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A Review of Pedestrian Walking Speeds and Time Needed to Cross the Road

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Executive Summary

Introduction

Living Streets has commissioned the Transport Research Laboratory (TRL) to undertake research to consider the appropriateness of the current method of calculating the time needed for pedestrians to cross a road at signal controlled pedestrian crossings both stand alone and at junctions.

Context

Musselwhite et al (2011) refer to the World Health Organisation (WHO, 1999) saying that maintaining mobility in later life is important for maintaining health and wellbeing. Furthermore, both physical and mental health benefits are derived from increased activity. It therefore follows that the maintenance of mobility is seen as good and to be encouraged.

Safety is also a concern. In the UK, older people represent around 16% of the population, yet around 43% of all pedestrians killed (DfT, 2009).

Whether they are stand alone or part of signal controlled junctions, signal controlled pedestrian crossings work on the following principles:

- Pedestrians press a button to demand the relevant pedestrian phase;
- When the demand matures into the pedestrian phase the pedestrian is invited to start crossing by an illuminated green man;
- Following the green man period is the clearance period. The period is intended to be long enough for pedestrians who have started to cross, during the green man period, to complete their crossing. The time of this clearance period depends on the width of the road and is calculated as per DfT advice (DfT, 2009). For most crossing types the clearance period is calculated on the basis of the minimum walking speed of 1.2ms^{-1}.

The origins of the value for minimum speed and its use in the UK are unknown. LePlante (2007) reviewed research conducted in 1952 by James Exnicios and it appears that this is where the speed of 4 ft/sec (1.22ms^{-1}) used in the USA and a 15th percentile figure of 3.5 ft/sec (1.07ms^{-2}) came from. The research noted lower speeds for other pedestrian groups such as the elderly with a 15th percentile figure of 3.0 ft/sec (0.92ms^{-1}) quoted.

Since the 1960s the average age of the UK population has increased leading to a greater proportion of older people. Many older people are unable to walk at 1.2ms^{-1}. Additionally, roads are many times busier now, which means that there are fewer opportunities to cross roads in the absence of signal control. Additional issues with sight and mobility, combined with today's busier roads, mean that more pedestrians become reliant on signal controlled crossings and pedestrian facilities at junctions.

If pedestrians feel that there is not enough time to cross the road using signal controlled crossings, they may feel disinclined to use them. This may cause them to avoid going out, or use other forms of transport to undertake journeys that would otherwise be possible on foot.

The DfT document 'WebTAG' (https://www.gov.uk/transport-analysis-guidance-webtag) gives guidance for calculating the cost of traffic using the road network. This is used in calculating the overall cost-benefit ratio of new road schemes. Pedestrians are rarely included in appraisals and there appears to be no requirement for this. If 'WebTAG' values were included, pedestrian time would be valued at less than other road users due to a built in assumption that walking tends to be carried out by people with lower incomes. Therefore, the appraisal process does not appear to be geared up to encouraging walking – rather the opposite.

Increasing the clearance period will give people longer to complete their crossing, assuming everything else remains the same. The consequences of increasing the clearance period would be increased delay to motorised traffic, which may be substantial when the network is operating close to capacity. Encouraging modal shift – and increasing the clearance time may help this – could reduce the impact on motorised traffic. Providing slower pedestrians with longer to complete their crossing will improve perceived safety and amenity for them, though the effect on the behaviour of other pedestrians is not known.

Research undertaken in this project

The research consisted of:

- a literature review that concentrated on walking speeds and the consequences of giving pedestrians insufficient time to cross the road;
- a modelling exercise to consider the cost of delay to all road users (including pedestrians);
- consideration of the effects of implementing the current WebTAG guidelines on the net results of the modelling process

Limitations

In order to encourage walking, the speeds that are relevant to this study are for those who find it difficult to complete their crossing in time, and would also consider walking if the issue was resolved. The speed should also be representative of the speed achieved under the conditions to which they apply. None of the data gathered captured those key requirements. Rather they mostly measure:

- the speed of pedestrians actually using the crossing (thereby have made the choice to walk already),

  or, less frequently:

- the speed of people who would never use pedestrian crossings, for a multitude of reasons (e.g. medical conditions including mental illness) even if the clearance period was sufficiently generous.

Literature review

Walking speeds

The average walking speeds found in the literature search ranged between 0.54ms^{-1} for women over 80 (Dunbar et al, 2004) and 1.31ms^{-1} (Knoblauch et al, 1996) with many examples between. Most of the data have been captured from measurements of pedestrians actually crossing the road. As already mentioned, this will tend to exclude people who would be interested in walking if the time available to cross at signal controlled crossings was longer. However, it is not clear to what extent the speeds are representative of the speeds that people could achieve if they needed to. Nevertheless, there is a clear indication that 1.2ms^{-1} is more often than not likely to be inadequate for older people.

Safety and encouragement

One of the aims of making walking safer and more comfortable is to encourage walking as a means of transport for a whole host of reasons. Nothing was found that addresses this issue. Consequently it is impossible to say to what extent people may be encouraged to walk should they be allowed more time to complete their crossing. People do complain about the issue, however, so it seems likely that some may choose to walk more often, particularly if a crossing they would use frequently has the issue addressed.

These are the issues that may arise if clearance periods were increased:

- Significant delay to traffic when networks are close to or oversaturated;
- Extra delay to pedestrians due to longer cycle times that will be necessary to reduce the consequences of increasing clearance periods which may lead to more pedestrians crossing in gaps and increased risk taking in general;
- Safety issues if the changes are not made – slow pedestrians will continue to take longer to cross than their time available;
- Different pedestrian crossing types – a change in the clearance period will have different consequences on the different crossing types.

Attitudinal surveys

Maxwell et al (2012) reported on a trial comparing a standard Puffin with the same on one with far-side pedestrian aspects added. Considering the standard Puffin only, one statement to which participants were asked to respond to was 'I feel hurried when on the crossing'. Sixty one percent disagreed or strongly disagreed, 21% were neutral, and 18% agreed/strongly agreed. When it was put to participants that the 'Green man time was long enough', 59% agreed/strongly agreed, 18% neutral, 22% disagreed or strongly disagreed

Hoxie and Rubenstein (1994) conducted a study of one intersection in Los Angeles, California, USA where 73 people took part with a mean age of 77 years. Seventy four percent considered themselves to be in danger when they crossed the junction: 46% crossed daily and 43% were aware that they did not get to the opposite side before the light changed. Eighteen had fallen over in the past year.

Mathieson et al (2013) reported on a European project SaMERU - Safer Mobility for Elderly Road Users. Amongst the findings for Puffins and Junctions, 62% of respondents agreed when asked 'are longer crossing times required?'

Technical changes required

In the majority of cases, most signal controllers would require a PROM (Programmable Read Only Memory) change to allow for an increase in the clearance period. This can be undertaken at a modest cost. However, this may not be the only cost. The consequences of making changes to the operational efficiency of a junction (as opposed to standalone crossing) will need to be considered. This in itself will require time even if it proves that the junction or network will operate satisfactorily. If operational efficiency is compromised unacceptably, further work to mitigate the consequences will be required.

The degree to which network efficiency changes after the introduction of an increased clearance period depends both on the nature of the junctions within the network, the network itself and traffic intensities. Increasing clearance periods will always reduce network capacity (all other things being equal). This is unavoidable. However, at low to medium traffic intensities, the increase in delay to road users could be minimal. Closer to saturation though and the reduction in capacity will lead to a large increase in queuing delay. This may be offset to some extent if modal shift away from motorised vehicles is achieved.

Potential solutions

Attempts to use technology to make pedestrian crossings more user-friendly have been tried with varying degrees of success. Puffin crossings were found to be 19% safer than Pelican crossings (Maxwell et al, 2011). PCaTS proved very popular with users (York et al, 2009) although such crossings are not compatible with variable clearance periods, as provided by Puffin crossings, and are likely to encourage pedestrians to look at the countdown display rather than observe vehicles. A more recent application of technology (under trial at the time of writing) is using detectors to count pedestrians, such that the invitation period can be varied. This may help slower pedestrians who join the back of a crowd by helping them to become established on the crossing before the green man ends.

Government policy on the issue of pedestrian crossings has been clear in favouring Puffin crossings and Puffin facilities at junctions for many years. Policy has stopped short of insisting that Puffins are used in place of Pelicans. However, DfT have recently announced that Pelicans are to be ‘phased out’ as part of a consultation exercise on the new Traffic Signs, Regulations and General Directions (TSRGD). A complication is that TfL are keen to use countdown timers, currently an increasingly common sight at junctions in London, at standalone crossings. It remains to be seen how this unfolds.

Conclusion and Recommendations

From the literature it would appear that the current assumed walking speed of 1.2ms^{-1} is higher than can be achieved by a significant and growing proportion of the population. However, the consequences of reducing the assumed speed need to be considered carefully. Therefore the following recommendations are made.

1. There is a clear indication that 1.2ms^{-1} cannot be achieved by a proportion of the population, particularly the elderly. There is an increasing need to addressed this issue.

2. Further research would be required to estimate the number of people affected by the clearance period particularly those who would choose to walk if more time was allowed. Once the estimated number is known it will be possible to consider and quantify those benefits in terms of costs. WebTAG considers the cost of walking as less than that of driving which reduces the impact of and discourages walking interventions. Costs should be made more equitable and there should be a requirement to include pedestrians in all appraisal processes.

3. Wider implementation of Puffin crossings (and the equivalent PedEX crossings that utilise on-crossing detection to vary the clearance period).

4. Implement longer maximum periods at Puffin crossings.

5. Employ technology to detect pedestrians to vary the time they have to cross. For example the technology that TfL is trialling at the time of writing to detect the number of pedestrians waiting to cross and varying the invitation to cross period. This approach allows the use of countdown timers as the clearance period is not varied.
6. Increasing the clearance period would address the issue of walking speeds being lower than $1.2ms^{-1}$. However, behavioural changes could result which may have an impact on safety. Therefore, the most important next step would be to assess the safety impact of lengthening clearance times, both with respect to crossings with fixed clearance periods and those with variable times up to a maximum.

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1 Introduction

Living Streets has commissioned the Transport Research Laboratory (TRL) to undertake research to consider the appropriateness of the current method of calculating the time needed for pedestrians to cross a road at signal controlled pedestrian crossings both stand alone and at junctions.

1.1 Context

Musselwhite (2014) refers to the World Health Organisation (WHO, 1999) saying that maintaining mobility in later life is important for maintaining health and wellbeing, affording older people[1] close contact with family and friends, enabling access to services, shops and facilities, to engage in sports and leisure and to enhance connectivity and inclusion while remaining actively engaged with society. Furthermore, both physical and mental health benefits are derived from the activity. Indeed, the opposite also holds – a lack of mobility will lead to both physical and mental deterioration. It therefore follows that the maintenance of mobility is seen as good and to be encouraged.

