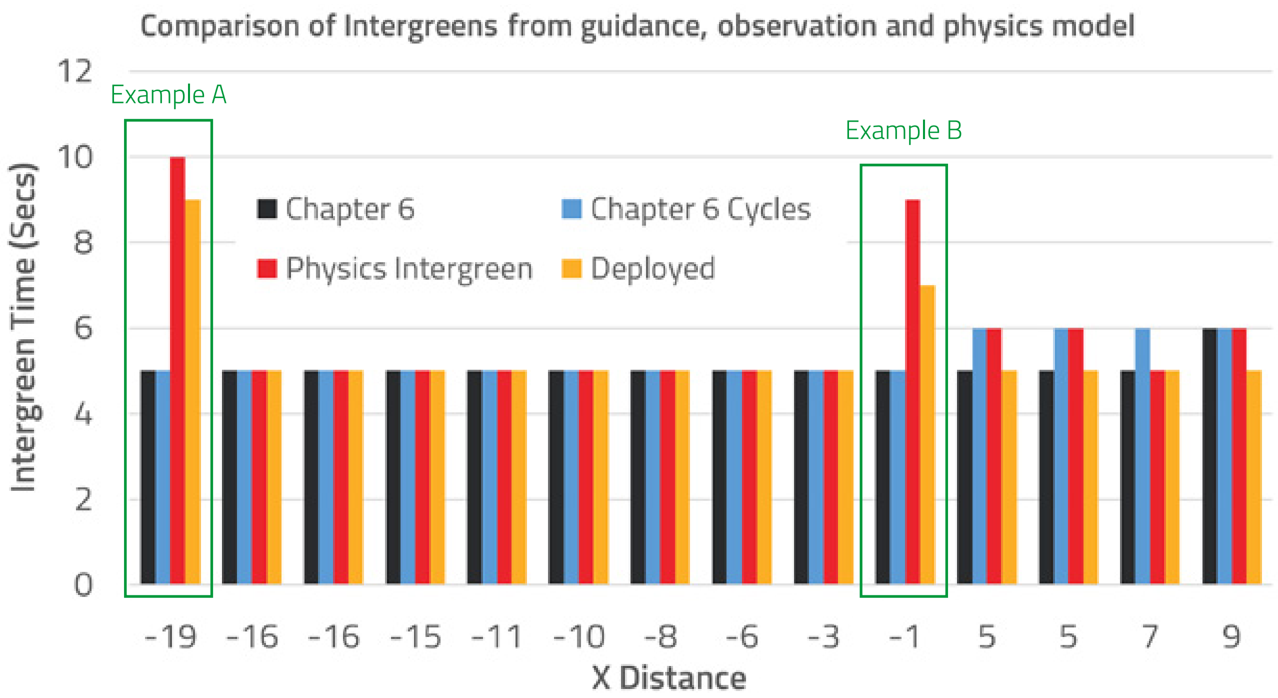
Various methods of validation have been employed. In the simplest case, a comparison of intergreen values generated by the model with those suggested by the formal guidance is a useful starting point. However, given the model is intended to go beyond the guidance, numerous other sources of validation are required.

Comparison with Historic Schemes

Having now deployed many temporary signalling schemes designed using Signal Studio, TGS has available a library of historic schemes with a complete audit trail for each, recording any manual corrections made to the intergreens that were originally derived from guidance. By re-calculating the intergreen periods for these specific transitions using the physics model, it is possible to determine whether the physics model achieves a result closer to the required value than was achieved by the guidance alone.

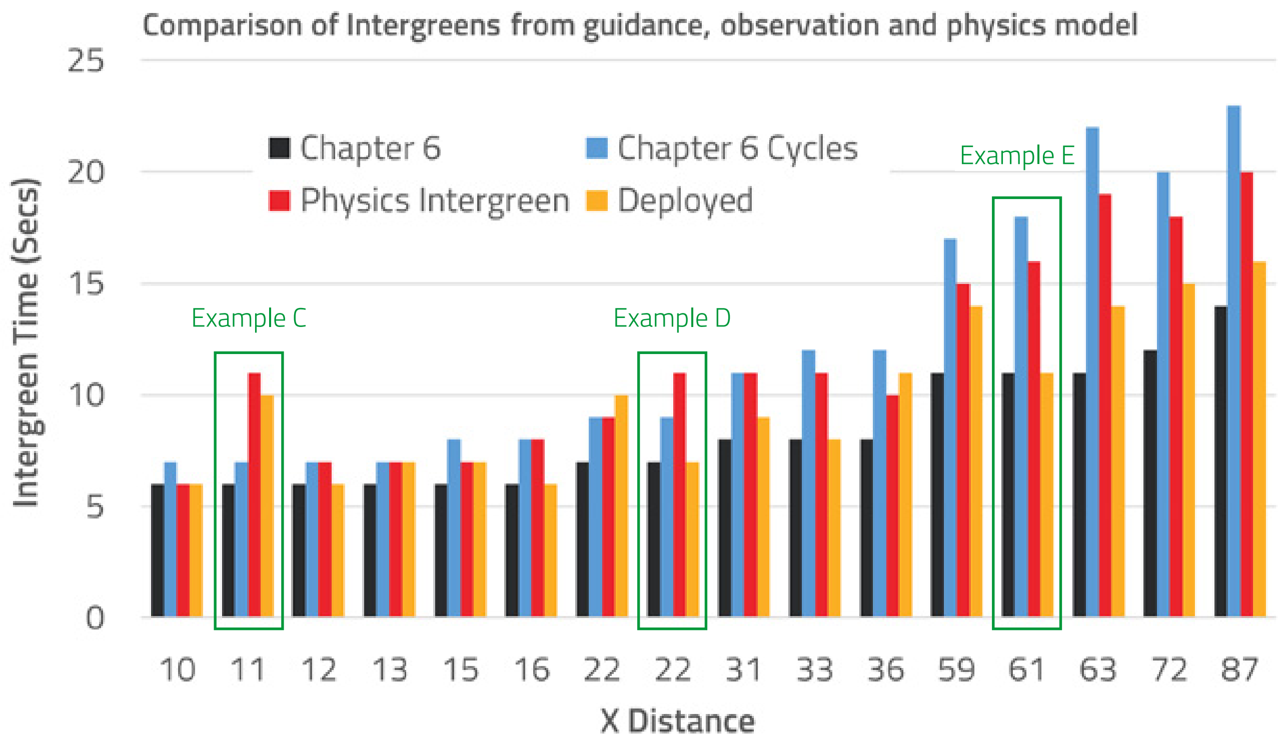
The two figures that follow show 30 individual intergreen calculations across a number of schemes. For each case, the values suggested for the Intergreen from the guidance are provided (both the table 6-1 based value and also the table 12-2 cycle specific values). The graphs also show the Intergreen that was deployed on site (derived from the guidance plus a manual correction) along with the intergreen suggested by the physics model, with no manual corrections applied.

