Vehicle Speed from Throw Distance – Searle and Appel
Professional Development Certificate in Forensic Road Accident Investigation.
An extract from the distance learning course notes.

Searle's Method

As mentioned in the introduction to this section there are several different methods of establishing the speed of a vehicle from the distance a pedestrian is thrown. Probably the most commonly used equations within the UK are those derived by John Searle in 1983. They are simple to use and in field studies have been found to be accurate to an acceptable degree. However the investigator must remember that they give a general indication of vehicle speed rather than an absolute value. This means that it is *desirable* to confirm the speed calculated using 'pedestrian throw' with other evidence such as speed from skid marks.

As we saw in the previous section on projectiles the range was measured between the launch point and the landing point. Searle realised that pedestrians rarely marked the surface at the landing point, rather they bounced, rolled or slid to the final resting point which was more easily defined. Thus his research was based on the *total distance* covered by the pedestrian to the point of rest.

The initial approach was a mathematical one in which the pedestrian was represented by a simple particle. As we saw in section 2.4, when struck by a vehicle, a pedestrian will normally be projected through the air before landing. It is possible that the pedestrian, after a short period of contact with the ground, may bounce. Alternatively they may simply roll or slide to a stop.

Let's consider what happens during these 'bounces'. Whilst in contact with the ground the reaction with the ground is high. Since the frictional force slowing an object is proportional to the normal reaction, when in contact with the ground a high frictional force is generated. This makes up for the periods when the body is in the air when there is no reaction with the ground. This reaction will be particularly high on first landing when the pedestrian has been out of contact with the ground for a long time. The upwards projection of the pedestrian at launch has disappeared by the end of the projection, so the bounces have effectively averaged the reaction with the ground thus averaging the frictional forces.

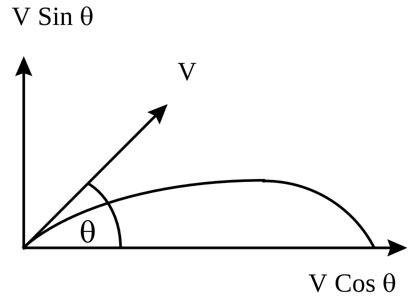
Where a pedestrian is launched with a vertical velocity v, and a horizontal velocity u, the total distance travelled can be found from

$$S = \frac{(u + \mu v)^2}{2 \mu g} - \mu H$$

Where H is the gain in height, which is usually negative.

The derivation of the above equation requires maths beyond the level taught on this Course.

In the equation u and v are components of the launch velocity, V, (as shown in the diagram below). We can therefore replace both with V Cos θ and V Sin θ where θ is the launch angle.



This gives an equation where,

$$S = \frac{V^2(\cos\theta + \mu \sin\theta)^2}{2\,\mu\, g} - \mu H$$

Transposed for V, the launch velocity,

$$V = \frac{\sqrt{2\,\mu\, g(S + \mu H)}}{\cos\theta + \mu \sin\theta}$$

It is unlikely that we will ever know the actual launch angle of the pedestrian. Considering a value for θ that minimises the velocity it can be shown that Tan θ = μ , so that θ = arctan μ. We can find an expression for V_{min} the minimum velocity required to project the pedestrian over a given distance.

$$V_{min} = \sqrt{\frac{2\,\mu\, g(S + \mu H)}{1 + \mu^2}}$$

Where there is no change in height, H will equal zero so the equation can be simplified,

$$V_{min} = \sqrt{\frac{2\,\mu\, g\, S}{1 + \mu^2}}$$

The coefficient of friction for sliding pedestrians

In our equations the mu referred to, is the coefficient of friction between the pedestrian and the road, or other surface.

Searle reported in his research, that the coefficient of friction of a sliding body was in the region of 0.66 and 0.79 and that it did not vary between tarmac and grass, wet or dry. What was not reported was how he determined these figures.

More recently, (1989), an extensive series of tests have been carried out by West Midlands Police in the UK. They calculated the value for mu of a dummy sliding across an airfield surface. Different types of clothing were used. The resulting coefficient was found to vary between 0.57 and 0.9. The lowest coefficient was produced by a nylon motorcycle suit.

Where unusual circumstances are encountered, such as pedestrians sliding on icy roads, the investigator must be aware of the effect that this will have on subsequent calculations. Searle produced a table of corrections for varying coefficients of friction.

Although the table is not reproduced here, it is worth noting however that within the normal range of coefficients, (0.6 to 1.0), the affect on the calculated velocities are small, between ± 3%. Coefficients below 0.5 result in quite large differences, (up to -36% for a value of mu of 0.2).