Safety is also a concern. In the UK, older people represent around 16% of the population, yet around 43% of all pedestrians killed (DfT, 2009).

The removal of barriers to this continuing mobility has to be addressed in order to provide encouragement to staying mobile. Much has been achieved over the last 20 years or so and the 1995 disability act puts a responsibility particularly on local highway authorities to cater for the less able-bodied people in society.

One aspect that has been highlighted as a potential problem many times over the years, but not acted upon in any substantive way in the UK, is the time required for pedestrians to cross the road at either a pedestrian facility at a signal controlled junction, or at stand-alone signal controlled pedestrian crossings. This report considers the need for, and the implications of changing the signal timings to allow pedestrians more time to cross.

1.2 Principles of pedestrian crossing operation

Whether they are stand alone or part of signal-controlled junctions, signal-controlled pedestrian crossings work on the following principles:

- Pedestrians press a button to demand the relevant pedestrian phase;
- When the demand matures into the pedestrian phase the pedestrian is invited to start crossing by an illuminated green man;
- Following the green man period is the clearance period. The period is intended to be long enough for pedestrians who have started to cross, during the green man period, to complete their crossing. The time of this clearance period depends on the width of the road and is calculated as per DfT advice. For the Pelican crossing a formula is used to calculate the clearance period (the flashing green man period) which effectively allows for walking speeds of 1.0ms^{-1} for crossings of 6 metres to 1.1ms^{-1} for crossings of 12 metres (DfT, 2009). For all other crossing

[1] Generally in this report the term 'older people' refers to those over the age of 65. However some studies vary from this age.

types the clearance period is calculated on the basis of the minimum walking speed of $1.2ms^{-1}$ (DfT, 2009)

The origins of the value for minimum speed and its use in the UK are unknown. The United States have long since used 4 ft/sec ($1.22ms^{-1}$) which appears to have come from research conducted in 1952 by James Exnicios whilst a student Graduate of Yale University. This research was reviewed by LePlante (2007) and it also gave a 15th percentile[2] figure of 3.5 ft/sec ($1.07ms^{-1}$). The research noted lower speeds for other pedestrian groups such as the elderly with a 15th percentile figure of 3.0 ft/sec (0.92 m/s) quoted.

In the UK the value of $1.2ms^{-1}$ is used for all crossings apart from Pelican crossings. Many other countries use the same speed to calculate clearance periods, although some have reduced that speed: e.g. Singapore and Toronto use $1.0ms^{-1}$. UK advice specifies that crossings having a high proportion of slower pedestrians should adopt a lower speed when calculating the clearance periods.

1.3 Mobility in an ageing population

Pedestrians trying to cross the road will need larger gaps if they are slower than average. Since the 1960s the average age of the UK population has increased. This has led to a far greater proportion of older people, many of whom are unable to walk at $1.2ms^{-1}$. Additionally, roads are many times busier now, which means that there are fewer opportunities to cross roads in the absence of signal control. Anecdotally some pedestrians feel that there is not enough time to cross the road. Recent trials carried out in the UK by Maxwell et al (2012) show that at one experimental crossing, when asked 'do you feel hurried on the crossing', about 20 percent agreed or strongly agreed.

Additional issues with sight and mobility, combined with today's busier roads, mean that more pedestrians become reliant on signal controlled crossings and pedestrian facilities at junctions. The provision of pedestrian facilities appears to be given a reasonably high priority in general, with the acceptance over the past decade or more that pedestrians are entitled to be able to walk about safely.

However, at signal controlled pedestrian facilities and crossings, some pedestrians may not be able to, or at least feel they are not able to, complete their crossing within the time available. If pedestrians feel that there is not enough time to cross the road, they may feel disinclined to use signal controlled crossings. This in turn may cause them to be reluctant to cross the road, effectively limiting their mobility. It may even cause them to not go out, or use other forms of transport to undertake journeys that would otherwise be possible on foot.

Increasing the clearance period will give people longer to complete their crossing, assuming everything else remains the same. This may encourage walking as a means of transport as a benefit. However, there are always consequences of making changes and the size of the effect of those consequences has to be taken into account. This report considers the consequences in detail.

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[2] The 15th percentile value is the speed above which 85% of the population walk and represents a pessimistic view of the achievable speeds of the sample.

1.4 Literature review and project objectives

The research reported herein consisted of:

- a literature review that concentrated on walking speeds and the consequences of giving pedestrians insufficient time to cross the road;
- a modelling exercise to consider the cost of delay to all road users (including pedestrians);
- consideration of the effects of implementing the current WebTAG guidelines on the net results of the modelling process

Estimating the cost of making changes to the clearance period for a typical junction factored over the whole country has been considered. Such an exercise would include an assessment of the potential for modal shift and the benefits that it could bring in terms of improved health and reduced pollution. Also to be considered is the extent to which existing traffic network modelling techniques consider pedestrian movement and in particular how DfT's WebTAG relates to the issue

1.5 Limitations of the research found

When conducting this literature review a significant issue became apparent regarding the data on which the evidence of walking speeds is based. One of the key objectives of better pedestrian provision is to encourage walking as a means of transport with all the benefits that brings. This means making it possible, safe and desirable, in order to encourage those who currently don't walk at all, or avoid certain journeys for various reasons. Specifically, in the context of this report, we are interested in those people who avoid walking because they find that the clearance period is not long enough for them to cross the road at either signal controlled junctions or stand-alone crossings.

The issue is that, in order to consider walking speeds that are relevant to the issue, information regarding the speeds of those who are both affected by the crossing time issue and would consider walking if the issue was resolved, is required. This would mean obtaining walking speed data not only for such people but in such a way that is representative of the speed achieved under the conditions to which they apply. None of the data gathered captures those key requirements. Rather they mostly:

- measure the speed of pedestrians actually using the crossing (thereby have made the choice to walk already),

  or, less frequently:

- include the speed of people who would never use pedestrian crossings, for a multitude of reasons, even if the clearance period was sufficiently generous.

In addition, the data available is rarely categorised in terms of age other than over 60 or 65. Mobility at the age of 60 to 65, and several years after, is likely to still be satisfactory for the majority relative to the issues under consideration. Furthermore, the category of 'over 60/65' is likely to consist of a skewed distribution biased, possibly quite significantly, to the lower end of the age range. This doesn't help in terms of quantifying the extent of the problem.

Further research would be required to estimate the number of people affected by the issue. Once the estimated number is known it will be possible to consider the benefits and quantify those benefits in terms of costs.

2 Literature review

2.1 Literature found

A number of keywords were used to search for information regarding pedestrian walking speeds and related subjects. Together with literature already identified by the client, other references came to light and were perused. Most of what follows is about pedestrian walking speeds and safety in general because this is the main focus of the work. Other information on, for example, severance, would have been of peripheral interest only to the research found.

2.2 Walking speeds

Musselwhite (2014) examined speed of walking of 365 people aged 65 and over at three sites in the North-West of Britain representing urban shopping, residential suburban and shared space[3]. The female mean age was 71.2 (standard deviation 5.42) and male mean age 69.84 years (sd=5.48). Older people's average speed was recorded at 0.95ms^{-1}, the distribution relatively normal. The speeds varied significantly by location. Older people walked 'much quicker' (sic) in 'urban shopping' area (mean=0.99ms^{-1}; sd=0.22) than they did in 'residential suburban' (mean=0.93ms^{-1}; sd=0.21) and 'shared space' (mean=0.91ms^{-1}; sd=0.21). No explanation as to why was offered

Asher et al (2012) used data from the Health Survey for England, which is an annual, cross-sectional survey of a nationally representative sample of adults and children living in private households in England (Craig and Mindell, 2007), to consider the issue of walking speed. The study population consisted of 3,145 older adults (46% men). Mean age was 73.6 years in men and 74.6 years in women. Walking speed was assessed by timing how long it took the participants to walk 8 feet at their normal pace in their own home. It was not an attempt to measure high performance. Participants could use walking aids but could not be supported by another person. The test was not carried out if they were unable to walk the distance, were unsafe, unwilling, if there was no suitable space, or if their walking aid was unavailable. The mean walking speed was 0.9ms^{-1} (SE 0.01) in men and 0.8m/s (SE 0.01) in women, with a decrease in speed as age increased. Of the sample, 76% of men and 85% of women had a walking speed under 1.2ms^{-1}. Also in the sample, 93% of woman and 84% of men had walking impairment. See Table 1. The speeds are markedly slower than the majority of others mentioned in this report. This would seem likely because of the measurement methods and particularly the location within the home.

Table 1. Asher et al: Walking speeds of older people measured in their homes

Walking speed (ms^{-1})	**65-69**	**70-74**	**75-79**	**80-84**	**85+**	**ALL 65+**
Mean, (ms^{-1})	1.0	0.9	0.9	0.8	0.7	0.9
25th percentile	0.8	0.8	0.7	0.6	0.5	0.7

[3] Shared space refers to pedestrianized streets where vehicles are still allowed

Research carried out by Sterling et al (2009) considered a reduction in the invitation to cross (or green man) period at nine sites in London of mixed residential and commercial use. Up to that time, the rule for setting up the invitation to cross period in London was that it should be long enough to allow pedestrians to get past the half-way point if they started crossing at the beginning of the green man. DfT guidance says that the invitation period should be 6, 7 or 8 seconds, depending on crossing length and pedestrian flow. The London method usually resulted in times longer than 6 seconds, and often more than 8 seconds. This increases time lost to vehicular traffic particularly at stand-alone crossings on wide roads and at junctions that employ an all-red (to vehicles) pedestrian stage. Sterling looked at a reduction to 6 seconds at 10 sites where the previous values ranged between 8 and 12 seconds.

Walking speeds were amongst the data collected before and after. Little detail or breakdown was supplied on the data or any explanatory commentary provided. The information that was given was that approximately 20 measurements per site were made over the course of a working day. Thus there was no indication of demographics, age or intent, though there was probably a range for each relative to each site, even if each site had its own range of pedestrian types restricted due to its location. The 15th percentile speeds over all sites was 1.14ms^{-1} before the change and 1.32ms^{-1} after. The change was statistically significant, though no explanation was given. The average walking speed across all the sites was virtually unchanged at 1.46ms^{-1} before and 1.45ms^{-1} after. The lowest average walking speeds at any one site were 1.05ms^{-1} before and 1.09ms^{-1} after, both measured at the same site. None of the average speeds were statistically significantly different before and after.

Knoblauch (undated) recorded the speed of 3,665 over-65 pedestrians and a similar number under that age crossing 16 crosswalks over 4 urban locations: Richmond, Virginia; Washington DC; Baltimore, Maryland and Buffalo, New York. The relevant figures are included in Table 2

Table 2. Knoblauch: Average and 15th percentile speeds for under and over 65s – whole sample

	Under 65 Average/15th percentile (ms^{-1})	Over 65 Average/15th percentile (ms^{-1})
Male	1.56/1.30	1.31/1.02
Female	1.46/1.20	1.19/0.93

Pedestrians who comply to the signals generally walked slower as shown in Table 3.