The examples below are those for low and negative 'X' distances. Note the broad agreement between all methods other than a couple of outlier cases named here as examples A and B.



Validation

Unsurprisingly, the level of difference between the various intergreen calculation methods starts to increase at higher X distances. Three further example cases are identified here. The detailed calculations and physics model results for all five of the highlighted cases will now be presented.

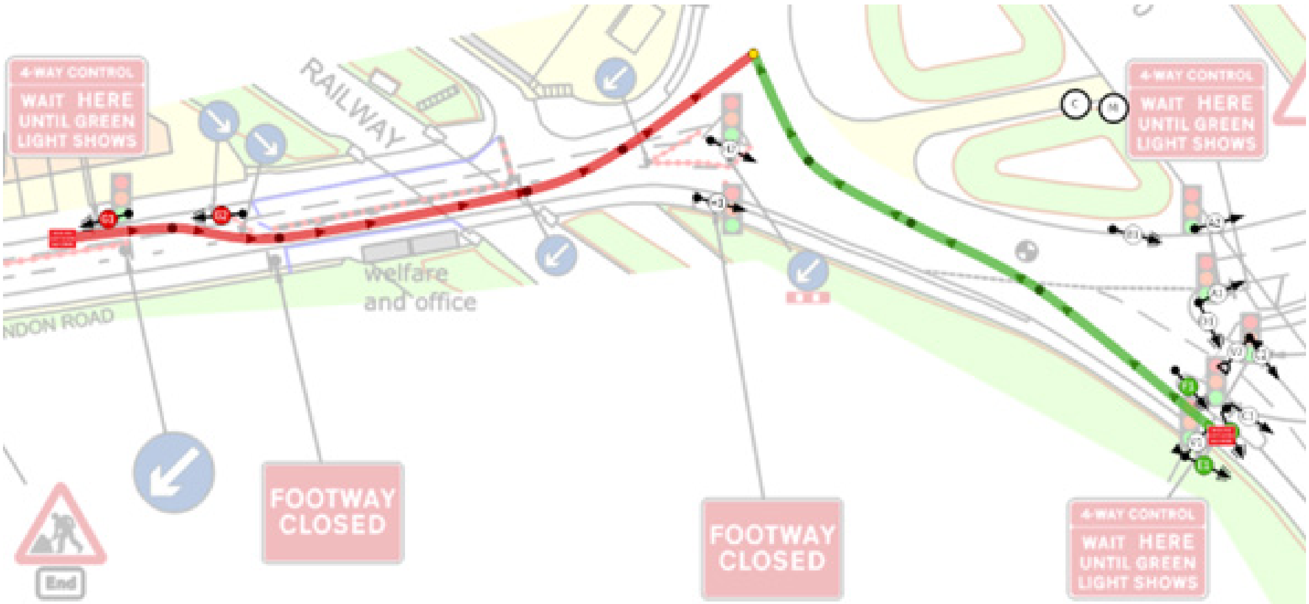


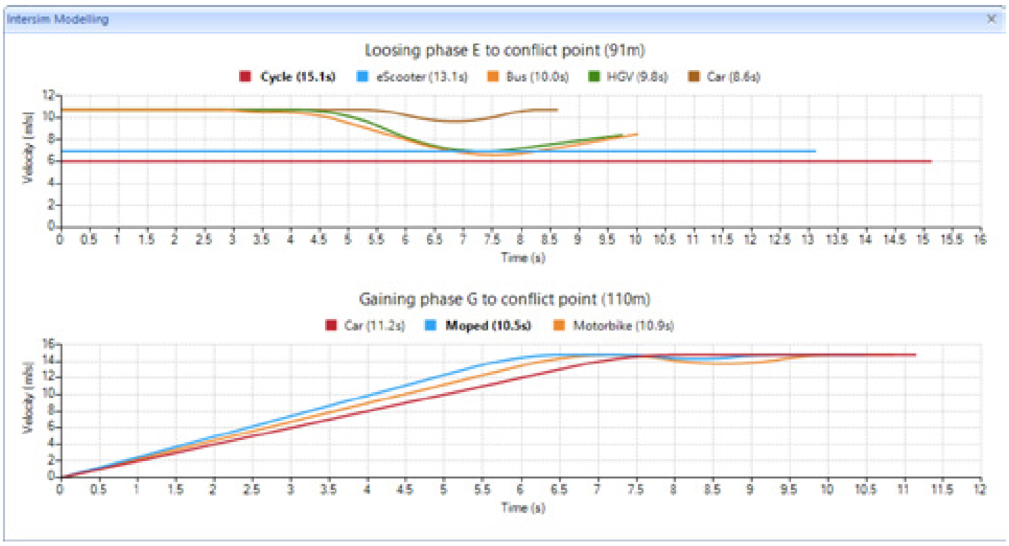
Example A: Reading Phase E to Phase G

USING GUIDANCE AND SITE OBSERVATION	
Losing Phase to Collision Distance	91m
Gaining Phase to Collision Distance	110m
'X' Distance	-19m
Guidance Intergreen (Ch6 Table 6-1)	**5s**
Guidance Intergreen (Ch6 Table 12-2)	**5s**
Manual Correction	4s
Deployed Intergreen (Table 6-1 + Correction)	**9s**

USING PHYSICS MODEL ONLY	
Losing Phase Time to Collision	15.1s
Gaining Phase Time to Collision	10.5
Time Difference	4.6s
Amber Time	5s
Physics Intergreen	**10s**

Despite the X distance being a relatively large negative value, there is clearly a need for an intergreen time above 5s. This was manually corrected following on-site observation with an extra 4s added however, the physics model picked this up at the design stage.