In collision reconstruction a value for mu of 0.7 for a body sliding on a 'normal' surface should not, under normal circumstances, be challenged.

The effect of changes in the projection angle

In the V_{min} equation the projection angle has been idealised. The actual projection angle, if it could be measured, will also result in different velocities.

For a value of mu of 0.7, a projection angle of between 20 and 50 degrees will result in an increase in velocity of up to 4%. This increases to 10% if the range is increase to between 10 and 60 degrees.

Field studies have shown that the launch angle is rarely above 40°. Thus under normal circumstances the results obtained from the equation appear to be quite stable.

The effect of gradient

For values for mu of between 0.6 and 0.8 the value for V_{min} was found to be within 5% of the actual value for slopes up to 1 in 16 (6%). Where the slope was steeper then the effects became more noticeable.

The equation can be adjusted to take account of the gradient. Where the angle of the slope is α then only a component of g will be acting on the frictional force. The equation can be rewritten to include gradient as shown below,

$$V_{\min} = \sqrt{\frac{2\ \mathrm{g}(\mu \mathrm{Cos}\,\alpha + \mathrm{Sin}\,\alpha)(\mathrm{S} + \mu\,\mathrm{H})}{1 + \mu^2}}$$

The effect of changes in height

Finally the effect of a change in height can be considered. Searle estimated that the actual height from which a pedestrian is projected will be approximately 1 metre. This does not seem unreasonable as, under normal circumstances, the pedestrian will be projected from the bonnet (hood) of a vehicle.

For small changes in height the equation can be rewritten to exclude H.

$$\mathrm{V}_{\min} = \sqrt{\frac{2\ \mu\ \mathrm{g}\ \mathrm{S}}{1 + \mu^2}}$$

For a value for mu of between 0.2 and 1.0 and a projection distance of 10 to 40 metres the difference between the two calculations is within 4%.

For larger changes the original equation can be used to include the change, where a negative height represents a landing lower than launch,

$$V_{min} = \sqrt{\frac{2\ \mu\ g(S + \mu\ H)}{1 + \mu^2}}$$

Maximum velocity

The maximum launch velocity for a pedestrian can be calculated from,

$$V_{max} = \sqrt{2\ \mu\ g\ S}$$

V_{max} holds provided the launch angle is below a critical value. We are highly unlikely to be able to calculate the actual projection angle. However Searle produced a table of critical launch angles which are shown below.

Coefficient of friction	Critical launch angle θ_{crit}
0.3	33
0.4	44
0.5	53
0.6	62
0.7	70
0.8	77
0.9	84

Therefore for a value for mu of 0.7 the angle of launch must not have been above 70°if we wish to calculate V_{max} . The table shows that under normal conditions the critical angle is high, higher than a pedestrian would normally be projected. From the table it appears that problems are only likely to arise when low coefficients of friction are encountered. We stated earlier that in practice field studies have shown that the launch angle is rarely above 40°. Thus the equation for V_{max} will be valid in the majority of collisions to give an upper bound to the range of launch velocities.

The V_{max} equation is also more sensitive to the coefficient of friction between the pedestrian and road. The differences are however relatively small. As an example the difference between a coefficient of friction of 0.7 and 1.0 gives a 13% difference in the calculated speeds.

Searle’s method - conclusion

In a typical case a pedestrian will be projected by a vehicle. On landing the contact force is high and the impact results in a loss of horizontal speed. In theory this loss in speed is equal to the coefficient of friction multiplied by the vertical speed of the pedestrian. Following the initial contact with the ground the pedestrian bounces or skids to a stop. It does not matter in which manner the pedestrian behaves, as periods of low contact force and low drag must be compensated by periods of high contact force and high drag.

It can be seen that for minimal gradients and changes in height the standard formula can be used without the need for adjustment. Thus, under normal circumstances,

$$V_{min} = \sqrt{\frac{2\ \mu\ g\ S}{1 + \mu^2}}$$

Where site circumstances require it, the equation can be adjusted to take account of gradient and changes in height.

It should be noted that unlike our projectile equations, our pedestrian is unlikely to be accelerated to the full speed of the vehicle with which they collide. The calculation for V_{min} is likely to be an underestimate of the actual vehicle speed.

Searle suggests that a correction figure of +10% for children and +20% for adults could be applied to the calculated speed. The danger here is that V_{min} actually becomes $V_{probable}$ and this may lead to an over estimation of the vehicle speed. We suggest that no such correction is made to the speeds, and a range quoted.