Table 3. Knoblauch: Average and 15th percentile speeds for under and over 65s – compliers only

	Under 65 Average/15th percentile (ms^{-1})	Over 65 Average/15th percentile (ms^{-1})
Male	1.51/1.27	1.26/0.99
Female	1.41/1.18	1.14/0.91

The differences are small, but arguably indicate that:

- there is less pressure for compliers on average as compared to crossing in a gap in the traffic;
- non-compliers may be in more of a hurry generally than compliers;
- compliers tend to comply because they can't walk as fast as non-compliers;
- on average, most of those who comply wait for the green man before starting to cross (as opposed to arriving part way through the green man). They therefore have the whole of the green man period, plus clearance period, in which to cross, so not under so much pressure to cross quickly.

Knoblauch (undated) also recorded start-up time[4] (see Table 4). Start-up time will only apply to pedestrians who have stopped and are responding to the green man (or a gap in the traffic) and as such should become 'established' early in the invitation period and be at least part way across before the clearance period commences. Where pedestrians are already moving there is no start up time involved by definition.

However, once the start-up time reaches 4 seconds or more, and because this applies to the slower pedestrians, it may start to impinge on their ability to complete the crossing in time. Furthermore, when pedestrian demand is high, if a slow pedestrian joins the back of a crowd of waiting pedestrians, a slow start up time could easily prevent them from becoming established on the crossing within the standard 6 seconds of green man.

Table 4. Knoblauch: Average and 85th percentile start up times for under and over 65s

	Under 65 Average/85th percentile[5] start up time (secs)	Over 65 Average/85th percentile start up time (secs)
Male	1.82/2.76	2.39/3.66
Female	2.01/3.31	2.57/3.95

Gates et al (undated) recorded similar speeds (Table 5)

Table 5. Gates: Average and 15th percentile speeds

Average/15th percentile (ms^{-1})		
Under 30	30 - 64	65 and over
1.35/1.16	1.31/1.12	1.06/0.84

Gates also found that groups cross between 0.12 and 0.19 ms^{-1} slower than sole pedestrians as shown in Table 6, depending on group size.

[4] Start-up time is the time taken for a stationary pedestrian to react to the appearance of the green man and reach or just step off the kerb.

[5] The 85th percentile, i.e. the time below which 85% of the sample achieved, is used here (as opposed to the 15th percentile used for speeds) because it includes 85% of the population.

Table 6. Gates: speeds for groups of pedestrians

Group size	Mean	15^{th} percentile
1	1.44	1.20
2-4	1.32	1.12
Over 5	1.25	1.06

Hoxie and Rubenstein (1994) described work that included retiming to allow a greater time for pedestrians to cross at a number of intersections on Queens Boulevard, New York, as part of a pedestrian safety project (Queens Boulevard Pedestrian Safety Project). The other changes included:

- road markings to emphasize pedestrian crossings, traffic lanes, and the direction of traffic flow;
- pedestrian signals on median islands;
- oversized speed limit signs and increased police enforcement of the speed limit;
- safety education presentations at senior citizen centres.

Collision data revealed that there were 22 deaths and 18 'likely deaths' along a 2.5-mile length of the street over a 4-year period before the changes. The fatally injured pedestrians were disproportionately elderly; nearly all were at least 60 years old. These were particularly wide intersections of between 48 and 62 metres across. The work does not quantify the changes made to the timings. A 43% reduction in fatalities was achieved after the treatments.

In this project, Hoxie and Rubenstein also measured the walking speed of a sample of 1,229 pedestrians, 48% of whom were judged to be older than 65. Even with the clearance periods set in accordance with a walking speed of 4 ft/sec, 27% of the over 65s did not reach the other side before the signals changed to allow vehicles into the intersection. However, with large intersections the time needed for vehicles to reach the pedestrian crossing from standstill will be noticeable, and, in effect, could give pedestrians extra time to complete the crossing. Pedestrians may, therefore, not be under pressure to complete their crossing within the clearance period and may not be walking as fast as they could.

The speeds measured were 1.28ms^{-1} for under 65s and 0.86ms^{-1} for over 65s. Of the over 65s, 96% walked at less than the 4ft/sec (1.22ms^{-1}).

Romero-Ortuno et al (2009) reported that older pedestrians often report inability to complete their crossing within the time given by the pedestrian lights at urban intersections in Dublin, Ireland. He also measured 'comfortable' walking speed using the 'GAITRite™'[6] system and grouped pedestrians into different age categories (Table 7). The system appears to require subjects to start from stationary. It is not clear whether this is accounted for or not. It is also not clear whether the subjects were regular users of pedestrian crossings. Bohamon (1997) found that maximum speed of older pedestrians

[6] GAITRite™ is a portable Temporospatial Gait Analysis system that uses a mat and electronics to measure the walking gait of subjects

is approximately 30% greater than the comfortable speed. Romero-Ortuno recognised that this may not hold true for subjects in the older age ranges who may be less able to achieve a walking speed 30% higher than their comfortable speed. Nevertheless, Table 7 includes an indication of the maximum walking speed based on the 30% increase.

Table 7. Romero-Ortuno et al: Average comfortable and factored maximum speeds

Pedestrian walking speed (ms^{-1})				
Age group	60 – 69	70 – 79	80 - 89	all
Comfortable	1.18	1.04	0.82	1.05
Max (= comfortable x 1.3)	1.53	1.35	1.07	1.36

Taranweh (2001) refers to a number of studies that suggest the walking speed used to calculate clearance periods should be lowered. He also went on to suggest that faster speeds are achieved when vehicles are close by (1956 reference). The mean walking speed for over 65s was $1.17ms^{-1}$ and the 15^{th} percentile was $0.97ms^{-1}$. Some other categories of pedestrian recorded an average speed of under $1.2ms^{-1}$

As part of a project considering the benefits of Puffin crossings in general, Walker et al (2005) reported a walking speed of 1.1 to $1.5ms^{-1}$ for over 60s on a number of Pelican and Puffin crossings.

Gates et al (2006) found that in a study across 11 intersections (in Madison and Milwaukee, Wisconsin, USA) the walking speed for pedestrians over the age of 65 had mean and 15^{th} percentile speeds of $1.16ms^{-1}$ and $0.92ms^{-1}$ respectively. He also reported that speeds for those during the 'WALK' period (the equivalent of the green man) were lower than for the 'DON'T WALK' and 'FLASHING DON'T WALK' periods (see Table 1).

Table 8. Gates et al: walking speed by period in the signal cycle

Pedestrian walking speed (ms^{-1})		
	mean	15^{th} percentile
DON'T WALK (≡ red man)	1.53	1.29
FLASHING DON'T WALK (≡ clearance period)	1.56	1.31
WALK (≡ green man)	1.37	1.15

TfL (2005) conducted 541 roadside interviews at selected sites in Greater London, with 232 at Pelican crossings and 309 at Puffing crossings. Care was taken to interview at equivalent sites to avoid bias due to differences in site characteristics between Puffin and Pelican. It was reported that 88% of all those interviewed at Puffin crossings agree that they provide enough time to cross, whereas 8% don't agree (increasing to 90% and 6% respectively for subjects who were over 61). For Pelican crossings the corresponding proportions are 69% and 18% respectively (60% and 33% for over 61s). This is despite the fact that, in theory at least, the clearance period for Pelican crossings is longer than the maximum time at Puffins. However, this author is aware that the maximums for some of the Puffins considered in this work were set higher than current guidance suggests.

2.3 Attitudinal studies

Maxwell et al (2012) reported on a trial at a Puffin crossing that considered the benefits (or otherwise) of adding far side pedestrian aspects. An attitudinal study was undertaken before and after the introduction of the additional aspects. The modified crossing, with the far-side aspects, was considered to introduce safety issues in that pedestrians were paying less attention to the road and more to the far side aspects. Because of this, the figures for the modified Puffin have been disregarded in this report.

One statement to which participants were asked to respond to was 'I feel hurried when on the crossing'. Sixty one per cent disagreed or strongly disagreed, 21% were neutral, and 18% agreed/strongly agreed. When it was put to participants that the 'Green man time was long enough', 59% agreed/strongly agreed, 18% neutral, 22% disagreed or strongly disagreed

Also put to them was 'I feel anxious while on the crossing' – 13% agreed/strongly agreed, 14% were neutral and 74% disagreed/strongly disagreed. Another statement was 'If I started when the green man is showing I have enough time'. Fifty per cent agreed/strongly agreed, 23% were neutral, 26% disagreed/ strongly disagreed.

Eighty six per cent agreed/strongly agreed that they 'feel safe using this crossing', with 12% being neutral and just 2% disagreeing or strongly disagreeing. Fourteen (out of 91) said that the pedestrian phase was not long enough however.

Carthy et al (1995), summarising a pilot road-crossing observation study at two problematic sites in Newcastle, indicated that one of the two main causes of potentially unsafe crossings was the situation in which an older person carefully negotiated the first half of the road but did not consider the situation in the second half of the crossing. On the other hand, there have been reports that some older people express anxiety about becoming stranded at a refuge (Wilson and Rennie, 1981). Ekman and Hyden (1999) described results showing that on average refuges reduce pedestrian–vehicle conflicts at comparable locations.

Hoxie and Rubenstein (1994) conducted a study of one intersection in Los Angeles, California, USA where 73 took part with a mean age of 77 years. Seventy four percent considered themselves to be in danger when they crossed the junction: 46 crossed daily and 43 were aware that they did not get to the opposite side before the light changed. Eighteen had fallen in the past year.

Mathieson et al (2013) reported on a European project SaMERU - Safer Mobility for Elderly Road Users. Amongst the findings, 62% of respondents agreed when asked 'are longer crossing times required?' (for Puffins and Junctions).

2.4 Current activities

At the time of writing, TfL are engaged in trials that use detectors that count the number of waiting pedestrians. Armed with this knowledge, the invitation to cross period is varied, with longer times applied when there are more pedestrians waiting. Longer green man times will help ensure pedestrians become established on the crossing before the clearance period. This seems likely to be of benefit for slower pedestrians who may otherwise not have reached the kerb before the clearance period commences.

There have been some recent examples of crossings having the clearance period altered:

- In June 2013, parents living in Islington who use the pedestrian crossing outside Tufnell Park tube station have been given more time to cross the road by transport engineers. Members of Tufnell Park Parents' Support Group raised concerns about a crossing which they found difficult to cross, especially when accompanying young children, within the time given.

  After the timings were altered, problems arose with junction capacity for vehicles during peak periods, so it was changed so that the additional time only applied during off peak periods.