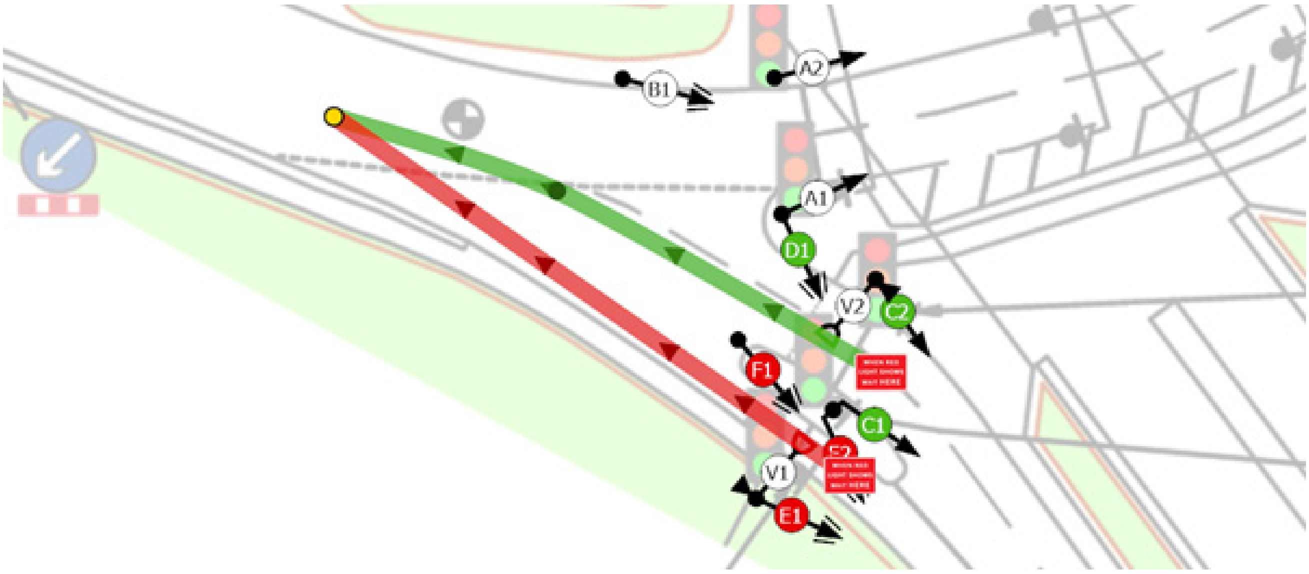
Validation

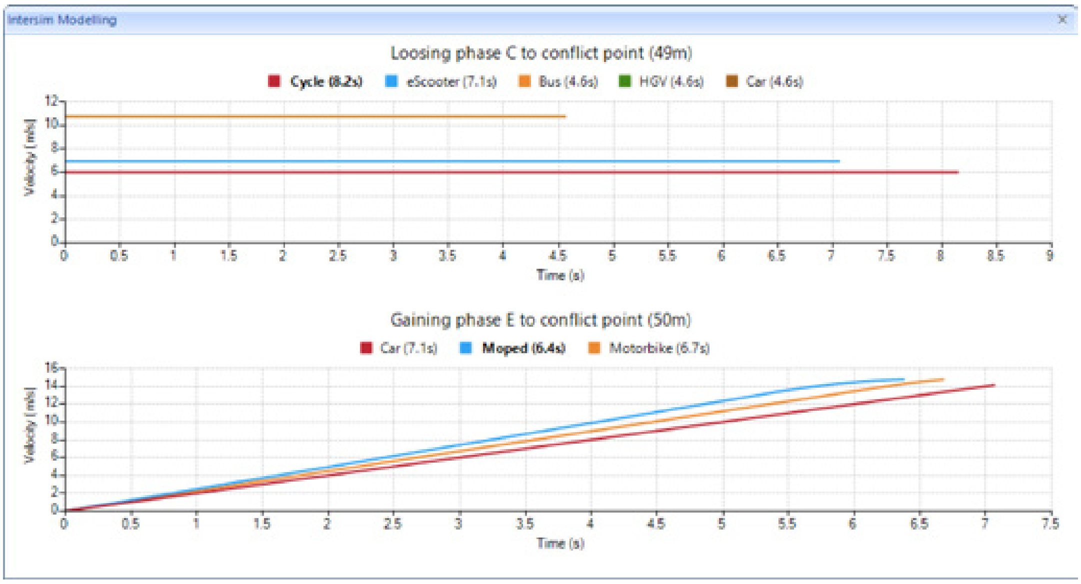
Example B: Reading Phase C to Phase E

USING GUIDANCE AND SITE OBSERVATION	
Losing Phase to Collision Distance	49m
Gaining Phase to Collision Distance	50m
'X' Distance	-1m
Guidance Intergreen (Ch6 Table 6-1)	**5s**
Guidance Intergreen (Ch6 Table 12-2)	**5s**
High Speed Approach	2s
Deployed Intergreen (Table 6-1 + Correction)	**7s**

USING PHYSICS MODEL ONLY	
Losing Phase Time to Collision	8.2s
Gaining Phase Time to Collision	6.4s