Alternative applications of Searle's equations

Searle's equations were derived by considering the behaviour of an ideal particle. Therefore they can be applied to objects other than pedestrians where the launch and final positions are known and a value for mu can be calculated.
However caution must be exercised when low coefficients of friction are found because, as we have seen, under certain circumstances the results become unstable.

Vehicle Speed From Throw Distance - Empirical Method

An alternative method of estimating the impact speed of a vehicle is to use the results of real tests where pedestrians are struck by vehicles travelling at known speeds. If we measure the distance travelled by a pedestrian, from impact to point of rest, we can compare this with our test data to establish a range of likely speeds for a vehicle.

Data from experiments is known as experimental or empirical data, hence the name we give to this method.

This empirical method is based on a series of tests performed by Professor Appel in the early 1970's. His team used data from field studies that included both V form and pontoon shaped vehicles and distinguished between child and adult collisions. The resulting graphs produce an upper and lower speed.

These graphs are reproduced below. We can also determine the equations of the lines in the graphs. The equations of each of the lines used in the graphs are,

$$V_{pontoon} = \sqrt{\frac{S}{0.084}} \qquad V_{vform} = \sqrt{\frac{S}{0.065}}$$

$$V_{adult} = \sqrt{\frac{S}{0.070}} \qquad V_{child} = \sqrt{\frac{S}{0.084}}$$

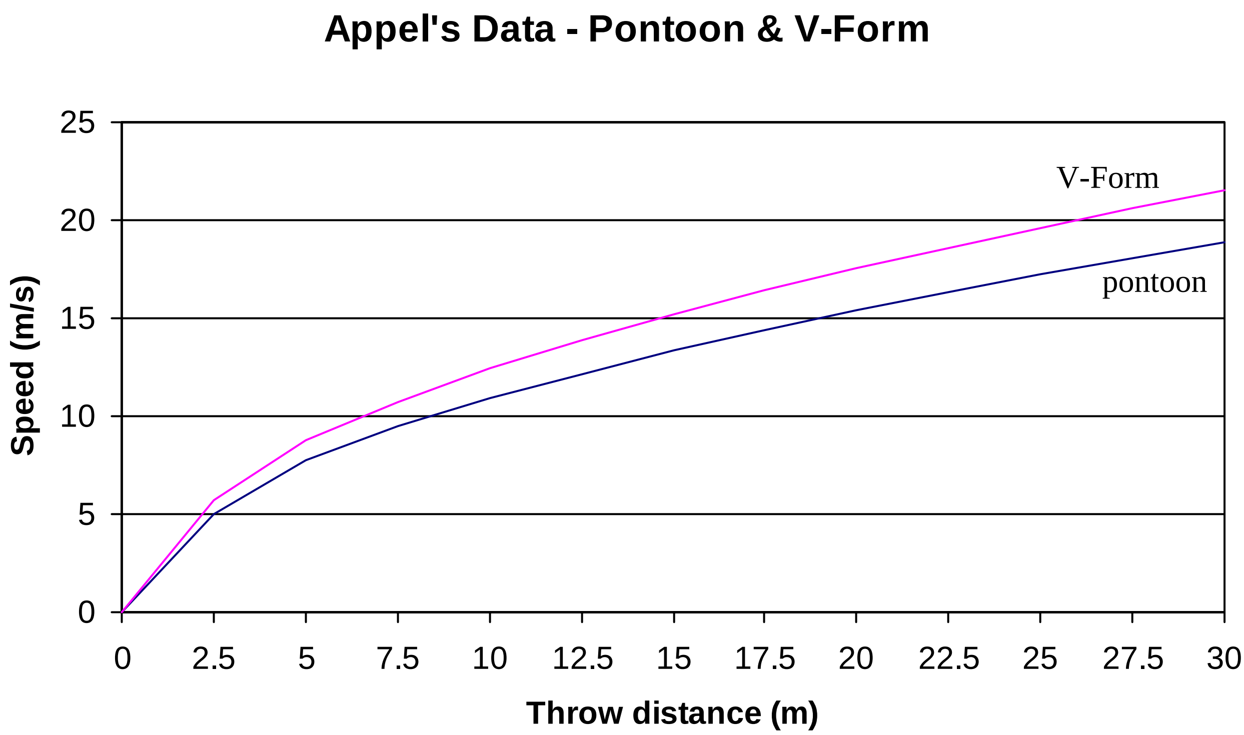
The speeds shown on the graphs relate to the *vehicle speed* rather than to the pedestrian. It is interesting to compare the results of Searle's mathematical approach with the empirical data recorded by Appel.