- In Rotherham in December 2013, pedestrians were starting to notice that they were having to wait unacceptably long for the signals to change in their favour. After investigation, the local highway authority corrected a detector fault, which avoided pedestrians waiting as long. http://www.southyorkshiretimes.co.uk/news/local/video-concerns-raised-over-crossing-delays-in-swinton-1-6321514

  The authority also said that they would look into the length of the clearance period if asked to do so.

- Changes to the pedestrian timings at Anniesland junction in Glasgow in February 2014 led to a sharp increase in complaints from drivers who were being delayed substantially longer than they were before. The local highway authority said that the timings were altered to bring them 'in line with standard sufficient crossing times for pedestrians' (presumably being too short before). They will continue to monitor the timings to 'balance the requirements of all road users'. http://www.eveningtimes.co.uk/news/light-changes-leave-furious-drivers-in-a-jam-150558n.23296510

2.5 Safety

Ward et al, (1994) in a study conducted in Northampton, UK stated that crossing the road leads to casualties: an increase of 15% in crossing activity leads to 50% collisions. However, crossing at Pelican crossings approximately halves the risk compared with crossing the road anywhere. There is also risk hierarchy with district distributor roads having the highest risk, followed by local distributor then residential

Maxwell et al (2010) reported on a study conducted in England comparing collisions at 40 stand-alone crossings and 10 junctions before and after they had been converted to Puffin crossings or Puffin type facilities at junctions. Statistically significant (at the 5% level) reductions in personal injury collisions of 19% overall were found, with 17% reduction at stand-alone crossings. The quality of the installations was carefully checked, including the maximum clearance time, which was to current advice in all cases, using $1.2ms^{-1}$ as the assumed walking speed. In some cases this would have resulted in a small difference in the time available to cross in the after study, because the previous Pelican crossings may have been set according to the advice for that type of crossing which is different to the advice for Puffin crossings.

The work established that Puffin facilities are safer, though without identifying, in any quantitative sense at least, the reasons for the improvements. However, behaviour is different in several respects compared to Pelican crossings, due to the way Puffin facilities work. It is potentially important to bear in mind that behaviour will change in response to changes in timings.

Kennedy et al (2009) suggests a significant propensity for pedestrians to cross in gaps rather than conform to the green man. She suggests more responsive signal control to increase compliance. Better compliance is found with older, female, impaired, if waiting under 30 seconds, if traffic is heavy or others already waiting. Reading (1995) reported that pedestrians are slower to cross at Puffin crossings as compared to Pelican crossings, particularly older pedestrians.

York et al (2009) reported some confusion of the meaning of the flashing green man, whilst Sterling et al (2009) reported significant confusion about what the blackout period actually meant.

Retting et al (2002) looked at recalculating the yellow period and the all-red clearance period (of the all-red pedestrians stage presumably, though it doesn't say) of 51 junctions. The collision statistics were compared with 56 similar control sites. A large number of the sites originally did not conform to the Institute of Traffic Engineers (ITE) recommended practice. There was a reduction in collisions involving pedestrians and cyclist of 37 percent as compared with the control sites. This indicates the potential for signal timings to make a difference to safety. However, it did not identify whether the ability of pedestrians to complete their crossing in time or not was a significant issue.

2.6 PCaTS Countdown timers

In a trial undertaken by TRL for Transport for London (TfL) pedestrian countdown timers were installed at 10 sites (York et al, 2011). The period counted down was the blackout (i.e. the clearance) period. The system is known as Pedestrian Countdown at Traffic Signals (PCaTS). With it the blackout period is augmented/replaced with a countdown. The time of the countdown is the clearance period minus 3 seconds which is the all red period immediately before starting amber for vehicles. It proved to be very popular with 83% across all groups saying they liked it, which rose to 94% for mobility impaired. Older pedestrians were not asked separately.

PCaTS was preferred over standard crossings (which were junctions with far-side aspects and used a 'blackout period' as the clearance period) by 69% of mobility impaired pedestrians and 56% of children, who directly experienced both types of crossing. At all sites there was an increase in the percentage of participants stating that they felt safe using the crossing.

The study found that, whilst there were no adverse impacts on safety, some pedestrians (mainly mobility impaired) reported feeling rushed and had concerns about the time available for safe crossing. At all trial sites fewer pedestrians reported feeling rushed when crossing the road with PCaTS despite a reduction in green man time. The proportion feeling rushed went down from 39% to 23% and this percentage decreased on nearly all sites. The percentage of pedestrians feeling they had sufficient time to cross the road increased from an average of 75% in the before surveys to 88% with PCaTS. In addition, for pedestrians still on the crossing when the green man phase ended, a higher percentage stated they were able to continue crossing with PCaTS: the average across the survey sites increased from 12% before to 37% after. By contrast, the perception individual pedestrians had of the time taken to cross the road became less accurate with PCaTS.

When comparing the two systems, there was a suggestion that the blackout and the countdown periods were interpreted differently with only 22% stating that if they arrive during the blackout period they could start to cross, whereas 81% said the same about the countdown period.

During the PCaTS study, statistically significant changes in walking speed before and after were observed at three sites showing that walking speeds had increased in the after surveys by between 3 and 10%. Whilst this was an average speed that includes crossing times during the Red Man, a similar percentage increase in walking speed was observed when Red Man crossings were excluded from the average. Average speeds for all those sampled over the three sites ranged from 1.30ms^{-1} at one site before PCaTS to 1.68ms^{-1} at another site after PCaTS.

Sometimes there is confusion about what the invitation to cross period is for. Carsten et al (1996) appears to make that mistake suggesting that whilst the average time to cross a typical two-lane road is 10 seconds, the green man period is often only 6 seconds. Interestingly, he mentions the possibility of using detection to extend the invitation to cross period. This could help address some of the issues at busier crossings.

2.7 Summary of walking speeds

Table 9 shows a summary of all the walking speeds found in the literature search. Most of the data have been captured from measurements of pedestrians actually crossing the road. As already mentioned, this will tend to exclude people who would be interested in walking if the time available to cross at signal controlled crossings was longer. However, it is not clear to what extent the speeds are representative of the speeds that people could achieve if they needed to. Nevertheless, there is a clear indication that 1.2ms^{-1} is more often than not likely to be inadequate for older people.

Table 9. Summary of walking speed information

Reference	Reference Within Paper (if applicable)	Sample Size		Identifying group/age	Walking Speed (m/s)					
					Mean		15th Percentile		Standard Deviation	
		Men	Women		Men	Wo-men	Men	Wo-men	Men	Wo-men
Hoxie et al (1994)				Judged as over 65	0.86±0.17				±1	
Oxley et al. (1995)				Older pedestrians	1.13					
Knoblauch et al (1996)	from paper table 1	940	1729	Over 65	1.31	1.19	1.02	0.93		
		1180	1198	Over 65 + complying with signals	1.26	1.14	0.99	0.91		
Tarawneh et al (2001)	Jordanian Study			Over 65s	1.17		0.97			
Dunbar et al (2004)	Todd and Walker 1982			60-69	1.06	0.73				
				70-79	0.89	0.74				
				80+	0.54	0.59				
Walker et al (2005)	speed range across sites			Over 60	1.0-1.2					
Fitzpatrick et al (2005)		92		Over 60 (but not '*elderly*')			0.97			
		75	31	'Older'			0.95	0.86		

Reference	Reference Within Paper (if applicable)	Sample Size		Identifying group/age	Walking Speed (m/s)					
					Mean		15th Percentile		Standard Deviation	
		Men	Women		Men	Wo-men	Men	Wo-men	Men	Wo-men
Gates et al (2006)		237		Over 65s	1.20	1.14	0.90	0.92		
LaPlante et al (2007)	Research by James Exnicios (1950)			Elderly Pedestrians	1.07		0.91			
	Research by Robert Sleight			Elderly Pedestrians			1.01			
	Guerrier et al (1998)			Older pedestrians	0.97		0.67			
	Coffin at al (1995)			Elderly at intersections			1.20			
				Elderly at intersections near nursing homes and senior housing			1.00			
Sterling et al (2009)				All peds before signal timing change			1.14			
				All peds after signal timing change			1.32			
Romero-Ortuno et al (2010)	Study Participants	133		60-69	1.18					
		153		70-79	1.04					
		69		80-89	0.82					

Reference	Reference Within Paper (if applicable)	Sample Size		Identifying group/age	Walking Speed (m/s)					
					Mean		15th Percentile		Standard Deviation	
		Men	Women		Men	Wo-men	Men	Wo-men	Men	Wo-men
Maxwell et al (2011)	Fitzpatrick et al			Over 60			0.92			
	Gates et al			Elderly			0.92			
	Knoblauch et al 1995			Older pedestrians			0.94			
Asher et al (2012)		1,444	1,701	Over 65s	0.90	0.80			0.30	0.30
Goh et al (2012)	(Malaysia)			Elderly at signalised (daytime)	1.23	1.18				
				Elderly at signalised (night time)	1.23	1.15				
Musselwhite et al (2014)		184	181	Older people overall	0.95					
				Older people in urban shopping area	0.99				0.22	
				Older people in residential suburban	0.93				0.21	
				Older people in shared space	0.91				0.21	

3 Changing the walking speed

3.1 Technical changes required

In the majority of cases, most signal controllers would require a PROM (Programmable Read Only Memory) change to allow for an increase in the clearance period. This can be undertaken at a modest cost even being carried out alongside other maintenance, thus minimising the cost of an engineer's time to make the changes. However, it may not always be that straightforward. The consequences of making changes to the operational efficiency of a junction (as opposed to standalone crossing) will need to be considered. This in itself will require time (and therefore money) even if it proves that the junction or network will operate satisfactorily. If operational efficiency is compromised unacceptably, further work to ameliorate the consequences will be required. Adaptive signal control strategies such as SCOOT and MOVA would normally deal with the consequences automatically, though not necessarily to the extent of completely offsetting reductions in efficiency, which may still need to be addressed. This makes it difficult to provide any reasonable estimate of the cost of making the changes. However, the cost will be many times the simple cost of altering the signal timings.

3.2 What are the risks of increasing the clearance period (and not doing so)

- Delay to traffic
- Extra delay to pedestrians due to longer cycles that will be necessary to reduce the consequences of increasing clearance periods;
- Safety issues if the changes are not made – slow pedestrians will continue to take longer to cross than there is time available;
- Safety issues if the changes are made:
    - longer clearance periods may lead to increased risk taking;
    - longer cycle times will be necessary to offset the increase in lost time, which may lead to more pedestrians crossing in gaps;
- Different pedestrian crossing types – a change in the clearance period will have different consequences to the different crossing types.

3.3 Chances of encouraging walking by increasing clearance periods

One of the aims of making walking safer and more comfortable is to encourage walking as a means of transport for a whole host of reasons. Nothing was found that addressed this issue. Consequently it is impossible to say to what extent people may be encouraged to walk should they be allowed more time to complete their crossing. People do complain about the issue, however, so it seems likely that some may choose to walk more often, particularly if a crossing they would use frequently had the issue addressed.

