

## **A review of the use of High Friction surfacing in London**

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### **ABSTRACT**

The use of High Friction Surfacing (HFS) on approaches to pedestrian crossings in London has become widespread. In commissioning new crossing facilities in London the provision of HFS on the approaches is considered mandatory. In 2011 The Road Surface Treatment Association and ADEPT published 'The service life of surface treatments' that indicated average service lives of 4 -8 years. There is over 500km of sites identified as 'approaches to crossings' on the London principal road network, which suggests a need to maintain 60 -100km per year.

In 2012 the London skid project commissioned a review of the use of HFS in London with the objective of:

- Reviewing the design standards applied to determine the appropriate length of HFS
- Consider the pattern of collisions in the vicinity of crossings
- Assess the performance of alternatives to HFS that may provide an alternative to the use of HFS.

This paper will review the methodology and findings from the assessment and consider a process of relaxation and departures that could be applied in London.

## **1. INTRODUCTION**

The London principal network varies significantly in terms of layout, traffic volume, composition and speed. A number of the principal roads are also residential streets and other has significant retail and commercial development. Traffic patterns also vary significantly throughout the day, often being slow moving at peak times; however off peak speeds can be significant. The nature and use of the network has resulted in the provision of over 4500 sites identified as crossings, or signal controlled junctions with a pedestrian phase on the 2156km network.

The evidence from accident studies carried out in London indicate that the accident rate is higher at 'approaches to crossings' than any other SCRIM site category, and the potential benefits in terms of casualty reduction from a targeted intervention strategy are greater than any other single site category. The adopted Investigatory Level (IL) for 'approaches to crossings is 0.50/0.55 with a presumption for the use of High Friction Surfacing (HFS) as a default treatment. In commissioning of crossings there is a requirement that a HFS is provided on the approaches to crossings; however the maintenance on the surface on approaches to crossings is left at the discretion of individual Borough Maintenance Engineers when specifying works. It is widely recognised that through a targeted programme of applying HFS on approaches to crossings significant benefits in terms of casualty reduction can be achieved,

In 2011 The Road Surface Treatment Association and the Association of Directors of Environment, Economy, Planning & Transport (ADEPT) published the Service Life of Surface Treatments.<sup>1</sup> This document predicted an average life of 4 years for 'Hot applied' and 8 years for 'Cold applied' High Friction Surfacing systems (HFS), recognizing 4 principle effects on the predicted life including workmanship, site selection, substrate condition and laying season. The predicted life is consistent with the anecdotal feedback from Maintenance Engineers in London Boroughs.

In terms of managing the skid resistance policy in London a default 50m 'Approach to Crossing' length is applied as an Investigatory Level. Standard practice has been to apply HFS for this length. With the predicted life of HFS this has given rise to a number of concerns about the sustainability of the blanket use of HFS. The London Technical Advisors Group (LOTAG) raised a number of questions about the current practice of applying HFS for a default 50m length on approaches to crossings, including what is an appropriate length and whether there are alternative materials that may provide a similar performance.

A review was therefore undertaken to assess the relevant design standards, review data held on accident location in the vicinity of crossings and to review the performance of alternative materials.

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<sup>1</sup> the Service Life of Surface Treatments. RSDA, ADEPT. May 2011

## 2. DESIGN STANDARDS

For road geometric designs, the Stopping Sight Distance (SSD) is calculated using the following equation specified in the Manual for Streets<sup>2</sup>.

$$SSD = vt + v^2/2d$$

where:

$v$  = speed (m/s)

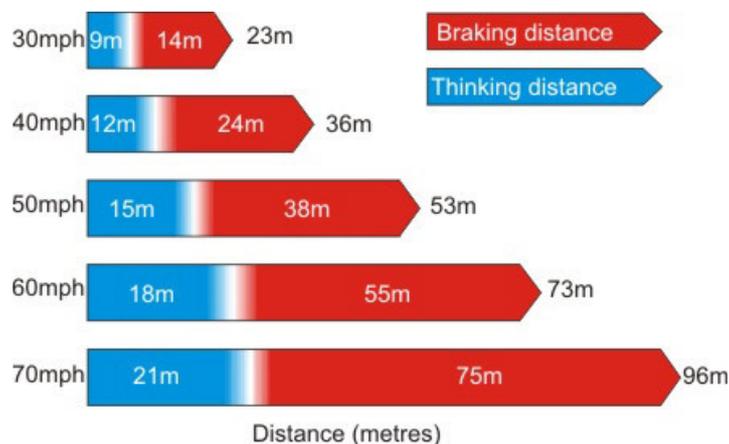
$t$  = driver perception–reaction time  
(seconds)

$d$  = deceleration (m/s<sup>2</sup>)

The SSD comprises of ‘thinking distance’ ( $vt$  in the equation) and ‘braking distance’ ( $v^2/2d$  in the equation). The thinking distance is dependent upon the speed and the perception-reaction time (i.e. from the moment the driver observes the need to stop to the start of braking), and the braking distance is dependent upon the speed and the deceleration rate (the rate of reduction of vehicle speed).

The general guidance provided by the Department for Transport (DfT) Highway Code<sup>3</sup> is that, on dry road conditions, the stopping distance required at 30mph is 23m, and at 50mph is 53m. This guidance is based on a thinking time (perception-reaction time) of approximately two thirds of a second (0.667s), and a deceleration rate of 6.57ms<sup>-2</sup>.

These parameters are based on safely stopping vehicles in an emergency. The typical stopping distances for various speeds provided in the Highway Code are shown in Figure 1.



<sup>2</sup> The Manual for Streets, Department for Transport, 2007

<sup>3</sup> The Online Version of The Official Highway Code, Department for Transport, 2012  
<http://www.direct.gov.uk/en/TravelAndTransport/Highwaycode/index.htm>

**Figure 1 – Guidance on Typical Stopping Distances in the Highway Code<sup>3</sup>**

The geometric design guidelines for the desirable minimum SSD's in the Design Manual for Roads and Bridges (DMRB)<sup>4</sup> use figures of 2 seconds for perception-reaction time and a deceleration rate of approximately 0.25g (2.45ms<sup>-2</sup>). These values appear to be very conservative, especially in relation to urban streets.

The Manual for Streets<sup>2</sup> uses figures of 1.5 seconds for perception-reaction time, and a deceleration rate of approximately 0.45g (4.41ms<sup>-2</sup>). The SSD's for various speeds for street design purposes are shown in Figure 2. Here, on dry road conditions, the stopping sight distance at 30mph is approximately 40m, and at 50mph is approximately 90m.

Speed	Kilometres per hour	16	20	24	25	30	32	40	45	48	50	60
	Miles per hour	10	12	15	16	19	20	25	28	30	31	37
SSD (metres)		9	12	15	16	20	22	31	36	40	43	56
SSD adjusted for bonnet length. See 7.6.4		11	14	17	18	23	25	33	39	43	45	59
Additional features will be needed to achieve low speeds												

**Figure 2 – Derived SSD's for Streets in Manual for Streets**Error! Reference source not found.

The primary objective of the Approach to Crossing site category is to prevent (or reduce the severity of) accidents at pedestrian crossings location. Due to the increased vulnerability of roads users at these facilities, crossings are usually assigned the highest Investigatory Level (IL) in skid resistance policies. As a minimum, the surface at the approach to crossing must provide enough length and skid resistance in wet conditions for vehicles to come to a stop safely before reaching the crossing point.