Time Difference	1.8s
Amber Time	5s
High Speed Approach	2s
Physics Intergreen	**9s**

There could be an argument in this case that these two phases could simply merge in turn. Having said that, in the case of a cyclist travelling the green line that is losing right of way, the concern here could be a vehicle accelerating quickly from phase E and undercutting the cyclist.

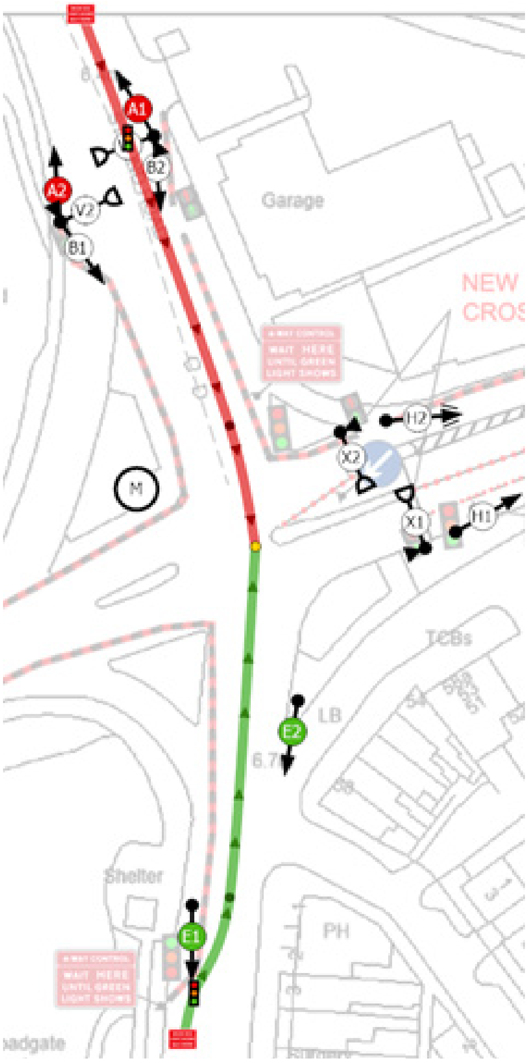




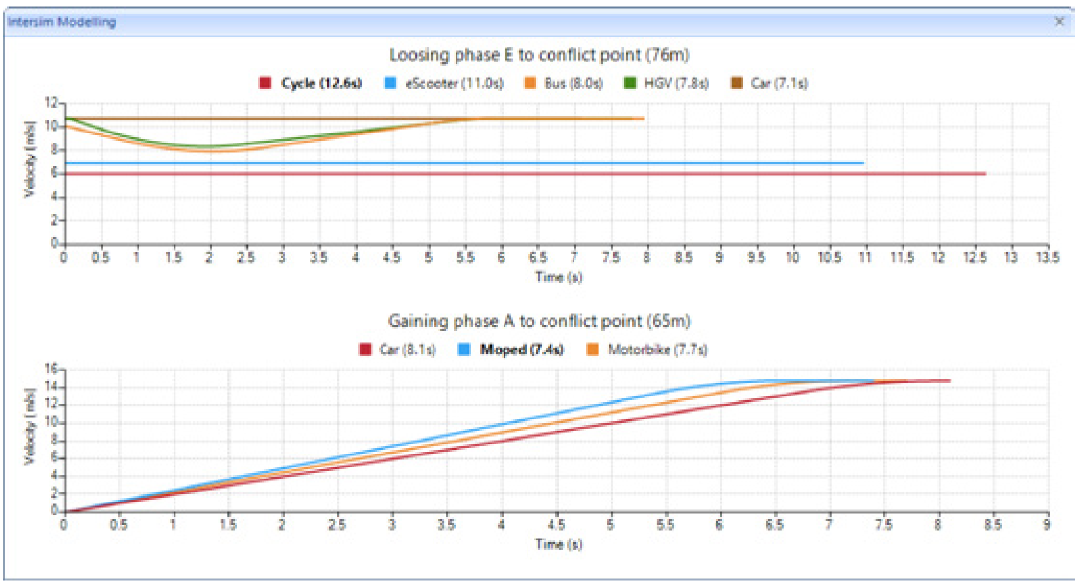
Example C: Preston Broadgate Phase E to Phase G