4 WebTAG and the inclusion of pedestrians

4.1 The role of WebTAG

The advice that the Department for Transport provides on transport modelling and appraisal is set out in WebTAG (https://www.gov.uk/transport-analysis-guidance-webtag). This web-based information system contains guidance on the conduct of transport studies. In addition the guidance includes or provides links to advice on how to:

- set objectives and identify problems
- develop potential solutions
- create a transport model for the appraisal of the alternative solutions
- how to conduct an appraisal which meets the department's requirements

The advice is given in a series of units, distinguished not only by content but also the audience to which they are directed. Associated with the units are spreadsheets containing data. Most of the detailed modelling advice is contained in units for the 'modelling practitioner' or the 'appraisal practitioner'.

Before considering what advice is given for active modes, in particular for walking, it is worthwhile emphasising two issues. Firstly much of the WebTAG advice was originally developed to aid the modelling and appraisal of highway schemes and is aimed to provide advice 'proportionate' to the scale of the scheme. Over time more specific advice has been given on the modelling and appraisal of public transport, and more recently on cycling. There is not a great deal of advice on modelling walk trips per se, although walking does feature more in appraisal advice. There is little or no advice on the modelling of walking in conjunction with junction modelling.

4.2 Modelling walking

In terms of advice on modelling walk trips then the most useful advice is found in the TAG unit A5.1 Active Mode Appraisal (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275394/webtag-tag-unit-a5-1-active-mode-appraisal.pdf) but this is largely concerned with appraisal. Purely modelling advice in the modelling units is largely confined to TAG unit M2 Variable Demand Modelling https://www.gov.uk/government/publications/webtag-tag-unit-m2-variable-demand-modelling.

This latter unit sets out advice on the development of multi-modal modelling including those models with variable demand responses such as trip frequency, mode-choice, redistribution and time-of-day responses. It deals with transport models that include non-motorised or 'active' modes within their modelling. The presence of walking in a transport model will mean that the mode-choice models must estimate the generalised costs[7] of walking (usually only travel time in the case of walking) and issues relating to the relationships between modes and trip generation models must include active modes

[7] Generalised cost of a journey, actually usually defined as generalised time, includes any time and money costs involved with any of the modes used in that journey. Walking and waiting time may be 'valued' than the actual time spent walking or waiting.

are discussed. However, in terms of advice on values the TAG unit advice is very limited for walking as the following quotation makes plain.

'If they *(active modes)* are treated as a separate mode, as opposed to them being included in a general non-car mode, it will normally be adequate to treat their generalised costs as linearly dependent on Origin Destination (OD) distance travelled, via an average speed that is conventionally 4 km/h for walking and 12 km/h for cycling. Walking speeds in particular are a function of the number of roads crossed, and the amount of traffic on these roads, but this aspect is rarely captured in modelling.' (TAG Unit M2 para 4.7.8)

The quotation above relates to walking as a mode by itself. The walking time involved where another mode is the main mode such as train or car is calculated and added to the generalised cost of traveling by that mode.

Thus a 'conventional' walking speed is given largely for pedestrian links such as paths alongside a road or off-road and this may or may not be applicable to the speeds of crossing roads in different circumstances. No reference is made to any variations by person type.

One section within the Active Mode appraisal unit (Unit A5.1) does refer to the possibility of forecasting by person type or more commonly trip purpose. In addition, other non-conventional categorisation could be chosen (see below)

'Estimation of the demand for cycling and walking might also need to take into account the different types of user. For example, pedestrians could be characterised as "striders", who are using walking to get somewhere and might be sensitive to changes in travel time or "strollers", who might be less concerned about travelling efficiently but more sensitive to environmental factors (Heuman, 2005). DfT (2004b) suggests a number of different types of "design pedestrian types" and "design cyclist types". These include commuters, utility cyclists and shopper/leisure walkers all of which might be expected to react differently to different interventions in the form of facilities.' TAG unit 5.1 Para 2.5.4.

The issue with this strategy is both estimating the proportion of the population in these categories, and measuring quantities such as walking speed and other, non-measurable, quantities such as the propensity to 'obey' crossing instructions, or use uncontrolled sections of the road to cross as opposed to controlled crossings.

The modelling of active modes, in connection with 'smarter choices', is covered in TAG Unit M5.2. This advice covers the modelling of schemes such as Travel Plans and other smarter choice policies. Whilst it does emphasise the need to measure in some way (and forecast) 'soft measures' it provides no firm values especially for measures aimed at improving the pedestrian experience (such as pedestrian 'walk days').

4.3 Appraising walking within schemes

In contrast to the little advice on modelling walking trips, there is slightly more advice on appraising schemes with a walking content although that advice is scattered among a number of TAG units.

4.3.1 Valuing walking

As mentioned in footnote 7, there are circumstances when appraising a scheme when walking times are valued at more than the time actually taken. This applies to non-working time but not to time on Employer's Business.

One specific application of the second type of variability is that there is consistent evidence that people value time saved when walking or waiting more highly than they do for an equivalent saving in a vehicle journey. Therefore the 'commuting' and 'other' values in the TAG Data Book should be factored by 2.5 for time spent waiting for public transport and by 2 for time spent accessing or interchanging between modes of transport by walking or cycling. (TAG unit A1.3 para 4.3.5)

Table 10 shows what this advice means in terms of the valuing of time. It should be noticed that walkers (and cyclists) have a lower value of time than other modes, probably because they have, on average, lower incomes. The value of time does not vary, for appraisal purposes, by type of person travelling, although it can do when modelling (for example by income in tolling studies).

Table 10. Values of time from Tag Table A1.3.1

Table A 1.3.1: Values of Working (Employers' Business) Time by Mode (£ per hour, 2010 prices, 2010 values)			
Mode	**Resource Cost**	**Perceived Cost**	**Market Price**
Car driver	22.74	22.74	27.06
Car passenger	17.25	17.25	20.52
LGV (driver or passenger)	10.24	10.24	12.18
OGV (driver or passenger)	12.06	12.06	14.35
PSV driver	12.32	12.32	14.66
PSV passenger	13.97	13.97	16.63
Taxi driver	10.89	10.89	12.96
Taxi / Minicab passenger	21.96	21.96	26.13
Rail passenger	26.86	26.86	31.96
Underground passenger	22.08	22.08	26.28
Walker	17.54	17.54	20.88
Cyclist	17.47	17.47	20.78
Motorcyclist	19.42	19.42	23.11
Average of all working persons	22.75	22.75	27.07
Values of Non-Working Time by Trip Purpose (£ per hour, 2010 prices, 2010 values)			
Trip Purpose	**Resource Cost**	**Perceived Cost**	**Market Price**
Commuting	5.72	6.81	6.81
Other	5.08	6.04	6.04

4.3.2 Appraising schemes involving pedestrians

As mention earlier, much of WebTAG advice on non-motorised modes is couched in terms of 'active modes', meaning cycling and walking. Active mode appraisal does set out the types of key impacts to look for and measure when appraising walking and cycling schemes. These are summarised in the table below taken form Unit A5.1.

TAG Unit A5.1 explains in some detail the indicators and the appraisal quantities they are used to measure. What is important is the requirement to estimate the number of 'new' walkers/cyclists through model choice modelling. This is important when estimating the benefits from increased physical activity because such impacts typically form a significant proportion of benefits for active mode schemes. The method for calculating these impacts is taken from 'Quantifying the health effects of cycling and walking' (WHO, 2007) and its accompanying model, the Health Economic Assessment Tool (HEAT). The method requires estimates of the number of new walkers or cyclists as a result of the scheme; the time per day they will spend active; and mortality rates applicable to the group affected by the scheme. The economic benefit of reduced mortality should be valued using the value of a prevented fatality given in TAG Data Book. More detailed guidance on estimating these benefits is given in the physical activity section of TAG Unit A4.1 - Social Impact Appraisal.

Table 11 Indicators used in the economic appraisal of walking and cycling schemes (source Table 2. TAG unit A5.1)

Indicator	**Used to appraise**
Cycling and walking users	Journey quality
New individuals cycling or walking	Physical activity Journey quality
Car kilometres saved	Accidents Green House Gas emissions, air quality and noise Indirect tax revenue Travel time (decongestion)
Commuter trips generated	Absenteeism

Further relevant advice on appraisal is available in TAG Unit A4.1 –Social Impact Appraisal, which covers a range of impacts, namely:

- Accidents
- Physical Activity
- Security
- Severance
- Journey Quality
- Option and non-use values
- Accessibility
- Personal Affordability

The Unit then describes how these impacts should be measured, either quantitatively and valued, as in the case of accidents, on a number scale, or simply as levels for qualitative measures such as severance. The advice in the unit covers all modes but it does acknowledge that there are likely to be missing gaps especially in relation changes in levels of cycling or walking activity. In the case of physical activity impacts which are important for active appraisal, there are two important issues that may need to be taken into account.

'The impact of a shift to walk or cycle is assumed to be the same for all individuals'. However, an active individual may derive little additional benefit from walking or cycling to reduce the chance of death by inactivity, or have a reduced relative risk through being partially active. There are some allowances made for this in the HEAT methodology, although this is subject to a large degree of uncertainty. WHO stress that this methodology should not be used for populations with high average levels of physical activity;

The studies used surveyed those between the age of 20-64 for cycling and 20-74 for walking. Care should be taken in appraising the impact on individuals outside of this range and where this population is significant, the assumptions used should be clearly stated.' TAG Unit A4.1 Para 3.3.1.

In the case of journey quality the example quoted in the Unit refers to London-based schemes and the following example is given (from Table A4.1.7). It is emphasised that evidence is strictly limited for this aspect so these values may not have wider applicability.

Table 12 Valuing aspects of the pedestrian environment (from TAG data book A4.1.7)

Table 4.1.7: Values of aspects in pedestrian environment (2010 values and 2010 prices)		
Scheme type	**Value p/km**	**Source**
Street lighting	3.8	Heuman (2005)
Kerb level	2.7	Heuman (2005)
Crowding	1.9	Heuman (2005)
Pavement evenness	0.9	Heuman (2005)
Information panels	0.9	Heuman (2005)
Benches	0.6	Heuman (2005)
Directional signage	0.6	Heuman (2005)

Up to now the advice has considered travellers by the mode they choose but there are aspects of the appraisal process which consider traveller/person by other categories. One of these issues is 'severance' where the advice considers the use of walking catchment areas of up to 800m for walk journeys to community areas and 400m to bus stops (walking distance not crow-fly distance). The advice continues:-

'Furthermore the distances should take account of the needs of the groups who are particularly vulnerable to severance effects and the practical limitations on how far different groups of people can walk. For example, shorter catchments should be used for older people.' Other categories could be by income groups.