A review of literature on stopping distances suggests that the 50m approach requirement at 30mph seems to be conservative. However, it is evident that a range of contributory factors is involved in causing accidents; therefore, different drivers impose different levels of risk.

**2.1 DESIGN SPEED, PERCEPTION-REACTION TIME, AND DECELERATION**

<sup>4</sup> Design Manual for Roads and Bridges (DMRB), Highways Agency, <http://www.dft.gov.uk/ha/standards/dmr/b/>

The Manual for Streets: Evidence and Research<sup>5</sup> indicates that the average perception-reaction time of a driver is 1.4 seconds in response to a hazard. Furthermore, after reviewing 27 driver perception-reaction time studies, Olson<sup>6</sup> concluded that about 85% of drivers started to respond 1.5 seconds after first possible visibility of the object or condition of concern.

Another key factor is driver characteristics, including individual perception-reaction times. Research conducted by TRL<sup>7</sup> found that the 90<sup>th</sup> percentile perception-reaction time for drivers confronted with a side-road hazard in a driving simulator is 0.9 seconds. However, the practical situation is affected by various factors. Driver alertness, carefulness, tiredness, the road/surrounding conditions, driver distraction could result in varying perception-reaction times. What's more, the first sight of hazard/object itself could be hindered and delayed due to the same reasons.

These factors are immensely variable and any one of them could be the determinant of an accident happening and its severity. Therefore, the 85<sup>th</sup> Percentile perception-reaction time of 1.5 seconds reported by Olsen<sup>6</sup> is considered more appropriate. This figure is also adopted in The Manual for Streets in determining Stopping Sight Distances.

Figure 1 show how the stopping distances vary with the speed and the deceleration rate for a given perception-reaction time of 1.5 seconds. The deceleration rates plotted are in relation to g ( $9.81\text{ms}^{-2}$ ).

The following would give an appreciation of the effect of deceleration rates. An object travelling at 100mph would take just over 100m to stop at a deceleration rate equal to the acceleration due to gravity (1g), and the same would take approximately 1020m to stop at a deceleration rate of 0.1g. The deceleration rates of 0.25g ( $2.5\text{ms}^{-2}$ ) used in DMRB design specifications is approximately equivalent to stopping on snow without skidding. Carriageway surfaces are normally able to develop skidding resistance of at least 0.45g in wet weather condition.

Based on a 1.5s perception-reaction time, at 30mph, the stopping distances for a vehicle decelerating at 0.25g (DMRB Specifications), 0.45g (Design for Streets Specification), and 0.67g (Highway Code) are 56.8m, 40.5m, 33.8m respectively. At 30mph, increasing the deceleration beyond 0.67g appears to be a case of chasing diminishing returns. This is shown in figures 1 and 2.

Figure 2 illustrates the same information as in Figure , but only displaying the 30mph curve. Here, the Thinking Distance and the Braking Distance have been split and displayed in bar charts to visualise their contribution to the total stopping distance. Obviously, the Thinking Distance is constant as this is only showing 30mph speed, and

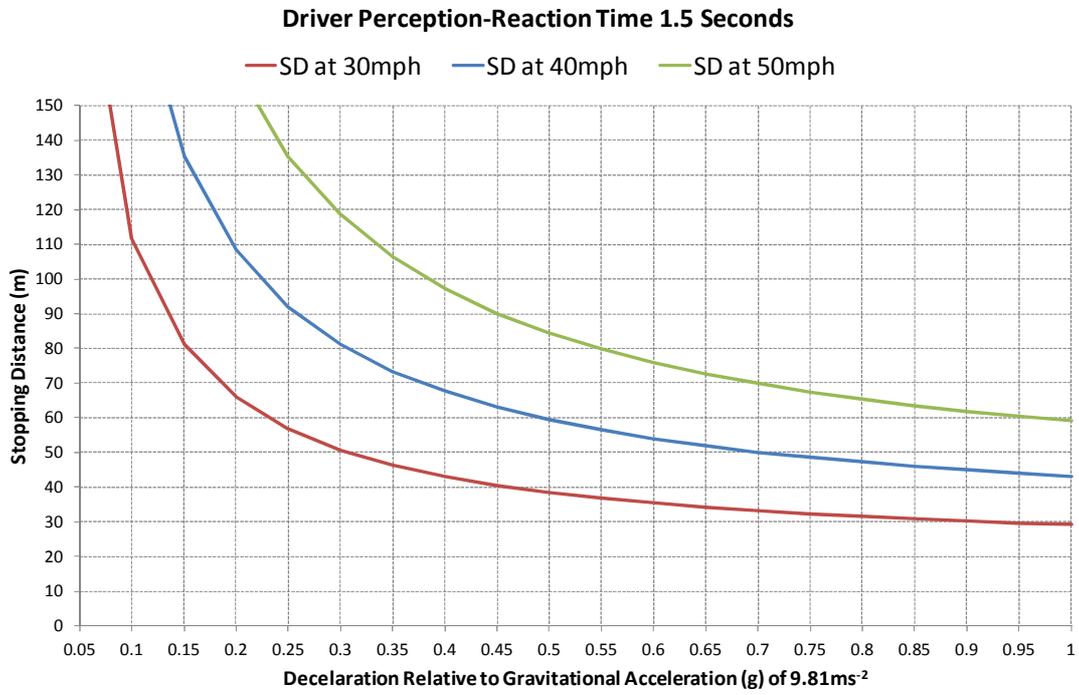
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<sup>5</sup> The Manual for Streets: Evidence and Research – Prepared for Traffic Management Division, Department for Transport, TRL Report TRL661, York, I., Bradbury, A., Ewings, T., Paradise R., TRL Limited, 2007

<sup>6</sup> Driver Perception-Response Time, Olsen, P., Institute of Traffic Accident Investigators, proceedings of the 3rd National Conference, Telford 14-16 November, 1997

<sup>7</sup> Road Layout Design Standards and Driver Behaviour, Maycock, G., Brocklebank, P., Hall, R., TRL Report 332, Transport Research Laboratory, 1998

the Braking Distances vary depending on the Rate of Deceleration. The higher the Rate of Deceleration, the shorter the Braking Distance.



**Figure 1 –Stopping Distances at Various Deceleration Rates and Speeds for Driver Perception-Reaction Time of 1.5 Seconds**



**Figure 2 – Stopping Distances (Thinking + Braking) at 30mph under Various Deceleration Rates, Driver Perception-Reaction Time 1.5 Seconds**

Theoretically, high friction is only required for the braking distance prior to the crossing. Consider a hypothetical scenario where road users travel at or below the 30mph speed limit, on a dry road with ideal driving and surrounding environment conditions, observe the hazard at a crossing well in advance, and all have perception-reaction times less than 1.5 seconds, and decelerate at a rate of  $4.41\text{ms}^{-2}$  (0.45g) or higher. Then, looking at Figure , the provision of approximately 20m of road surface that provides adequate skid resistance on the approach would be sufficient to stop vehicles comfortably before reaching the crossing point. However, the practical scenario is far from this, and extremely varied due to a number of variable factors.

The layout and types of crossings vary significantly in London. Figure 3 shows a sample of images from the Highway Code illustrating different types of crossing features, all of which impose different rules for pedestrian and road users. Figure 4 shows the layout of a crossing in Oxford Street opened in 2009 which is significantly different from conventional crossings.