USING GUIDANCE AND SITE OBSERVATION	
Losing Phase to Collision Distance	76m
Gaining Phase to Collision Distance	65m
'X' Distance	11m
Guidance Intergreen (Ch6 Table 6-1)	6s
Guidance Intergreen (Ch6 Table 12-2)	7s
Manual Correction	2s
Deployed Intergreen (Table 6-1 + Correction)	10s

USING PHYSICS MODEL ONLY	
Losing Phase Time to Collision	12.6s
Gaining Phase Time to Collision	7.4s
Time Difference	5.2s
Amber Time	5s
Physics Intergreen	**11s**



Although the X distance is short here, the absolute distances to the collision point are quite long. This means that more time is available for a fast vehicle on the gaining phase to catch up with a slow vehicle exiting the losing phase. The physics model identifies this and employs an Intergreen that is close in value to the intergreen that was employed for this transition on-site (which included 4s of manually added correction).



Validation

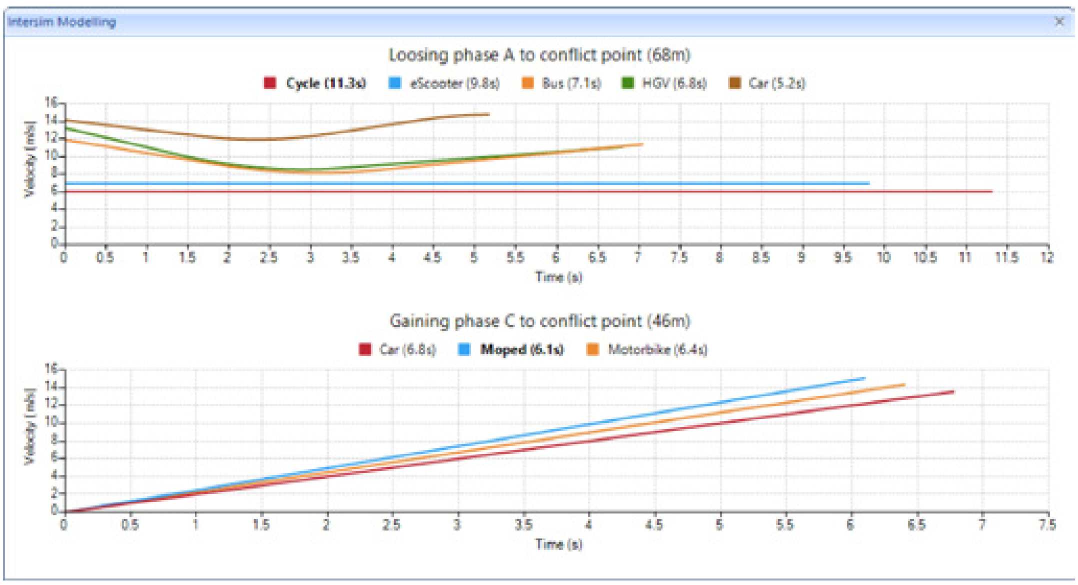
Example D: Buckingham Palace Road Phase A to Phase C

USING GUIDANCE AND SITE OBSERVATION	
Losing Phase to Collision Distance	49m
Gaining Phase to Collision Distance	50m
'X' Distance	-1m
Guidance Intergreen (Ch6 Table 6-1)	5s
Guidance Intergreen (Ch6 Table 12-2)	5s
Manual Correction	2s
Deployed Intergreen (Table 6-1 + Correction)	7s

USING PHYSICS MODEL ONLY	
Losing Phase Time to Collision	11.3s
Gaining Phase Time to Collision	6.1s
Time Difference	5.2s
Amber Time	5s
Physics Intergreen	**11s**

Shuttle arrangements like this are common in temporary traffic management schemes. Guidance was followed for this site with no correction added however it appears that potentially, with the wrong combination of road user types arriving at the wrong time, the intergreen value used may have been too short. The physics model suggests a value of 11s that is difficult to argue with when the associated graphs are reviewed.

This example shows that on-site observation is difficult to get 100% correct all of the time. There are many phase combinations to consider and each observation of a single intergreen needs to consider all road user combinations, not just car-to-car transitions. The worst-case combination of vehicles needs to be observed in order to validate that an intergreen time is correct.

