SACRED Example: D13 - Unified Metrics - Adhesion

Immediately, it is possible that our system does not know the location of the signal, this would be from a insufficiently detailed D7 from a hardware failure. The signal could not be in its correct place, due to a structural failure, we could be speeding before, during or after the junction current speed¿speed limit, we could have miscalculated the SVB, leading to an event where $T_¿SVB$.

Outside of this, we understand that our SVB shifts with context, we discuss the way that the geography of the track shifts the speed limits and how the weather shifts the viewing distance, however, rail is not only governed by what it can see, but also how effectively it can stop. Braking performance is heavily dependent on the available wheel–rail adhesion, which varies according to seasonal conditions, weather, vegetation, contamination, and infrastructure maintenance. Within [D6](ref:d6) we discuss how extreme weather shifts the operation of a system, one example of this could be a blizzard. However, non extreme snow also causes a shift in railway operation, with frost shifting the adhesion of a track.

To calculate stopping distance, the standard calculation is defined by the railway signalling handbook according to the following formula:

Using Newton's equations of motion
- $v = u + at$,
- $s = ut + 0.5\,a\,t^2$,
- $v^2 = u^2 + 2\,as$

a = acceleration (ms^{-2})
v = final velocity (ms^{-1})
u = initial velocity (ms^{-1})
s = distance (m)

▶ **Braking distance (S) / (BD)**

$$S = \frac{u^2}{2a}$$

Figure 1: Braking distance formula

Within this equation, "a" is the rate of braking in "m/s per sec" or m/s^2, at standard, it is assumed to be 0.5m/s^2, which is then modified by gradient and adhesion as defined within The Network Rail Signalling headway calculation.[64](cite:64) For our example route, the gradient would be descovered as part of our exporation as part of [D1](ref:d1), for the example of Swalwell to Newcastle can be seen in the following image:
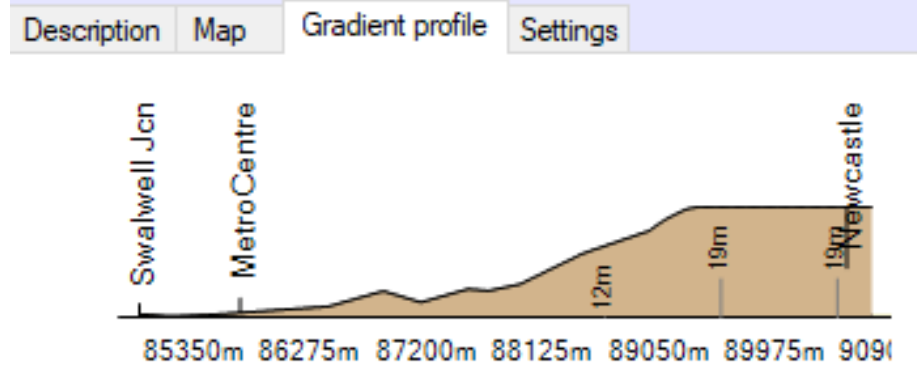

Figure 2: Gradient profile for the given route

So the very beginning has a flat to negative gradient, which for the simplicity of calculation, we will say is 0%. So, The Minimum Adhesion Coefficient ($\mu_{\min}$) is the lowest adhesion value at which the train can still satisfy the required braking profile for a given stopping distance and ensure that SVB>T.

In the event that the signal is red and the driver takes the full 4 seconds to react, meaning that the brake does not initiate until the cab is at the signal (0m), the train must reach an absolute stop before reaching the station, which is 200m away. Using the signalling handbook formula, we can understand the following:

We know the maximum distance we can cover is 200m, we know the train is initially moving at 30mph, or 13.4m/s, so we know $S = u^2/2a$, becomes $200 = (13.4)^2/2a \rightarrow 200 = 179.56/2a \rightarrow a = 0.4489$.

This means, that given both gradient and adhesion, our braking cohesion cannot drop below 0.45m/s^2. The formula for deceleration is $a = \mu g$ where μ is our adhesion and g is gravity, gravity is a constant at 9.81, our required deceleration is 0.45, so $\mu = 0.45/9.81$ or $\mu \approx 0.046$.

The factors of adhesion in which environmental factors modify adhesion is discussed within the book *Braking system design for passenger cars and light vans* by David Bryant and Andrew Day, chapter 3.3.2, as well as RSSB T1127 Research Project discusses adhesion with the values of:

Dry	0.15–0.25
Wet	0.05–0.15
Leafy	0.01–0.03

Table 1: Typical adhesion values under different conditions

Standard braking of the UK dictates that deceleration in non-emergency brakes is 0.5m/s/s.

Given our minimum required adhesion of $\mu = 0.046$, both dry and most wet-rail conditions provide sufficient adhesion for the train to stop within 200 m at 30 mph, because $\mu g \geq 0.45$ and the system is then limited by the nominal 0.5 m/s^2 brake rate. Under leafy conditions, where μ can fall to 0.01–0.03, the maximum achievable deceleration drops to 0.10–0.29 m/s^2, which is below the 0.45 m/s^2 requirement, so the train can no longer be guaranteed to stop within the same 200 m envelope.