The Distributional Impacts analyst should then use the existing walking catchments to inform the analysis of impacts as a result of the transport intervention. For example, the introduction of a new footbridge to replace an at grade pedestrian crossing could potentially add to the effective walking distance to cross the road (taking into account ramps) and will also involve a climb that could affect the effective distance travelled (affecting older people in particular).

The analyst should then plot the revised walking distance catchments with the intervention in place. The final stage involves the calculation of the numbers of people in the defined potential vulnerable groups likely to be positively or negatively affected with and without the intervention.' TAG Unit 4.2 para 6.4.5.

Issues related to accessibility to community facilities and/or public transport can also have a distributional aspect and may have relevance to pedestrian crossing times where alternative facilities are being considered.

4.3.3 Summary of DfT advice on modelling walking

There is very little advice on modelling walk trips within the DfT's main repository of modelling advice – WebTAG. Advice on the appraisal of schemes with a walking element is higher but the evidence is not as well developed as that for cycling. In summary the appraisal covers what impacts to consider without being able to provide firm values for walking for many of the impacts.

5 The effect on traffic of increasing the clearance period

In order to consider the question regarding the effect in general of increasing the clearance period, a TRANSYT (Binning et al, 2013) model has been developed. The model includes three signal controlled junctions and a stand-alone crossing. The network is entirely fictitious. However, the junctions have been designed to represent the different options that are experienced in a typical low-speed urban scene, typically with 30mph speed limits.

5.1 Model description

5.1.1 Junction 1

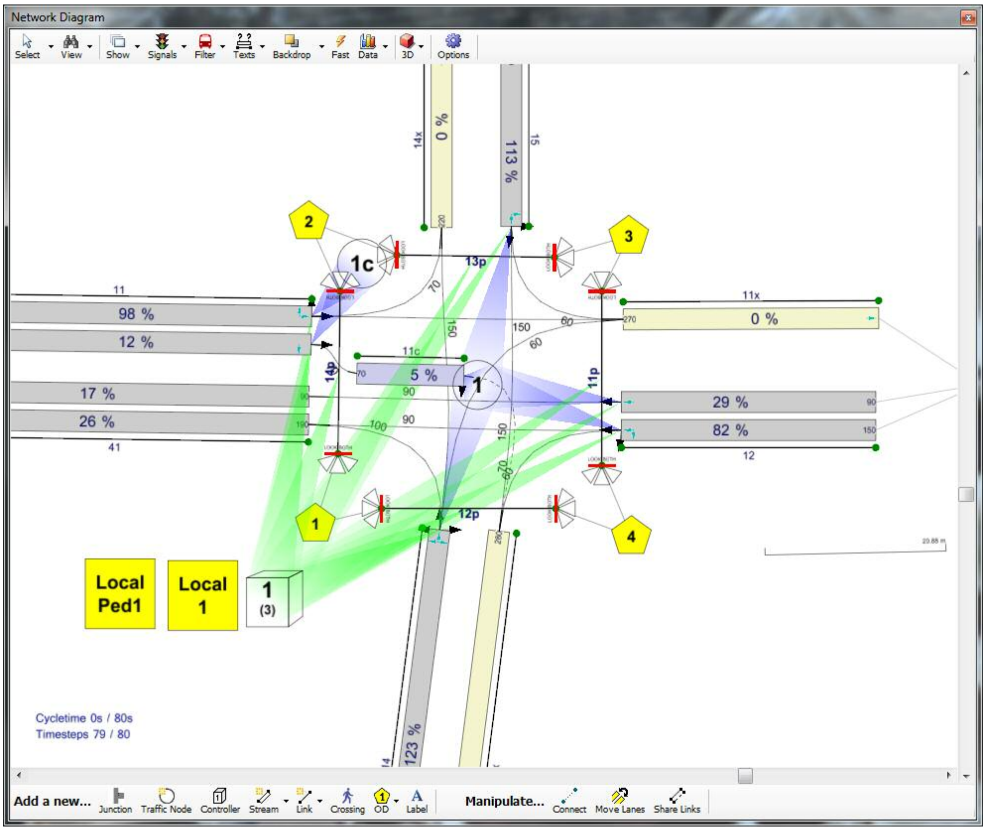

Figure 1. Layout for junction 1

The first junction is a crossroads with most movements allowed, with the exception of one right turn. The junction runs in 4 signal stages, including the all-red (to vehicles) pedestrian stage. The north and south approaches run separately, with the east-west running together including a fully opposed right turn from west to south. The eastern and western approaches are two lanes in each direction and are therefore considered to be 14 metres in width, which dominates the clearance period required which has to be longest of all the possibilities in an all-red pedestrians stage.

5.1.2 Junction 2

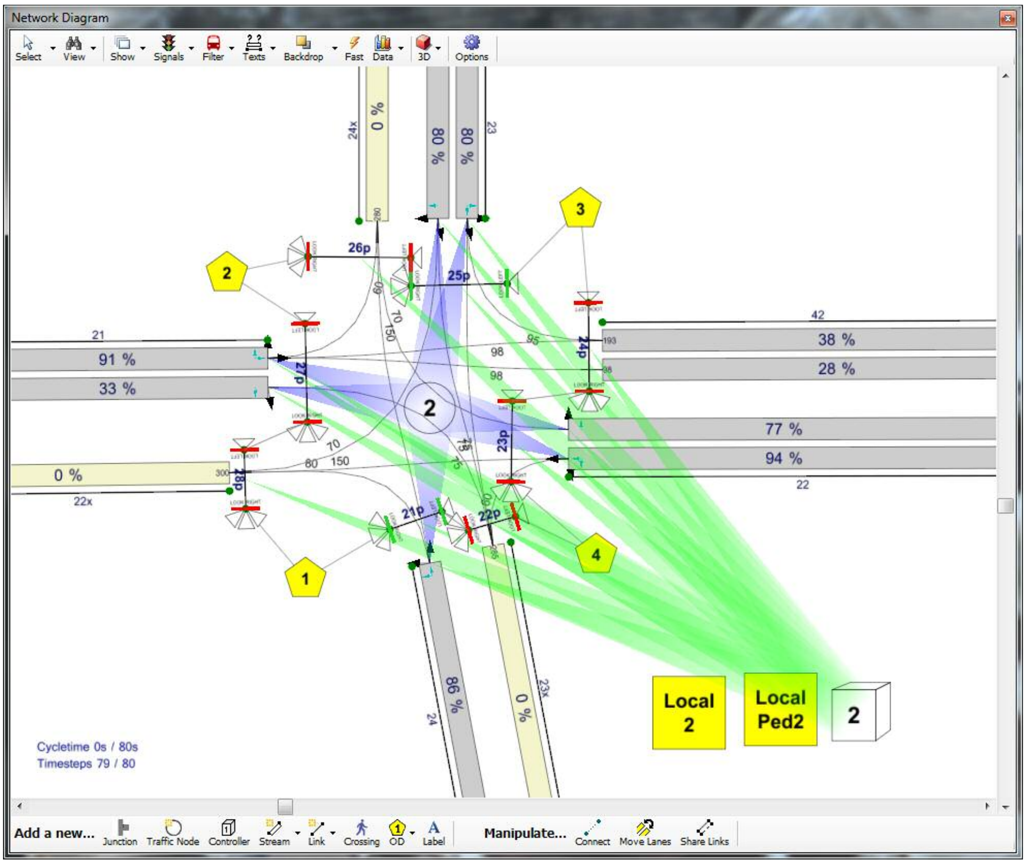

Figure 2. Layout for junction 2

The second junction has pedestrian refuges in the medians on all approaches such that all approaches are catered for with two separate phases for each half of the approach. With the banning of selected movements, all the pedestrian phases can run in parallel with vehicles, obviating the need for an all-red pedestrian stage. This also means that the longest crossing is only 7 metres, reducing the need for long clearance periods.

5.1.3 Junction 3.

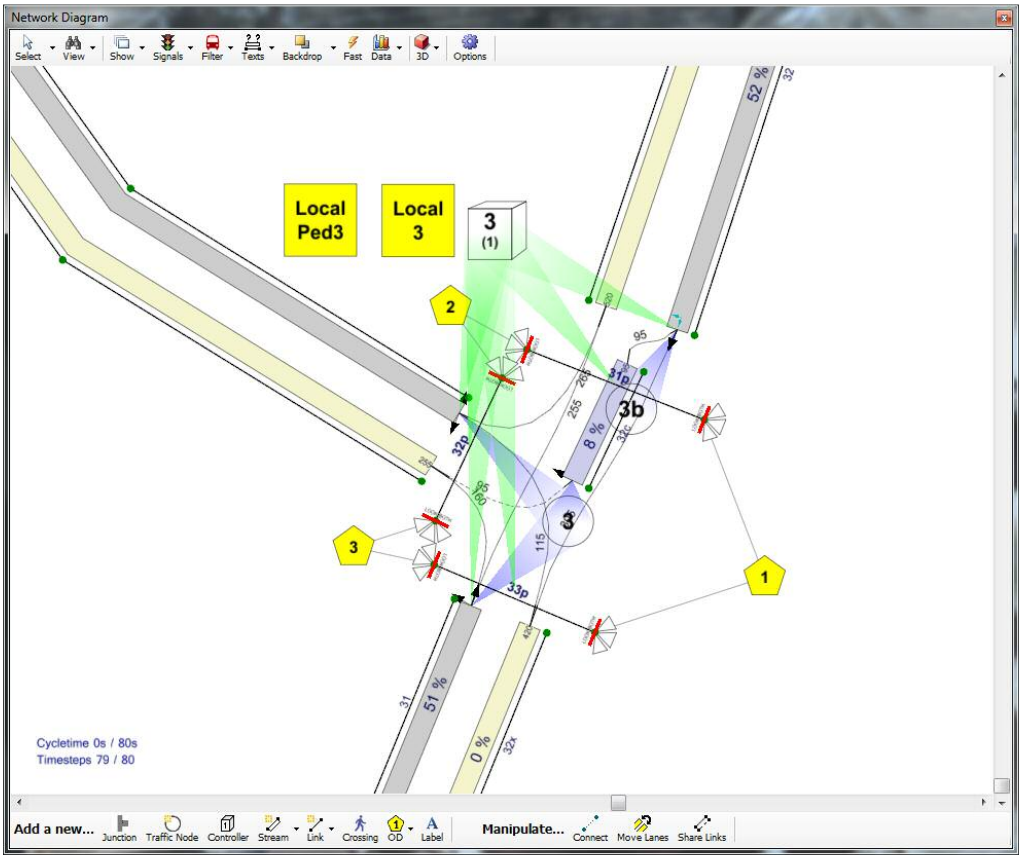

Figure 3. Layout for junction 3

The third junction is a simple 'T' junction with single-lane approaches in all directions. Once again an all-red (to traffic) pedestrian stage is employed, though this time with shorter clearance periods due to the single-lane roads present at this junction. This provides a contrast to the bigger first junction in terms of complexity and could be commonly found where pedestrian needs have to be catered for.