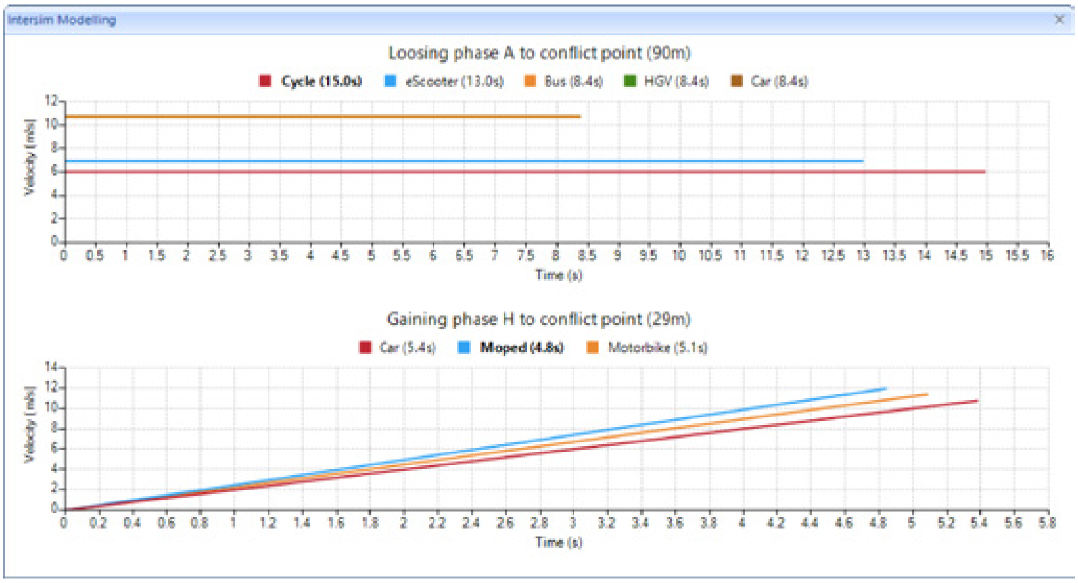


Example E: Preston Broadgate Phase A to Phase H

USING GUIDANCE AND SITE OBSERVATION	
Losing Phase to Collision Distance	90m
Gaining Phase to Collision Distance	29m
'X' Distance	61m
Guidance Intergreen (Ch6 Table 6-1)	**11s**
Guidance Intergreen (Ch6 Table 12-2)	**18s**
Manual Correction	0s
Deployed Intergreen (Table 6-1 + Correction)	**11s**

USING PHYSICS MODEL ONLY	
Losing Phase Time to Collision	15.0s
Gaining Phase Time to Collision	4.8s
Time Difference	10.2s
Amber Time	5s
Physics Intergreen	**16s**

A final example, this one is very simple because the vehicle trajectories are both straight. The physics model suggests a value that sits midway between the standard chapter 6 guidance (table 6-1) and the cycle specific guidance provided in table 12-2.