This illustrates the diversity of crossings, and the different expectations and road user behaviours that can be anticipated at the different locations. The network level assigned SCRIM site category does not distinguish the types of crossings and therefore a default 'Approach to Crossings' category has been applied.

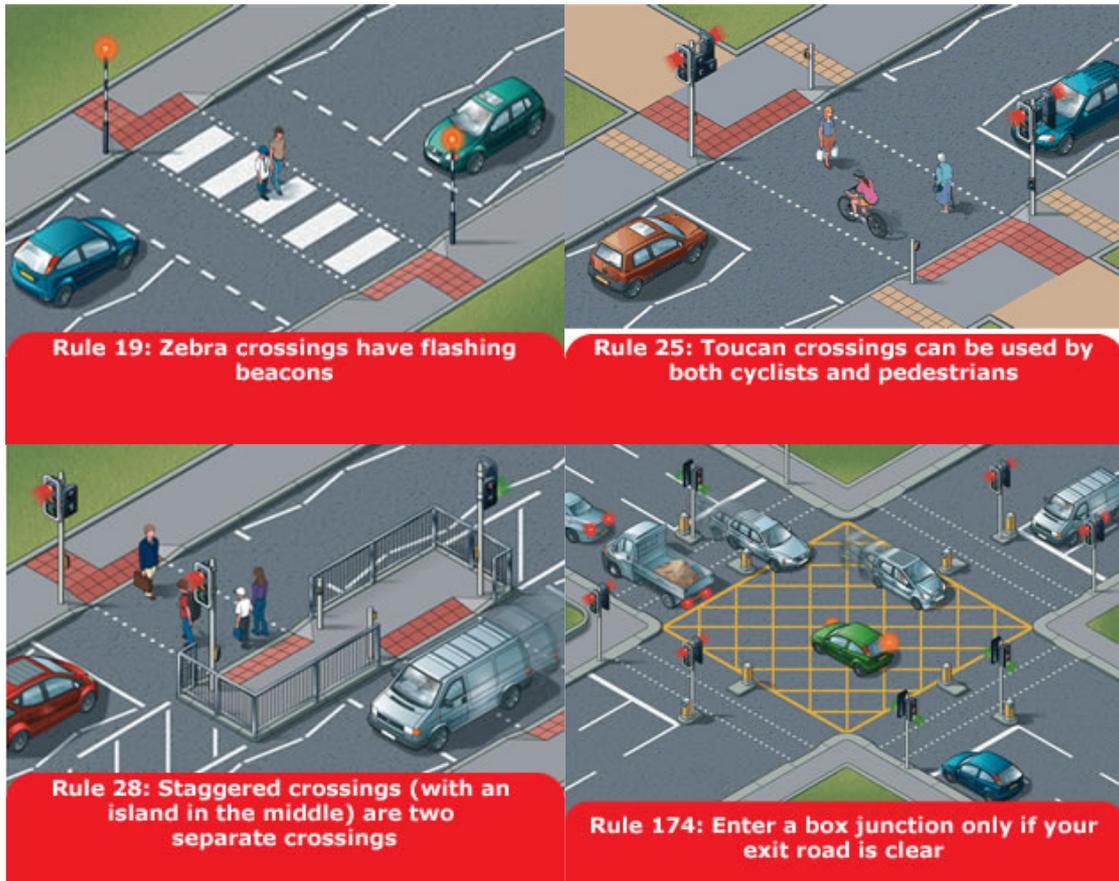


Figure 3: Highway Code crossing types



Figure 4: New Crossing in Oxford Street

### **3. ACCIDENT PATTERNS**

A review of 129 crossings and related accident data was undertaken to determine whether there was a pattern in the distribution of accidents adjacent to pedestrian crossings with the aim of determining the potential influence of the surface as a contributory factor. A three-year accident history (from the 1<sup>st</sup> January 2008 to the 31<sup>st</sup> December 2010) and Sideway-force Coefficient Routine Investigation Machine (SCRIM) data, was used in the accident review for both TfL and the London Borough networks.

#### **3.1 FITTING THE ACCIDENT DATA**

The three-year injury accident data up to the 31<sup>st</sup> December 2010 was fitted to the network using the WDM<sup>®</sup> Accident Manager Software. The total number of injury accidents in the SCRIM network during this period was 43,091. Road surface condition, whether or not there was a pedestrian casualty and accident severity were collected for each accident. The accidents were provided by TfL, and it is assumed that accident records include the best available location reference. The accuracy of accident referencing is beyond the scope of this report. For the review of accident data, only accidents that occurred at an approach to a crossing were considered. Over the 129 sites (258 approaches to crossings) there are 1,043 accidents (both wet and dry).

#### **3.2 ANALYSING THE ACCIDENT DATA**

Using the 1,043 accidents at the 129 sites, analysis of the HFS can be undertaken. It was possible to confirm that 56 sites had HFS systems using images of the sites. Out of the 129 sites, 100 had pedestrian controlled crossings, 27 had zebra crossings and two had pedestrian crossing islands. Of the accidents, 245 were wet accidents and 789 were dry accidents. It was found that 259 of the accidents directly related to pedestrians, so these accidents were considered on their own in addition to the analysis of all of the selected accidents.

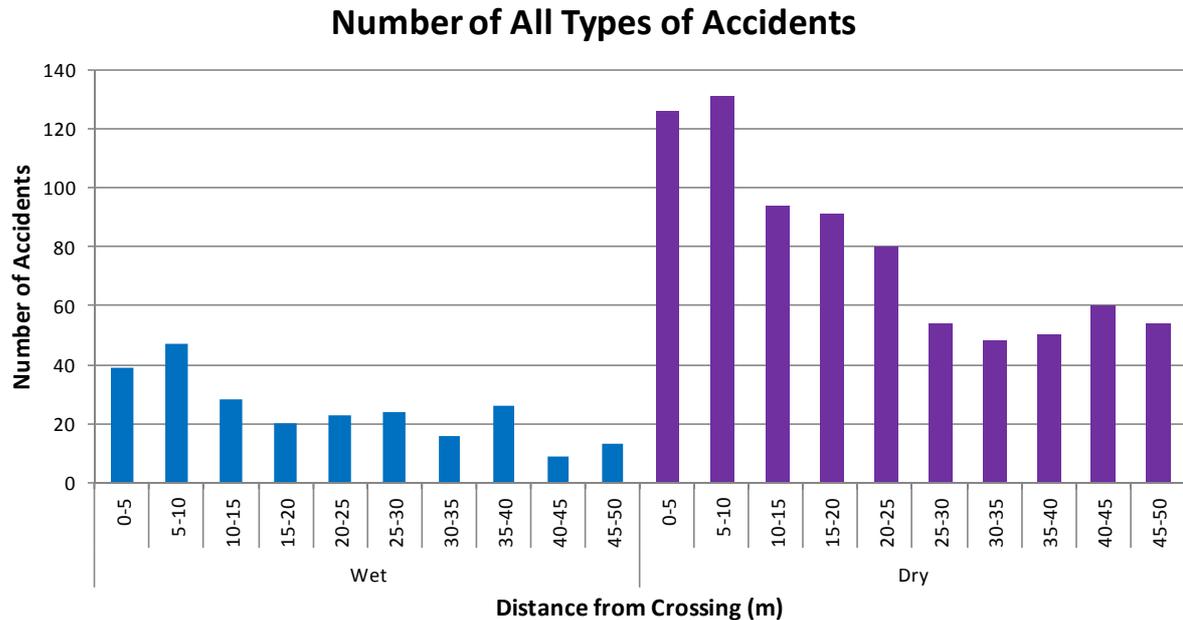
These accidents were displayed on overlay maps to illustrate the distribution of the accidents at each site. An example of this is shown in Figure .