5.1.4 Pedestrian crossing

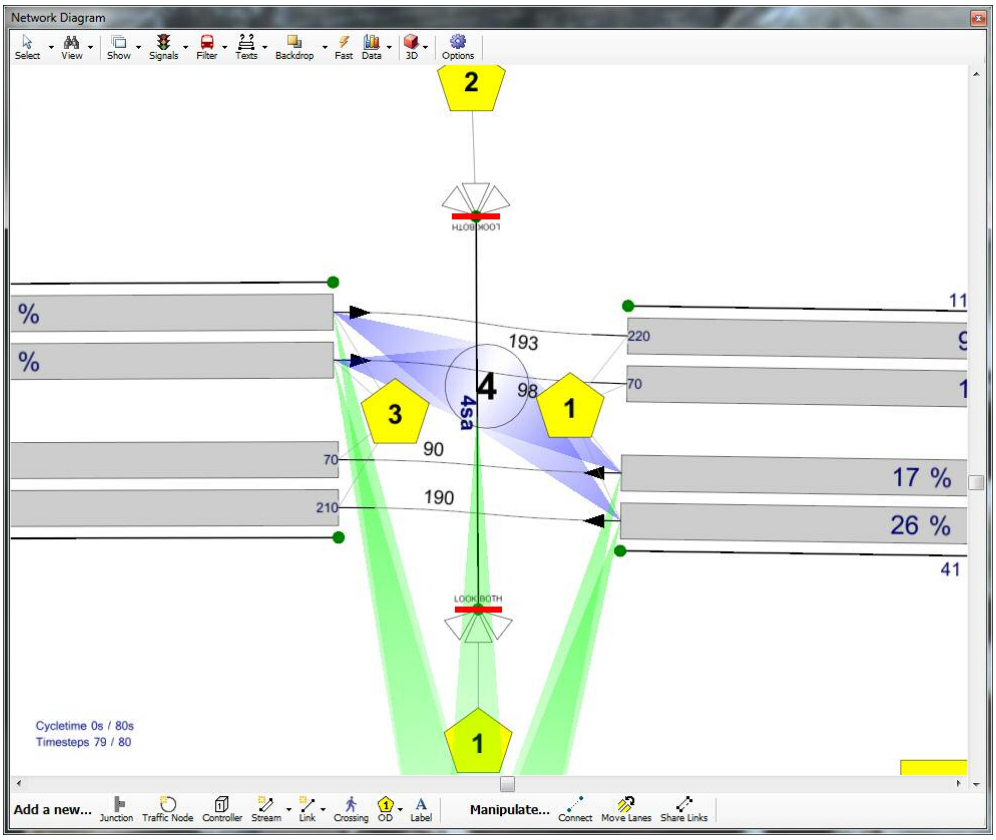

Figure 4. Layout for pedestrian crossing

The pedestrian crossing is straightforward, but is wide at 16 metres representing two lanes in each direction plus 2 metres for the refuge. This represents the most extreme likely to be found in the UK currently.

5.1.5 Traffic flows

Three levels of traffic flow have been developed for both pedestrians and vehicles. The traffic flows broadly represent lighter, medium and peak periods, whilst pedestrian flows represent a range of possibilities. The signal timings were optimised for vehicles in each run, with the delays to pedestrians being recorded but excluded from the optimisation process which is not relevant to this exercise. Pedestrians were modelled with a recently developed 'walk-on-red' model that accounts for pedestrians crossing in gaps in the vehicle flow.

5.1.6 Walking speeds

The TRANSYT model was developed and traffic flows set with the pedestrian clearance periods set to cater for a walking speed of 1.2ms^{-1}. Alternative clearance periods were then input catering for walking speeds of 1.0ms^{-1} and 0.8ms^{-1}. All the models were allowed to find optimal signal timings to provide the best performance for the alternative clearance periods.

5.2 Results from the modelling

5.2.1 Output from the model

The Performance Index (PI) is shown which is the cost of a combination of delay and stops, with a biased towards delay. It is a better value to use as a comparison tool than using delay alone.

Table 13. Vehicle Performance Index

Vehicle Performance Index (£/hour) by vehicle flows (% difference from $1.2ms^{-1}$)															
	$1.2ms^{-1}$			$1.0ms^{-1}$						$0.8ms^{-1}$					
Node	Low	Medium	High	Low	% diff	Med	% diff	High	% diff	Low	% diff	Med	% diff	High	% diff
Ped	10	43	71	38	280.0	76	76.7	79	11.3	50	400.0	32	-25.6	52	-26.8
1	151	242	1262	177	17.2	310	28.1	1338	6.0	248	64.2	553	128.5	1727	36.8
2	205	347	482	211	2.9	337	-2.9	692	43.6	383	86.8	849	144.7	1230	155.2
3	92	151	142	91	-1.1	126	-16.6	531	273.9	155	68.5	105	-30.5	434	205.6
total	458	783	1957	517	12.9	849	8.4	2640	34.9	836	82.5	1539	96.6	3443	75.9

Table 14. Highest degree of saturation and number of oversaturated traffic streams

	$1.2ms^{-1}$			$1.0ms^{-1}$			$0.8ms^{-1}$		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Highest degree of saturation	77.8	95.7	122.6	81.7	95.3	127.7	103.5	133.3	126.9
No. of oversat streams	0	2	5	0	2	8	4	5	10

Table 15. Average pedestrian delay (seconds/person)

Traffic flow level/Pedestrian flow level. Walking speed = 1.2ms^{-1}									
	Lo/Lo	Lo/Med	Lo/Hi	Med/Lo	Med/Med	Med/Hi	Hi/Lo	Hi/Med	Hi/Hi
Ped	15.2	19.2	19.2	8.9	15.3	8.7	16.9	16.9	16.9
Node 1	23.7	18.4	18.4	16.9	18.0	17.1	24.0	24.2	24.3
Node 2	17.0	14.2	14.2	12.7	15.1	12.8	17.1	17.2	17.2
Node 3	13.3	20.0	19.9	15.8	11.9	16.2	19.6	19.4	19.3

Traffic flow level/Pedestrian flow level. Walking speed = 1.0ms^{-1}									
	Lo/Lo	Lo/Med	Lo/Hi	Med/Lo	Med/Med	Med/Hi	Hi/Lo	Hi/Med	Hi/Hi
Ped	14.5	13.2	13.2	13.2	13.2	13.2	15.2	15.2	15.2
Node 1	22.5	15.6	15.6	16.2	16.5	16.4	23.5	23.7	23.8
Node 2	16.0	11.9	11.9	12.5	12.6	12.6	16.9	17.0	17.1
Node 3	20.1	16.6	16.6	15.5	15.5	15.6	13.4	13.3	13.3

Traffic flow level/Pedestrian flow level. Walking speed = 0.8ms^{-1}									
	Lo/Lo	Lo/Med	Lo/Hi	Med/Lo	Med/Med	Med/Hi	Hi/Lo	Hi/Med	Hi/Hi
Ped	13.3	8.8	8.8	16.8	16.8	16.8	11.2	11.2	11.2
Node 1	21.8	15.0	15.0	15.0	15.3	15.3	22.3	22.5	22.6
Node 2	15.4	11.5	11.5	12.2	12.3	12.3	16.3	16.4	16.5
Node 3	18.8	15.1	15.0	16.6	16.6	16.7	14.1	14.0	14.0

5.2.2 Commentary on the modelling

For Table 13 and Table 14, the pedestrian flow is irrelevant – it is only the effect of changing the clearance period on vehicular traffic that we are interested in. Pedestrian delay is considered separately in Table 15.

Considering the results in Table 13 and Table 14, it can be seen that at the low and medium flow levels, overall there is not a great deal of difference between when considering walking speeds of $1.2ms^{-1}$ and $1.0ms^{-1}$. This is mainly because the network is not overly saturated at those flow levels, and the few extra seconds makes little difference to the ability of the network to cope. The PI for pedestrians at the pedestrian crossing are low overall, even though the percentage differences look high.

When the walking speed used to calculate the clearance periods is $0.8ms^{-1}$, the story changes somewhat, with a sharp increase both in PI and in the saturation of the network judging from the highest degree of saturation and the number of oversaturated links. Note that the degree of saturation above which a traffic stream is deemed to be oversaturated is 90%. No clear pattern emerges with the different junction types.

The results for pedestrians (Table 15) show that at higher vehicle flows, pedestrian delay increases. Remembering that walk-on-red modelling has been used to represent pedestrians who cross in gaps, the increase in delay to pedestrians will correspond with a reduced opportunity to cross in gaps as the vehicle flow increases. The slight improvement in pedestrian delay when the walking speed is reduced corresponds with an increase in the clearance period during which pedestrians can gap accept more easily than during green to vehicles.

The main conclusion to draw is that, as expected, increasing the clearance period reduces the vehicle capacity of individual signal controlled junctions and a network of junctions. When a junction or network starts to become overloaded, any reduction in capacity will result in increased queuing delay, and this will tend to increase exponentially as the degree of saturation increases. At low traffic intensities changes to the clearance period will go largely unnoticed. Similarly, stand-alone crossings rarely operate at high degrees of saturation and a change in the clearance period will not have a great deal of effect at them. However, at a junction or network that is already operating close to, or above capacity, a small increase in the clearance period will have a disproportionately large consequence.

Re-optimising the network after an increase in the clearance period will reduce the impact on delay to vehicular traffic to some extent, though the ability to do so becomes less as the network becomes more saturated.

It is conceivable that optimising for the movement of people could rebalance the operation of a network. In other words if there is a mode transfer from vehicles to walking as a result of encouragement to walk for example, network capacity and delay may be better as a result of more walking trips and fewer vehicle trips.

6 Discussion

6.1 Project objectives

There is a greater and increasing proportion of older people in the population than in the past and with it comes issues with mobility. Combine this with today's busier roads, more pedestrians become reliant on signal controlled crossings and pedestrian facilities at junctions. The provision of pedestrian facilities appears to be given a reasonably high priority in general, with the acceptance over the past decade or more that pedestrians are entitled to be able to walk about safely. However, some pedestrians feel that there is not enough time to cross the road and there is plenty of evidence from the literature found that many pedestrians are unable to walk at $1.2 ms^{-1}$, the speed used to derive the clearance period time.

If pedestrians feel that there is not enough time to cross the road, they may feel disinclined to use signal controlled crossings. This in turn may cause them to be reluctant to cross the road, effectively limiting their mobility. It may even cause them to not go out, or use other forms of transport to undertake journeys that would otherwise be possible on foot.

Therefore it follows that if more time is given for pedestrians to complete their crossing, more people may be encouraged to walk as a means of transport.