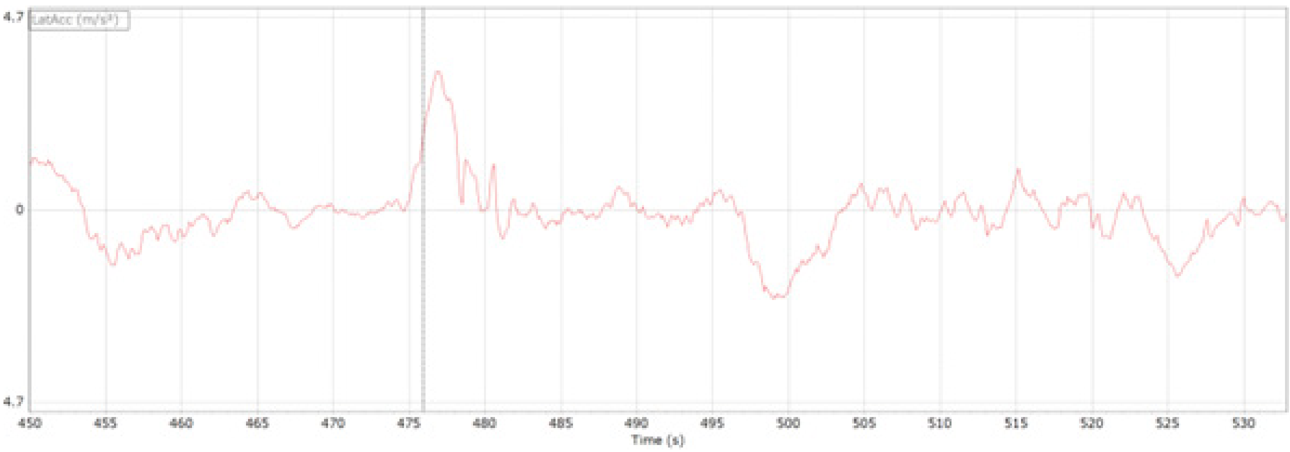


Validation

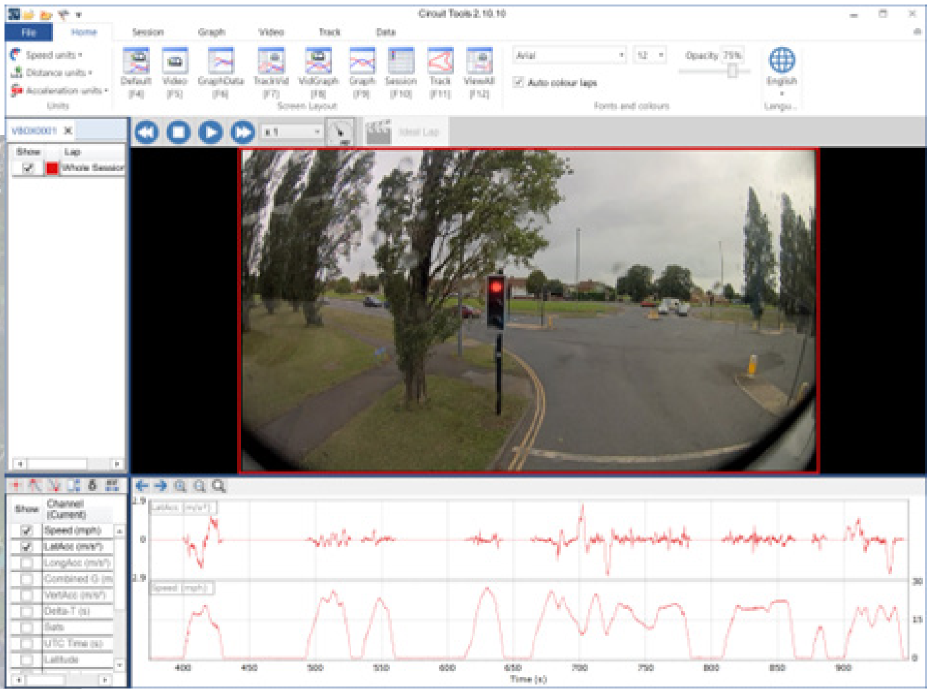
Racelogic Recordings

Additionally, a Racelogic HD Lite unit has been employed in the validation process. This GPS-equipped compact unit captures video along with a full set of kinetic measurements, which can then be plotted or extracted. The device has been used in two ways. Firstly, it has allowed specific parameters to be spot-checked (e.g. acceleration, braking or cornering accelerations). Additionally, it has been used to record micro-journeys such that their duration and speed profile can be compared with those generated by the physics model.

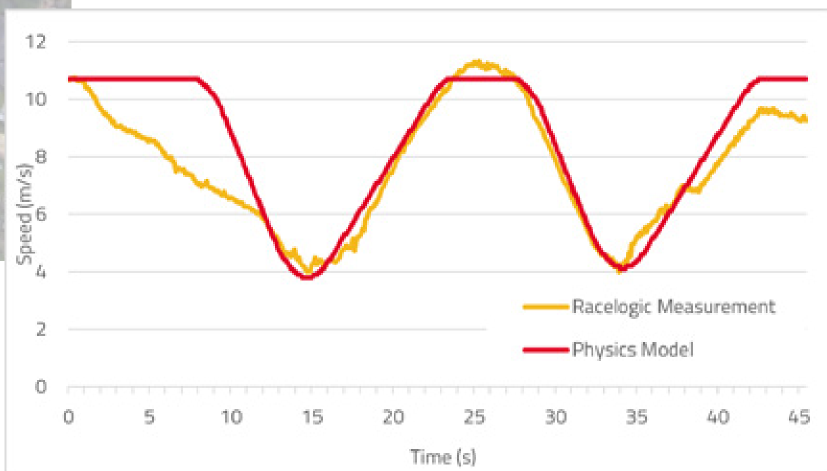
The plot below shows an example of data being recorded in order to establish a value for the typical lateral acceleration of cycles. By performing repeat runs that each adopt a different driving / riding style (from gentle to athletic / fast), it was possible to gain estimates for any model parameters that could not otherwise be derived.



The other application of the Racelogic unit is illustrated below. In this case, a very long bus micro-journey is plotted. This was longer than would be normally experienced with traffic signals but serves as a useful validation. The key aspect here is proving that the model generates a speed profile for vehicles through the micro-journey that has the same key characteristics as the recorded data. An exact match is not the aim, as real-world vehicles include variations due to driving style and other external factors that the model is not equipped to understand.



The key observation to make on this data is that the speed profile generated by the physics model, whilst not an exact match for the real-world bus, exhibits very similar overall characteristics in terms of speed, acceleration and jerk.



Retrospective Look at the Guidance

Part of the validation process for the model has involved a comparison of its results with those that would have been generated using guidance from TSM Chapter 6. Specifically, tables 6-1 and 12-2 that provide a lookup from 'X' distance to intergreen duration.

Using the terminology of this paper, the 'X' distance is calculated by subtracting the length (in metres) of the gaining phase micro-journey from the length (in metres) of the losing phase micro-journey.

To suggest that the intergreen time can be derived from this difference in distance alone requires some assumptions to be made. Possible assumptions inherent in the guidance could be:

- Vehicles on the losing and gaining phases travel at similar speeds therefore only the difference in distance is required in order to lookup an intergreen value.
- The guidance does consider the relative difference in speed between the losing and gaining phase vehicles but assumes that road geometries to which the guidance is applied are all those with relatively short distances to the collision point.

During this work it has been observed that when calculating intergreen times for signalling schemes that have a physical scale similar to that of a permanent junction, there is usually a good correlation between the intergreen values proposed by the physics model and the values that would be arrived at by calculating an 'X' distance then using this to lookup an intergreen value using the guidance tables.

However, if the length of the micro-journeys is then increased to the sort of distances that are not uncommon in the temporary traffic management environment (for example, ~70m distance to a collision point) then the values derived from the model start to deviate from the guidance.

The drawings below show the calculation of three different intergreens. All three have an 'X' distance of 0. However, they all have different micro-journey lengths (20m, 40m then 60m).