**Figure 5: Example Site with the Distribution of Accidents**

Having selected the 129 sites, the distances from crossing point to the location of the accidents was calculated. Any accidents that were fitted to a point where both CL1 and CR1 were approaches to crossings, the shorter distance from the crossing was considered in the study. This Distance from Crossing is then banded into 5m intervals to group accidents into distance bands.

Figure 6 shows number of accidents by Distance to Crossing band (at 5m intervals). This shows that, when all types of accidents are considered, the number of accidents gradually decreases with the increasing distance from the crossing point, however, the number of accidents slightly increases around 35-40m in both wet and dry conditions.

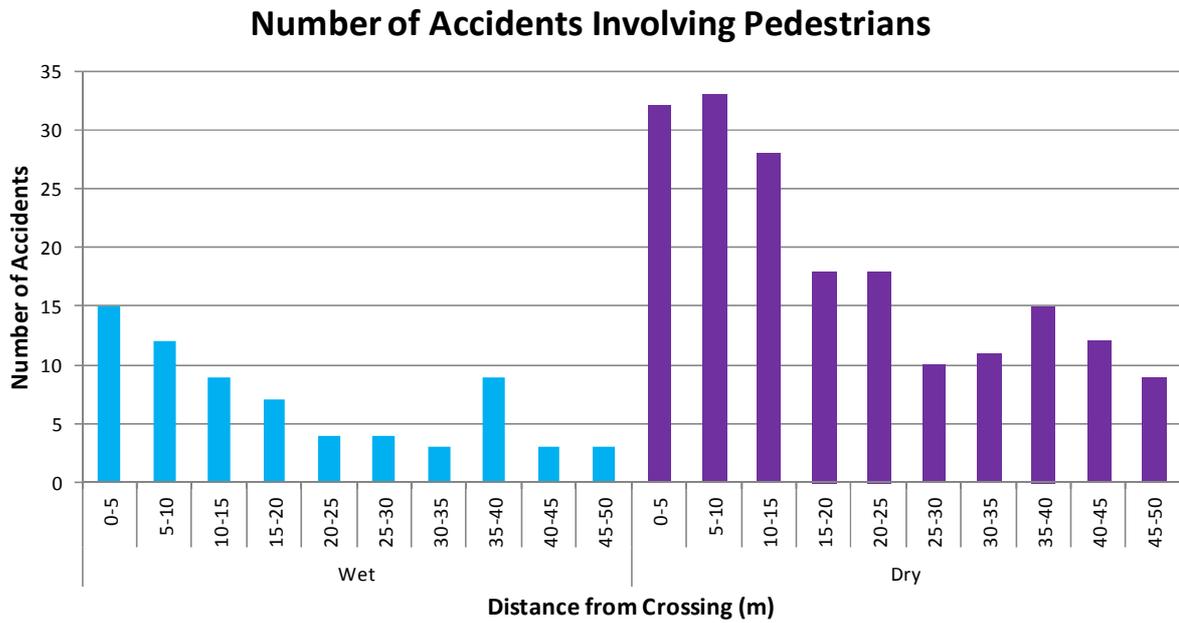


**Figure 6: The Number of Accidents and Distance to Crossing (5m Bands)**

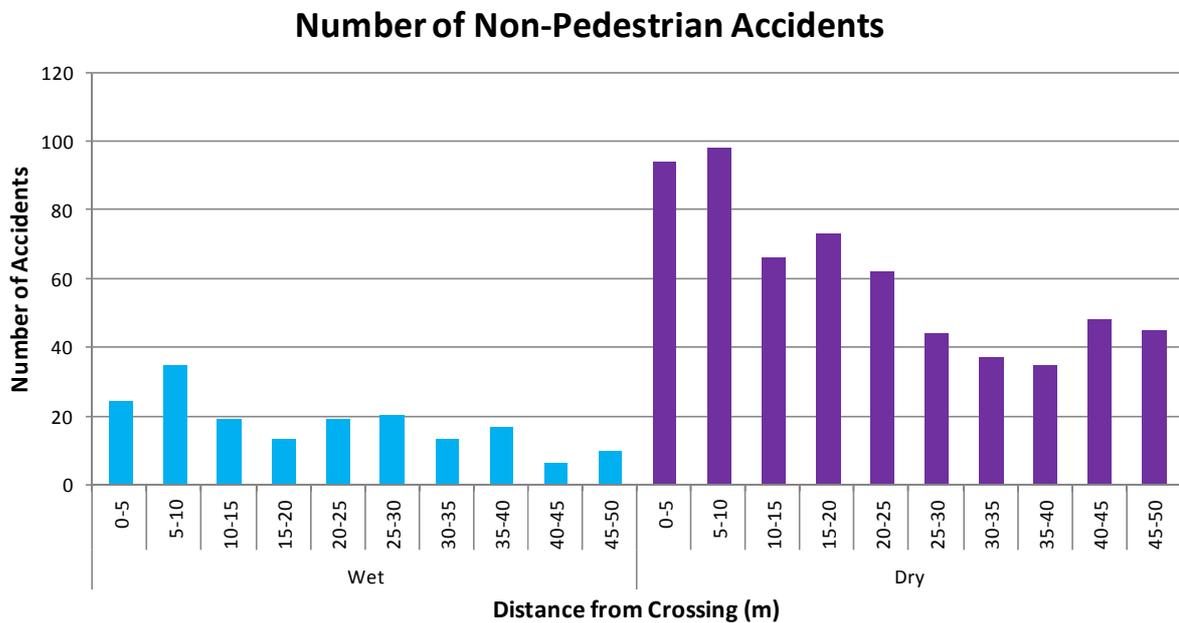
Similar analyses were undertaken separately for ‘pedestrian related’ accidents and ‘non-pedestrian related’ accidents, in figure 7 and 8 respectively.

Similar to all accidents the pedestrian related accidents also show that the number of accidents gradually decreases with the increasing distance from the crossing point, however, it seems to increase around 35-40m in both wet and dry conditions. For the 259 accidents, there is no significant difference between this data and all of the accidents

With respect to ‘non-pedestrian accidents’ generally a similar pattern is observed, with slightly increased number of accidents at a 5-10m distance from the crossing location. This is expected; as non-pedestrian accidents at approaches to crossings are likely to occur when vehicles attempt a sudden stop prior to the crossing point, likely to result in rear-end accidents.



**Figure 7 – The Number of Accidents Involving Pedestrians and Distance to Crossing (5m Bands)**



**Figure 8 – The Number of Non-Pedestrian Accidents and Distance to Crossing (5m Bands)**

The above analyses resulted in three main findings.

1. That the location of accidents within 50m of approaches to crossing is similar whether the accidents involved a pedestrian or not
2. The number of dry accidents within the 50m approach to crossings are about 2-3 times more than the wet accidents at any point within the approach
3. That the number of accidents gradually decreases with increasing distance from the designated crossing point, but shows a slight increase around 30-45m. This is more notable in the pedestrian accidents.

Figure 7 showed that regardless of the crossing facility, some pedestrians choose to cross away from the crossing point. This is undesirable to the highway engineer, but may be a natural consequence of providing the crossing facility itself and the pedestrian perception of safety at the vicinity of a crossing. From the accidents that occur at or near crossings, the severity of accidents that involve pedestrians are likely to be higher than the severity of non-pedestrian accidents.