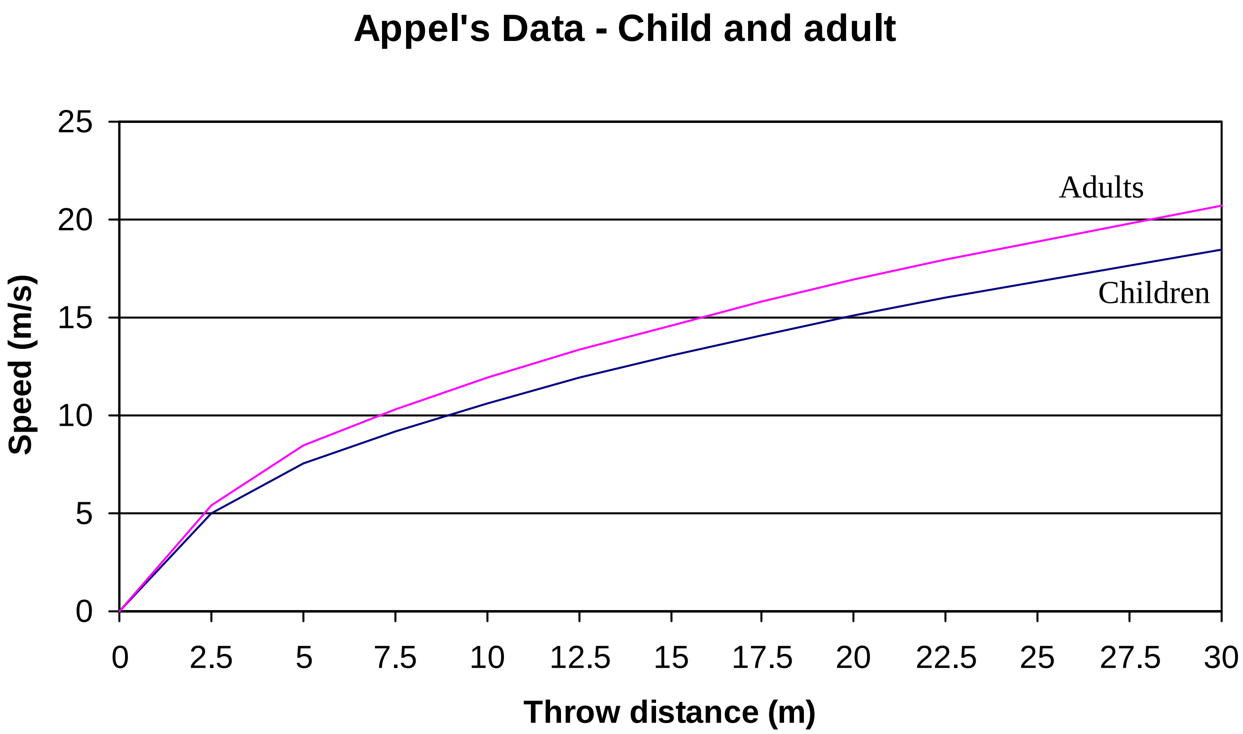
Written in the same format as the four equations above, and using a value for mu of 0.66, Searle's equations become,

$$\mathrm{V_{min}} = \sqrt{\frac{\mathrm{S}}{0.111}} \qquad \mathrm{V_{max}} = \sqrt{\frac{\mathrm{S}}{0.077}}$$

The value for V_{max} is similar to that found for adults whereas that for V_{min} is lower than any of the empirical data. We can compare this numerically to give an example of the differences.

With a throw distance of 20m Searle's method predicts a range of 15 to 16 ms^{-1} Using Appel's data, comparing V form and pontoon we have a range of 15.4 to 17.5 ms^{-1}





Pedestrian Throw - Conclusions

The subject of pedestrian collisions covers a number of different disciplines and numerous books and papers have been written specifically about the subject.

In practice the actual mathematical calculation to find the speed of the vehicle is probably the smallest part of the reconstruction.

Whether you choose to use Searle’s or Appel’s method is one of personal choice. With Searle’s method the speed of the vehicle is more likely to be an underestimation.

Whichever method you do choose remember above all else that you must ensure that the initial collision with the pedestrian was a ‘clean’ strike and that they were not carried on the vehicle.