Phase A to Collision	20m
Phase B to Collision	20m
'X' Distance	0m

Phase A to Collision	40m
Phase B to Collision	40m
'X' Distance	0m

Phase A to Collision	60m
Phase B to Collision	60m
'X' Distance	0m

'X' Distance	0m
Intergreen (Guidance: Table 6-1)	5s
Intergreen (Guidance: Table 12-2)	5s
Intergreen (TGS Physics Model)	**5s**

'X' Distance	0m
Intergreen (Guidance: Table 6-1)	5s
Intergreen (Guidance: Table 12-2)	5s
Intergreen (TGS Physics Model)	**6s**

'X' Distance	0m
Intergreen (Guidance: Table 6-1)	5s
Intergreen (Guidance: Table 12-2)	5s
Intergreen (TGS Physics Model)	**8s**

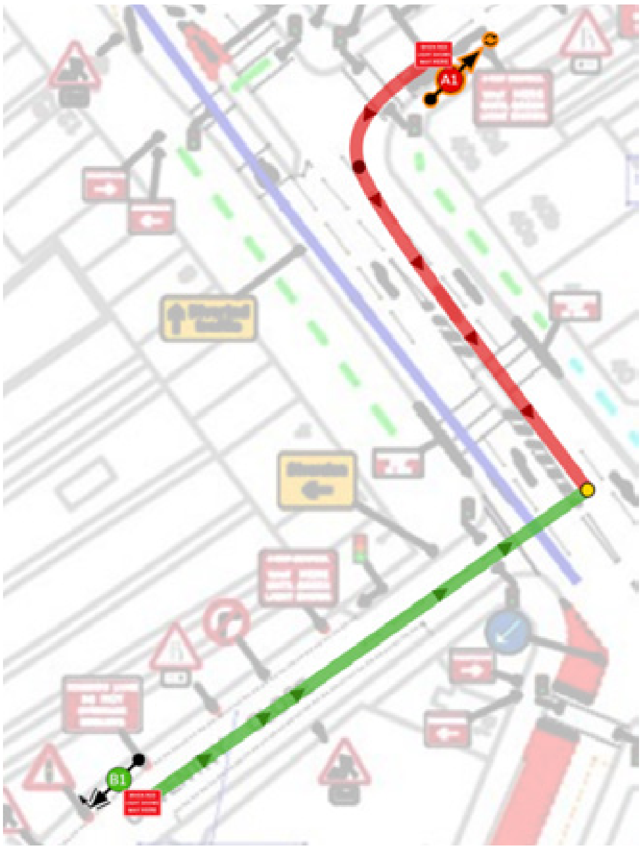
Note that the physics model indicates that as the micro-journey length increases, there becomes a need for more intergreen time. This is because the impact of the gaining phase vehicle being faster than the losing phase vehicle becomes more pronounced, the longer the overall journeys run for.

The example opposite further illustrates the benefit of employing the physics model rather than a lookup table based on 'X' distance. Again, the 'X' distance is zero.

The fact that gaining phase vehicles are making a left turn, slows these vehicles down sufficiently that the intergreen proposed by the model is now 7s. This is a reduction of 1s as compared with the model where both vehicle paths are straight.

Whilst the guidance proposes the same intergreen value for all of these cases, the physics model calculates each intergreen uniquely and from first principles based on its precise geometry.

Having identified this discrepancy, it would appear that it may be the cause of observed inaccuracies of intergreen times that TGS experienced when applying Chapter 6 guidance to temporary works schemes and which ultimately gave rise to the motivation to perform this work.



Conclusions

The following conclusions can be drawn from this work:

- The process of manually calculating an intergreen time from guidance is time-consuming as it requires two distances to be measured, an 'X' distance to be calculated and then a guidance table to be consulted. By reducing this to the task of simply drawing two lines onto a calibrated map, the task becomes much quicker and less error-prone. The review process is also quicker and less error-prone.
- Whilst many sources of guidance are available for determining intergreen times, these vary significantly for intergreen calculations at larger 'X' distances. The designer is faced with what can sometimes be a tricky decision regarding which version of the guidance should be adopted. This decision can be removed if all of the intergreen calculations are derived from a single physics-based model.
- The guidance is, by its nature, generic and intended to cover all geometries and distances. As a result of this it makes various assumptions. For some sites, the guidance may be less accurate as a result. The physics model on the other hand, calculates each site using detailed knowledge of the geometry of the site and the characteristics of different vehicle types. It still makes numerous assumptions about driving behaviours however it has potential to remain accurate over a broad range of geometries.
- Validation of the physics model is ongoing however results generated to date show that it generates values that are similar to the guidance in many cases. In cases where the physics model deviates from the guidance, this appears to be with good reason in terms of the site geometry.
- Finally, it is noted that the road user group most impacted by incorrect intergreen timings at temporary works are cyclists. The Pink Book guidance used at the vast majority of sites assumes a minimum speed of vehicles through works of 10m/s or 22.4mph. This is unrealistic and it is no surprise that cyclist groups raise numerous complaints about works. Cyclists are often either asked to dismount or given insufficient time to clear through a shuttle lane before being faced with oncoming traffic. The physics-based model presented here allows for informed decisions to be made earlier in the design process in regard to schemes that could have an undue impact on cyclists.

References

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- Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal, John Parkin & Jonathon Rotheram, 2010
- In-Depth Investigation of E-Scooter Performance, TRL, 2022

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