#### **4. RECOMMENDATIONS ON LENGTH OF ‘APPROACH’**

The DfT reported that, in 2011, on built-up roads in Great Britain as a whole, 47% of cars exceeded the speed limit on 30mph roads, and 23% exceeded the speed limit on 40mph roads (in Free Flow Vehicle Speeds in Great Britain 2011**Error! Reference source not found.**<sup>8</sup>). These proportions have been approximately similar at least for the past five years.

Due to congestion and high traffic volumes, most of the vehicles in London (traffic during peak periods) experience different/low traffic speeds. As reported in TfL Travel in London: Key Trends and Developments Report**Error! Reference source not found.**<sup>9</sup>, the average weekday Greater London main road traffic speeds is 23.7km/h (14.7mph); the mid-day inter-peak period is 29.3km/h (18.2mph); and the weekday evening peak period is 25.6km/h (15.9mph). Furthermore, the traffic speed for Central London is significantly low even compared with the above averages for Greater London.

From the average speeds published by TfL, it is reasonable to assume that a majority of traffic at peak periods travel under the speed limit. For this reason, it may be argued that the 50m HFS surfacing may be too conservative for London.

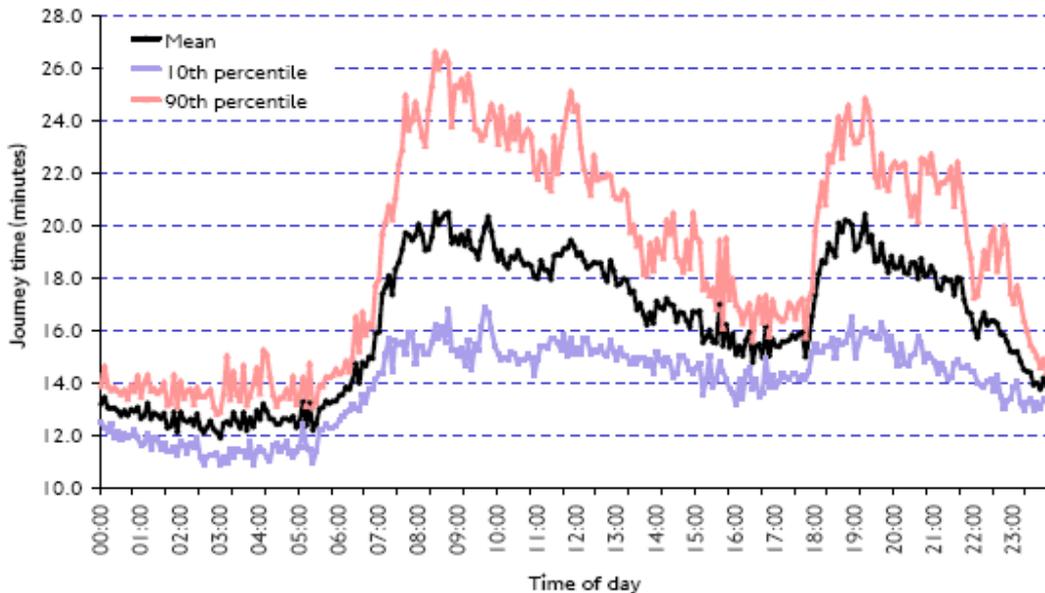
Despite the low average speeds however, there will be traffic in London that travel at or above the speed limit, especially during the off-peak periods. Figure 9 shows an example of a corridor analysis undertaken by TfL reported in the Travel in London report**Error! Reference source not found.**. The data shows the distribution of journey times by the hour of day on a typical weekday for approximately 10km distance between Chiswick Roundabout and Hyde Park Corner through inner West London (eastbound direction). This shows how the journey time changes by the time of day; the peak-hour

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<sup>8</sup> Free Flow Vehicle Speeds in Great Britain 2011, Vehicle Speed Statistics – Statistical Release, Department for Transport, June 2012

<sup>9</sup> Transport for London - Travel in London: Key Trends and Developments Report Number 1, Mayor of London, Transport for London, 2009

journey times could be twice as long as off-peak times. This indicates that there is a significant difference in speed of travel between peak traffic and off-peak traffic.



Source: TfL Road Network Performance

**Figure 9 – London Corridor Analysis Example**

Although excessive speed is unlikely to be the major factor in many of accidents in London, TRL Report PPR241 published in 2006<sup>10</sup>, found that 97% of pedestrian accidents in London occurred on roads with a speed limit of 30mph. The severity of pedestrian collisions is directly related to the speed of impact. One of the key objectives of installing HFS systems is, if a pedestrian collision does occur in wet conditions at whatever driving speed, to reduce the impact speed and reduce the severity of injuries including the prevention of fatalities. Therefore, it is very important to make sure that, if the length of HFS in the approach to crossings is reduced, it does not compromise safety at these locations.

Road surface skid resistance is significantly reduced in wet/damp conditions; this includes during raining and until the surface becomes completely dry. The risk of accidents increase due to reduced skid resistance and impaired visibility. TRL Report PPR241 found that in London, 88% of pedestrian collisions occurred in fine weather, but as expected the injury severity was higher in wet weather.

A before and after treatment study on 338 sites undertaken by A.E. Young<sup>11</sup> found that by increasing the average skid resistance from 0.35 to 0.65, the wet-road accidents reduced by approximately 35%.

<sup>10</sup> Factors Influencing Pedestrian Safety: A Literature Review, Martin, A., TRL Report PPR 241, TRL Limited, 2006

<sup>11</sup> The Potential for Accident Reduction by Improving Urban Skid Resistance levels, Young A.E., PhD Thesis, Queen Mary College, University of London, 1985

Different approaches to crossings may be subject to various levels of queuing hazard. This could be due to the volume of pedestrian movements (i.e. busy intersections, transport hubs, shopping areas, etc), lack of approach sight distance, demographics of pedestrians using the crossing facility, etc. The queuing hazard may require vehicles to brake and stop before the crossing position, hence there may be an increased skid resistance demand in order for vehicles to stop due to queuing.

Vehicles may also need to brake and slow down early for pedestrians that choose to cross the road away from the crossing point. It is recognised that pedestrians may choose to cross the road away from the designated crossings point due to various reasons. These may include shorter walking distance to their destination on the other side of the road, pedestrian choosing to use the perception of a safer crossing environment close to the crossing facilities, absence of guardrails, longer waiting times, distance between the pedestrian access point (i.e. bus stop, entrance/exit to buildings, walkways) and the crossing position being too far, etc. TRL Report PPR241 also found that most of the pedestrian accidents in London occurred away from pedestrian crossing facilities; however, approximately 40% did occur at or close to crossing facilities. National Statistics from the DfT on reported road casualties<sup>12</sup> shows that in 2010, 11% of pedestrian collisions occurred on a pedestrian crossing, and 7.3% occurred within 50m of a crossing.

Features of road geometry and road layout including bends, gradients, junctions, side access roads, etc also cause variations in braking and stopping patterns in the approach to pedestrian crossings.

It is not appropriate to determine the length of HFS surface at pedestrian crossings based on the 'emergency' stopping distance requirements detailed in the Highway Code; therefore, there should be a factor of safety to incorporate the variables discussed above. However, there may be scope for using shorter than 50m lengths for HFS treatments on low-risk sites. Low risk sites could be defined in terms of the number accidents, visibility, road layout, traffic count, etc, and they could be identified through a field inspection/audit on an individual basis.