6.2 The target audience

If the objective is to encourage a given group of the population to walk more, it is necessary to know the information specifically about that group, or infer it from other data. The group of interest is those who would walk more if there was more time given to crossing the road at signal controlled pedestrian facilities. The literature found does not cover that group specifically so it becomes necessary to consider the information that has been found and what can be inferred from it.

6.3 The evidence that the clearance period is inadequate

There is evidence that a significant number of pedestrians (eg 20% of those interview in Maxwell et al, 2010) who use signal controlled crossings feel they do not have enough time in which to complete their crossing. Additionally, there is observational evidence that some pedestrians are unable to complete their crossing before the signals change to green to traffic.

Many existing road-using pedestrians (i.e. those using signal controlled pedestrian crossings) have been measured as walking at less than $1.2 ms^{-1}$ especially the elderly. However, from the limitations of the methodologies use to measure walking speeds it is difficult to know whether they did so because they could not walk faster, or because they did not need to at the time their speed was measured. However, from the literature reviewed it is possible to conclude that there is enough evidence to suggest that some pedestrians who already walk and are prepared to use pedestrian crossings require longer to complete their crossing than they are given by the clearance period.

6.4 Is the solution to simply increase the clearance period?

The clearance period is currently derived from an assumed walking speed of $1.2 ms^{-1}$ yet there is evidence that many pedestrians cannot achieve this speed. Therefore increasing the crossing clearance periods would provide a solution, and the main disbenefits would be the additional delay that vehicles incur, which would be of relatively little consequence unless the network was operating at high degrees of saturation.

However, when considering safety, it may not be so simple, because increasing the clearance period may induce changes in pedestrian behaviour. For those who can walk more than fast enough it may be tempting to start to cross sometime after the green man period has ended because of the perception that there is time to complete the crossing. This type of behaviour occurs already – would increasing the clearance period make it more risky? Would driver behaviour change? There is already a perception of harassment at Pelican crossings – increasing the length of the flashing period may not help this trait. Research is needed to consider behavioural changes that could lead to a reduction in overall safety and also ways to mitigate any changes in behaviour.

Another solution is Singapore's Land Transport Authority's pilot scheme - "Green Man Plus". The new Green Man Plus now allows up to 12 seconds more green man time for elderly people who tap their senior citizen concession card on the reader mounted above the standard push button on the traffic light pole.

See http://app.lta.gov.sg/apps/news/page.aspx?c=2&id=830c5cd6-f3cf-4624-b35b-f0f84dbb441d.

This would not be suitable if it was abused on a regular basis and would have the same potential issues as increasing the clearance period if made use of most of the time.

6.5 Puffin crossings

Puffin crossings, which use on-crossing detection to extend the clearance period as necessary, may at first glance provide a solution. It would seem possible to provide a long clearance period which would be reached only when necessary. However, the Puffing Good Practice Guide (2006) advises that the clearance period is calculated using the 1.2ms^{-1} walking speed. There is a school of thought that if it was any longer, it starts to introduce potential confusion and can encourage risky behaviour: For example, pedestrians may start to cross late in the all-red period just as the signals change in favour of vehicles. A potential danger comes from vehicles approaching as the signals change in their favour so that they are able to proceed without stopping. If the pedestrian already crossing is obscured by stationary traffic in other lanes there is a risk of being in collision with the moving vehicle. This author has observed this behaviour when on-crossing detectors have failed or aren't present (they should be for all Puffin crossings, but not necessarily for far-sided Toucans). However, the evidence has not been captured formally.

6.6 Government policy and trends

At the time of writing it would appear that DfT policy will be for the Pelican crossing to be phased out. DfT policy, which has been in place since 1999, was that Pelican crossings should not be used at new installations: this advice was frequently rejected in practice, though increasingly less so with time. However, at the same time, TfL have announced that they are no longer going to implement Puffin crossings, favouring instead the use of countdown timers to countdown the clearance period. Now, one of the advantages of Puffin crossings is that the clearance period is extended (up to a maximum) by on-crossing pedestrian detection. This has advantages in terms of efficiency by providing enough time to cross and no more, allowing traffic to start moving as soon as possible, but without displaying the confusing blackout or flashing periods. It is not regarded as feasible to count down the clearance period when that period is variable. It remains to be seen whether the desirability of countdown from a political point-of-view can be combined with the scientifically proven effectiveness of the Puffin crossing.

6.7 Results from modelling

The results show that the degree to which a change in walking speed can be tolerated (from a junction or network performance point-of-view) will depend greatly on what part of the operational envelope the junction or network is operating at. In less busy periods, an increase in clearance period corresponding to a change from $1.2ms^{-1}$ to $0.8ms^{-1}$ can be tolerated. However, at higher traffic flows, often found in peak periods, queuing and delay can increase substantially and, based on the modelling carried out, could be too high a price to pay for the increased time allowed to cater for slower pedestrians. The modelling does not include pedestrian delay and does not factor in benefits to pedestrians in other ways, such as the benefits gained from a greater number of people walking if they change mode from vehicle to foot.

6.8 What to do next

There are a number of actions that could be relevant to the main issue of providing pedestrians with sufficient time to complete their crossing:

- Wider implementation of Puffin crossings
- Implement longer maximum periods at Puffin crossings
- Provide 'PedEx' crossings with countdown timers or on-crossing detection[8]
- Increase the clearance period

Only the first of the above is backed up by significant research. Countdown timers have been the subject of some research and are being more widely implemented. However, the research is limited when compared with that carried out for Puffin crossings and was restricted to junctions (replacing the blackout period) as opposed to stand alone crossings (where they would replace the flashing period if replacing a Pelican, or the variable clearance period and nearside aspects if replacing a Puffin)

Increasing the clearance period has not been researched and it would be risky to assume that pedestrian and driver behaviour would not change if implemented. In particular:

- would the more able-bodied pedestrians start to take more risks when it becomes apparent that they have longer to cross?
- What will happen if drivers start to become aware that there is often a greater period in which they are held at red with no pedestrian activity?

These are important questions and need to be researched carefully before widespread implementation of increasing the clearance period.

7 Conclusions

The World Health Organisation (WHO, 1999) says that maintaining mobility in later life is important for maintaining health and wellbeing, affording older people close contact with family and friends, enabling access to services, shops and facilities, to engage in sports and leisure and to enhance connectivity and inclusion while remaining actively engaged

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[8] This is a new type of crossing that is being put forward by TfL. It retains the far-side pedestrian aspects and uses *either* on-crossing detection to extend the clearance period, *or* countdown timers. The two are not compatible.

with society. Furthermore, both physical and mental health benefits are derived from the activity. Indeed, the opposite also holds – a lack of mobility will lead to both physical and mental deterioration. It therefore follows that the maintenance of mobility is seen as good and to be encouraged.

A number of studies have been found in which walking speeds have been measured. Most of those included here measured the speeds of pedestrians crossing at signal controlled crossings. On the one hand, the speeds measured are not necessarily the speeds that would be achieved if the circumstances demanded a higher walking speed. There is some evidence that for certain age groups speeds are faster when there is a need to complete the crossing before an event, such as vehicle reaching the crossing point. On the other hand, the speeds are for people who have decided to walk as a means of transport. Those who choose either other means or to avoid walking as a means of transport may not be able to achieve the required speeds. Many could never contemplate walking as a means of transport, for a variety of reasons, for example if they suffer from debilitating illness, in which case their speeds are largely irrelevant.

Nevertheless, there is evidence that quite a fair proportion of people who use pedestrian crossings struggle to reach the $1.2ms^{-1}$ speed.

A number of attitudinal studies have been carried out in the UK. About $1/5^{th}$ of participants felt hurried or harassed when crossing (Maxwell et al 2010) and when asked directly if more time was needed to cross, Mathieson et al (2013) found that 62% said it was.

Attempts to use technology to make pedestrian crossing more user-friendly have been tried with varying degrees of success. Puffin crossings were found to be 19% safer than Pelican crossing and PCaTS has proved very popular with users. A more recent application of technology (under trial at the time of writing) is using detectors to count pedestrians, such that the invitation period can be varied. This may help slower pedestrians who join the back of a crowd by helping them to get established on the crossing before the green man ends.

Some examples of local authorities increasing the clearance period have been found. There isn’t much detail however, and it is not clear to what extent the clearance periods were shorter than they should have been to begin with.

Most of the studies that consider walking speeds of older people consider only those over 60 or 65. Further categorisation may be helpful since the walking speed of those between say 60 and 75 may be above $1.2ms^{-1}$ when necessary, whereas those above that age may find it increasingly difficult as age increases to sustain that speed.

The changes required to allow for a reduced walking speed in terms of changing signal timings are straightforward in themselves. However, the changes needed to reduce the impact of increasing the clearance period could require significant effort in terms of modelling the situation and deriving the best solution to counter the effects of the changes. Adaptive signal control strategies such as SCOOT and MOVA would normally deal with the consequences automatically.

The degree to which network efficiency changes after the introduction of an increased clearance period depends both on the nature of the junctions within the network, the network itself and traffic intensities. Increasing clearance periods will always reduce network capacity (all other things being equal). This is unavoidable. However, at low to medium traffic intensities, the increase in delay to road users could be minimal. Closer to saturation though and the reduction in capacity will lead to a large increase in queuing delay.

Government policy on the issue of pedestrian crossing has been clear in favouring Puffin crossing (and Puffin facilities at junctions). Policy has until recently stopped short of insisting that Puffins are used in place of Pelicans. However, recently, DfT have announced that Pelicans are to be 'phased out'. A further complication is that TfL are keen to use countdown timers, currently an increasingly common sight at junctions, and at standalone crossings. It remains to be seen how this unfolds.

8 Recommendations

1. There is a clear indication that 1.2ms^{-1} cannot be achieved by a proportion of the population, particularly the elderly. There is an increasing need to address this issue.

2. Further research would be required to estimate the number of people affected by the clearance period particularly those who would choose to walk if more time was allowed. Once the estimated number is known it will be possible to consider and quantify those benefits in terms of costs. WebTAG considers the cost of walking as less than that of driving which reduces the impact of and discourages walking interventions. Costs should be made more equitable and there should be a requirement to include pedestrians in all appraisal processes.

3. Wider implementation of Puffin crossings (and the equivalent PedEX crossings that utilise on-crossing detection to vary the clearance period).

4. Implement longer maximum periods at Puffin crossings.

5. Employ technology to detect pedestrians to vary the time they have to cross. For example the technology that TfL is trialling at the time of writing to detect the number of pedestrians waiting to cross and varying the invitation to cross period. This approach allows the use of countdown timers as the clearance period is not varied.

6. Increasing the clearance period would address the issue of walking speeds being lower than 1.2ms^{-1}. However, behavioural changes could result which may have an impact on safety. Therefore, the most important next step would be to assess the safety impact of lengthening clearance times, both with respect to crossings with fixed clearance periods and those with variable times up to a maximum.

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