#### **4.1 RELAXATIONS AND DEPARTURES FROM STANDARD**

The UK Roads Liaison Group has published guidance on applying 'Departures from Standards Procedures for Local Highway Authorities'<sup>12</sup> This uses the terminology of Relaxations and Departures where:

- Relaxation                      A permitted variation from the Declared Standard or other policy document
- Departure                        A non - compliance with a declared standard
- Declared Standard            The standards and specification used by the highway authority and stipulated in policy documents etc.

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<sup>12</sup> Departures from Standards Procedures for Local Highway Authorities. UK Roads Liaison Group. 2011

This recommends the detail of assessment should be proportional to the scale of the project and the likely risks. The objective is to demonstrate that the Highway Authority exercised a reasonable level of professional skill in considering departures from standards, and relevant factors and constraints are considered. In practice this will involve professional judgement.

#### 4.1.1.Declared Standard

It is recommended that the Investigatory Levels detailed in the London Skid Policy are considered a declared standard. Table 1 shows the Approaches to Crossings site category in the site category table. The Initial level of 0.55 has been applied by the London Boroughs, whereas TfL have adopted 0.50. The London Skid Policy adopts a 50m approach to the feature as a standard.

**Table 1 – London Site Categories: Approaches to Crossings**

Site category and definition		Investigatory level at 50km/h							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
K	Approaches to pedestrian crossings and other high risk situations						default		

#### 4.1.2 Relaxation from Standard

The London policy allows the SCRIM Investigatory Level to be reset at 0.50 based on an assessment of risk at a site. In the context of the UK Road Liaison Group guidance, this can be considered a relaxation from standard.

#### 4.1.3Departures from Standard

Where it is considered that a site does not require the full 50m approach, this should be considered a departure from standard.

It should be noted that there are locations where the current site category is less than 50m due to geometric constraints; for example, the crossing is shortly after a roundabout. This would not be considered as departure.

It is not considered appropriate to lower the IL for an ‘approach to a crossing’ below 0.50 as a departure.

In determining whether the approach length should be reduced, the following should be considered:

- Type of crossing including standard of control equipment and associated street furniture
- Approach speeds (including off peak speeds)
- Road alignment
- Accident pattern
- Visibility of crossing for approaching traffic
- Visibility of approaching traffic for crossing users
- Patterns of use of crossing
- Any route management strategies in place/ proposed

The principle is to assess whether the cost savings associated with reducing the length of approach treated with HFS should be set against the assessed increase of risk to the user (or potential user) of the crossing. The assessment should be fully documented, and if a departure is recommended, it should be appropriately authorised.

An assessment could be made for an individual crossing, or part of a street with a number of similar crossings.

All sites where a departure has been implemented should be monitored to assess whether there are any adverse consequence of the departure.

## **4.2 DISCUSSIONS**

Due to the variable factors that affect the stopping distance at crossings discussed above, a factor of safety may need to be included in the length of HFS at particular approaches to crossings. A possible option that would be suitable for TfL and London boroughs is to continue the current policy of minimum 50m length, but allow the flexibility for a departure from the policy based on risk assessments on a site-by-site basis. When budgets are constrained, which is usually the case; it is prudent to identify high/low risk crossings and to ensure that the funds are used at sites where the greatest accident savings and safety improvements are likely.

It may need to be ensured that individual sites meet the standard geometric design specification, and consider the factors that render crossings high or low risk (discussed above), along with a detailed study on the accident history at the site. Young, after considering various alternatives, concluded that examination of past accident data is by far the best method of assessing future accident risk at an existing site, and to-date this method has been widely used for identifying high-risk sites.

In determining the departure from the standard 50m HFS length, the Manual for Streets guidelines may be used by London highway authorities. A perception-reaction time of 1.5 seconds and a deceleration rate of  $4.41\text{ms}^{-2}$  (0.45g) appear to be a good starting point as these figures contain a reasonable factor of safety against wet weather conditions, visibility, and other variable factors that affect stopping distance, compared to the Highway Code guidance on emergency stopping. Carriageway surfaces are normally able to develop skidding resistance of at least 0.45g in wet weather condition; therefore, the use of HFS would provide an added factor of safety.

## 5. SURFACING OPTIONS

One of the concerns about High Friction Surfacing is that the cost can be significant, and typically it is laid after the main surface, requiring additional traffic management. With the predicted service lives discussed earlier there is a view that conventional surfacing materials with high PSV aggregate may provide a better whole life cost option to deliver a high level of skid resistance at approaches to crossings.

TfL provided a list of locations in the TfL road network treated with High PSV surfacings and a small number of HFS. A majority of these surfaces have been installed in 2009, 2010, or 2012. From this list, 23 locations were selected for a study that examined the condition of these surfaces using the annual SCRIM survey data. Due to the surfaces being only 3-4 years old, a full lifecycle analysis of the surface types cannot be undertaken, therefore the performance of these sites in the first 3-4 years in-service was examined.

### 5.1 SKID RESISTANCE PERFORMANCE

If some of the High PSV materials achieve skid resistance levels above the IL consistently, they may be suitable for Approaches to Crossings in the London principal road network. Most of the sites typically have a maximum of three post-construction surveys. This period is not long enough to determine any trends in skid resistance performance. The general observation is that, during the initial 3-4 years, the MSSC values appear to fluctuate from survey to survey, especially when data is examined at 10m subsection level.

The average skid resistance seems to provide a better representation of the overall skid resistance performance. Therefore, it was deemed sensible to examine the yearly averages of SCRIM values at these sites, separated into the various surface types. This provides the yearly trend of skid resistance as shown in figure 10 in a bar graph where yearly averages are displayed for each surface type.

The same information is illustrated using a line graph shown in figure 11.

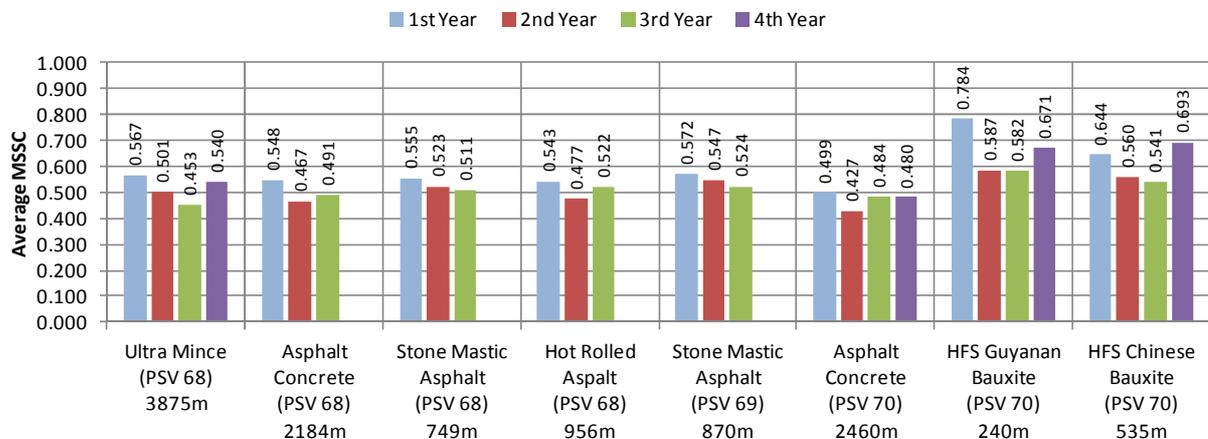
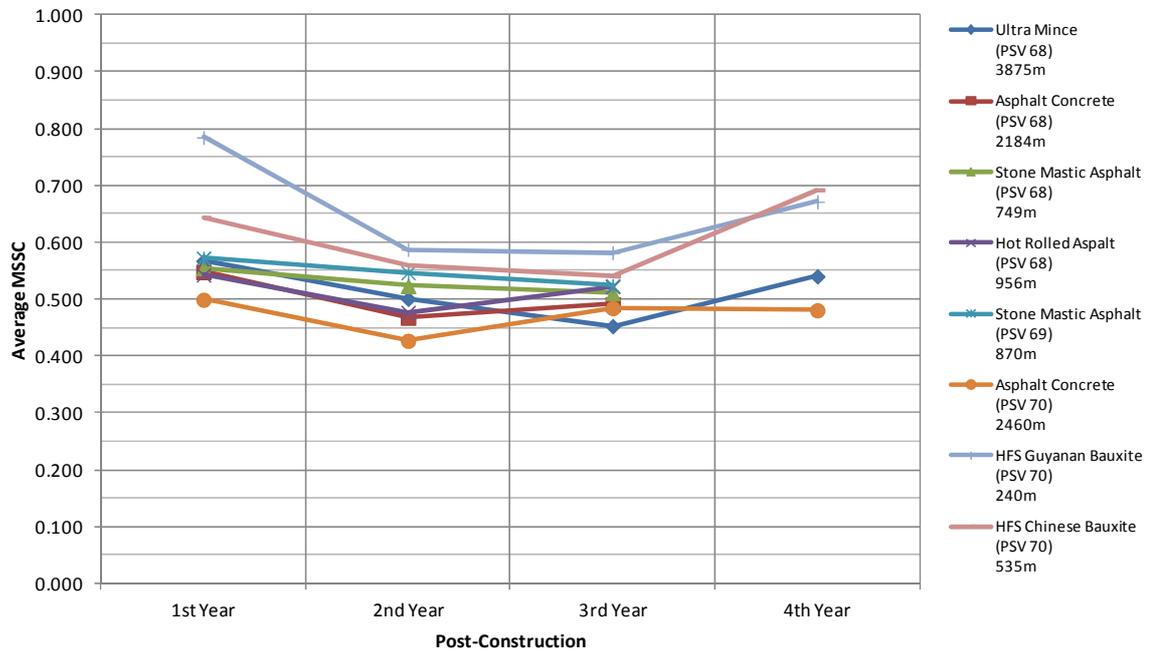


Figure 10 – Average MSSC by Surface Type (Sample Sites Only)



**Figure 11 – Performance of Post Construction Average MSSC by Surface Type (Sample Sites Only)**

Most surface types appear to have higher skid resistance initially then seem to reduce and settle after round 2-3 years. This is expected, as surface aggregates go through an initial phase of polishing until it reaches an equilibrium condition.

One particular HFS site showed unusually low skid resistance for a HFS surface. The data shows the skid resistance significantly reduced after the treatment was applied. It is suspected that the surface type may have been recorded incorrectly for this site. Except for that site, all other HFS surfaces have both average and 85%tile SCRIM values above 0.55.

Table 2 tabulates the percentages of 10m subsection lengths that are above 0.50 and the percentage above 0.55 in the data in the various surface types. This gives an indication of the level of skid resistance within each surface type.

**Table 2 – Level of Skid Resistance by Surface Type (using the latest data)**

Surface Type	Total Length of Data (m)	Length Above 0.50 (%)	Length Above 0.55 (%)
ULM Ultra Mince (PSV 68)	2550	86%	69%
Asphalt Concrete (PSV 68)	1160	79%	46%
Stone Mastic Asphalt (PSV 68)	670	79%	48%
Hot Rolled Asphalt (PSV 68)	960	84%	52%
Stone Mastic Asphalt (PSV 69)	720	61%	50%

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Asphalt Concrete (PSV 70)	2460	52%	3%
HFS Guyanan Bauxite (PSV 70)	240	100%	100%
HFS Chinese Bauxite (PSV 70)	540	81%	72%

As shown in table 2, at 10m level, 100% of Guyanan Bauxite subsections exceeded 0.55. The Chinese Bauxite subsections showed 72% exceeding the 0.55, but if the low skid HFS site mentioned above is removed from the analysis this figure increases to 89%. All HFS subsections exceeded 0.55 apart from a very small length; hence, these can confidently be used to meet IL's of 0.55.

This is expected, however the issue with HFS surfaces is their durability. Some of the High PSV materials appear to provide average skid resistances over 0.55 in the first year; however, they all seem to reduce after 2-3 years. There may also be individual High PSV sites where SCRIM over 0.55 has been achieved, but based on the overall performance the probability of a High PSV site achieving 0.55 beyond 3 years of service is low. This would mean that in order to meet a high skid resistance demand of 0.55, High PSV surfaces would have to be replaced every 2-3 years. Therefore, for higher risk sites (IL above 0.55) to sustain a SCRIM coefficient, the use of HFS may be the only option to give a high confidence of performing.

Some of the High PSV sites may be adequate to provide the level of skid resistance required at Approaches to Crossings on sites allocated as a 'low' risk using the 0.50 IL in the Boroughs IL table. The ULM Ultra Mince 68PSV, SMA 68PSV, and SMA 69PSV appear to provide average SCRIM of over 0.50 consistently in the first 3-4 years.. Furthermore, as shown in table 2, AC 68PSV and HRA 68PSV showed over 79% SCRIM values above 0.50. This suggests that the materials have the potential to achieve skid resistance above 0.50, but may need improvements in mix design, and/ or workmanship.

Apart from Asphalt Concrete 70PSV, all High PSV surface types had at least one site performing above 0.50, which indicates that these surface types are capable of achieving high skid resistance, but the variability may be due to individual surface designs, quality of workmanship, aggregate source, supplier, etc. The Asphalt Concrete 70PSV results are based on a single site of approximately 1200m long, where approximately 50% of the data was below 0.50. Given the site is a Dual Non-Event section; it is suspected that the surface type and/or the material types may have been recorded incorrectly.

## **5.2 ALTERNATIVE MATERIALS**

The review of material performance is based on conventional surfacing materials incorporating high PSV aggregates compared with HFS. There are proprietary products available that may provide an alternative to either conventional surface courses, or HFS.

Aggregate Industries have developed a road surface called Bardon Superflex72, which has been developed as an alternative to the use of HFS. It is claimed that Superflex72 offers friction levels equivalent to that specified for HFS systems, using a specific Aggregate Industries' aggregate source throughout the mixture. Furthermore, it is endorsed that if laid by Aggregate Industries, the material comes with a 10-year SCRIM warranty.

STEELSTOP® is a product developed from Steel Slag that has been claimed to provide an alternative to Calcined Bauxite. Devon County Council has undertaken trials of a HFS equivalent material utilising Quartzite in place of Bauxite.

It is beyond the scope of this paper to recommend any specific product or treatment; however, there do appear to be alternative materials to HFS being developed that may offer a solution to some of the issues identified in London.

## **6. CONCLUSIONS AND RECOMMENDATIONS**

### **6.1 REVIEW OF HIGH FRICTION SURFACING USE**

- Vehicle stopping distance depends on three main variables: speed, driver perception-reaction time, and the deceleration rate. Highway surface engineering measures can only influence the deceleration rate, which can significantly reduce during wet conditions.
- Speed and driver perception-reaction time also significantly vary: speed can depend on time of the day as well as the individual driver; the perception-reaction time inherently has a wide range based on the individual driver characteristics.
- A majority of highway authorities including TfL and London Boroughs apply the standard 50m approach to crossings, mainly due to the level of risk (vulnerability of accident victims) and the added factor of safety provided by HFS surfaces to improve the skid resistance, especially during wet conditions.
- The stopping distance guidelines in Manual for Streets may be appropriate for London highway authorities. It uses the 85<sup>th</sup> Percentile perception reaction time of 1.5 seconds and a deceleration rate of 0.45g. This deceleration rate is normally achieved by normal carriageway surfaces in wet weather conditions, so HFS surfaces provide an extra factor of safety.
- Manual for Streets suggests at 30mph the stopping distance would be 40m, at 40mph it would be 63m, and 50mph it would be 90m.
- A reduction in the length of HFS required should be treated as a departure from standard, and be based on a review of evidence relating to the site.

### **6.2 REVIEW OF ACCIDENT DATA**

- Approaches to crossing are given a high-risk rating due to the vulnerability of accident victims (i.e. pedestrians). Therefore, the primary objective of HFS surfaces at approaches to crossing is to prevent (or reduce the severity of) pedestrian accidents, hence primarily to enable vehicles to stop before the crossing point.

- To enable vehicles to stop before reaching the crossing point it may be sufficient to install a shorter length of HFS surfaces if the design calculations suggest a length less than 50m.
- Accident data analysis showed that pedestrian accidents occur through the entire length of a 50m approach, with a majority occurring in the first 15m. Interestingly, the study showed a slight increase in accidents around 30-45m from the crossing.
- In 2010, 11% of all pedestrian accidents occurred at the pedestrian crossing point; notably a significant 7.3% also occurred within 50m of a crossing.
- The above suggest that by providing adequate skid resistance within 50m of pedestrian crossings, a significant number of pedestrian accidents could be prevented (or severity reduced, for example fatalities prevented).
- Some pedestrians choosing to cross away from the crossing point is undesirable to the highway engineer, but may be a natural consequence of the pedestrian crossing facility itself. Therefore, it can be argued that by providing the 50m length of HFS surfacing, it not only performs the primary objective of reducing accidents at the pedestrian crossing point, but also likely to reduce a significant number of pedestrian accidents within 50m of the crossing.

### **6.3 PERFORMANCE ANALYSIS OF SURFACE TYPES**

- A list of High PSV and HFS surfaces installed in the last 3-4 years was supplied by TfL. A number these sites were examined using 3-4 years of post-installation SCRIM data.
- All HFS surfaces appear to provide skid resistance over 0.55 in the 3-4 years after installation.
- ULM Ultra Mince 68PSV, SMA 68PSV, and SMA 69PSV appear to provide average SCRIM over 0.50 consistently in the first 3-4 years after installation. These may be applicable at TfL approaches to crossings due to the low IL of 0.50, or borough crossings where a 'low' 0.50 IL has been selected based on a site based risk assessment.
- All High PSV sites appear to be capable of achieving skid resistance above 0.50. However, there is variability in performance at different sites where they did not achieve higher skid resistance. It can be expected that through consistent design, use of quality aggregate source/supplier, and perhaps through improved workmanship, all High PSV sites could be used to provide skid resistance above 0.50.
- High PSV surfaces on low risk approaches to crossings may be possible. However, it is recommended that a full 50m approach is treated with High PSV surfacing to provide an added factor of safety. The cost of High PSV surfacings is much lower than HFS.

- Alternative materials have been developed that may offer alternatives to the use of conventional HFS in providing high levels of skidding resistance.

#### **6.4 OVERALL**

- High PSV on low risk approaches to crossings may be possible. If using High PSV material, it is recommended that a minimum 50m approach is surfaced with the high PSV aggregate.
- DfT reported 47% of cars exceed the 30mph speed limit and significant percentages do so in other speed limits as well. TfL reported that most of London roads operate at low speeds due to congestion. At off-peak, free flowing, traffic conditions London traffic also exceed speed limits, therefore higher speeds cannot be ruled out at London's approaches to crossings.
- Due to the number of variables affecting vehicles stopping distance, in most cases the provision of the standard 50m approach to crossing seems appropriate. Although 50m may be more than the required stopping distance, it includes a factor of safety for vulnerable pedestrians as well as vulnerable drivers.
- At certain conditions, less than 50m length of HFS surface may be appropriate (i.e. a departure from standard), however that should be determined on a site-by-site basis through investigations. That should consider the level of risk of the site by investigating the layout of the site, visibility, traffic speed patterns, road user profiles (both pedestrians and vehicle users), etc.

### **Author Biographies**

#### **Mark Stephenson**

Mark Stephenson is a Chartered Civil Engineer and Head of Consultancy Services with W.D.M. Limited a post he has held since 2008. He is responsible for a range of projects undertaken for UK and overseas clients. These have involved the interpretation of highway condition surveys together with the development of tools and analysis to achieve cost-effective maintenance programmes. His current areas of interest include the measurement and management of skid resistance, Highway Asset Management, including lifecycle plans, scheme identification and prioritisation and policy implementation for clients.

He worked for twenty years at the Cornwall County Council where he was responsible for highway maintenance and construction. He represented the council on a number of national working groups and chaired the Highway Condition Assessment Group which reports to the UK Roads Board.

### **Mark Hodgson**

Mark Hodgson is Highways Group Manager at the Royal Borough of Greenwich (meaning he's responsible, amongst other things, for the maintenance and management of all the councils highway infrastructure). He has worked in London for 10 years and before that was a Route Manager for a section of State Highway in New Zealand. Prior to taking his current role for a number of years Mark was responsible for the delivery of the Road2000 project – a pan London initiative to collect consistent road condition data across all of the London A classified roads (except those managed by TfL) including DVI, SCANNER and SCRIM. Mark has been part of a number of working groups and is an active member within the London Technical Officer Group (LoTAG).

### **Dr Anuradha Premathilaka CEng MICE MIAM**

Anu is a Senior Asset Management Engineer at CH2M HILL's (formerly Halcrow) Transport planning and Advisory Business Group. He has worked both in the UK and in New Zealand, and has a range of experience in transportation asset management from a consultant, contractor, and researcher perspectives. His key experiences include lifecycle analysis, deterioration/financial modelling, economic evaluation, maintenance programme development and prioritisation, skid resistance, PAS55 assessments, and quantitative risk assessment. Anu undertakes consultancy work for a number of UK transport authorities. His recent projects include asset management and lifecycle modelling projects for the Highways Agency and the High Speed 1 railway, and risk assessment work on the Bristol Bus Rapid Transit Network project. Prior to joining CH2M HILL, Anu was a Senior Project Engineer in the Consultancy Services Division at W.D.M. Limited. In New Zealand, he worked at Downer EDI as a Project Engineer, then at Fulton Hogan as a Regional Technical Engineer. Anu has a Doctor of Philosophy (Civil) specialising in transport asset management, a Master of Engineering Studies specialising in transportation, and a Bachelor of Engineering in civil engineering. He is a Chartered Engineer and a Member of the Institute of Asset Management.