# SACRED Example: D13 - Unified Metrics - Adhesion

This document describes how adhesion, environmental conditions, and uncertainty were translated into conservative braking and distance margins during a worked application of SACRED. The example is framed around UK signalling and absolute stopping, but the intent is to demonstrate how environmental uncertainty propagates into safety margins as a whole.

## Signal Visibility Budget

The Signal Visibility Budget (SVB) defines the minimum amount of time for which a signal must be visible to guarantee that a train can perceive the signal, initiate braking, and come to a safe stop under the prevailing conditions.

A Signal Passed At Red (SPAR) occurs when this budget is exceeded, either because the signal is detected too late or because the available braking performance is insufficient once the signal is perceived. A SPAR therefore represents a failure of the combined perception–reaction–braking envelope, rather than a purely perceptual or control failure.

SVB varies with both approach speed and environmental context. Higher approach speeds reduce the available reaction time, while degraded adhesion increases the time required to brake safely. UK signalling practice assumes an effective reaction window of approximately 4–8 seconds under normal operating conditions; at higher line speeds this corresponds to proportionally higher required sighting distances, while degraded adhesion further pushes the required SVB toward the upper end of this range.

In practice, SVB is evaluated in the time domain, with distance derived from the current train speed. For example, 40 mph corresponds to 17.9 m/s, so an SVB of 4 seconds requires a minimum viewing distance of 71.6 m, however, in the event of lower adhesion, SVB could be as high as 8, making the minimum viewing distance 143.2m.

In this work, SVB is treated as an environmental, context-dependent safety margin. Under good adhesion conditions, the system may operate with a lower SVB requirement; under poor or icy conditions, the required SVB increases to reflect longer braking distances and reduced controllability.

Route safety is assessed by computing the available time T between signal visibility and signal passage, and verifying that $T > SVB$.

# Adhesion

Outside of this, we understand that 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] 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:

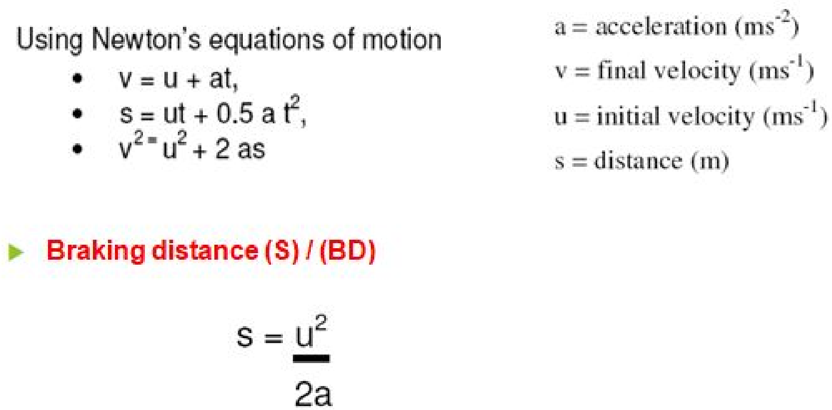


Figure 1: Braking distance formula

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$^2$ according to the GMRT2044 Iss 4, which is then modified by gradient and adhesion as defined within The Network Rail Signalling headway calculation. For our example route, the gradient would be discovered as part of our exploration as part of [D1], for the example of Swalwell to Newcastle can be seen in the following image:

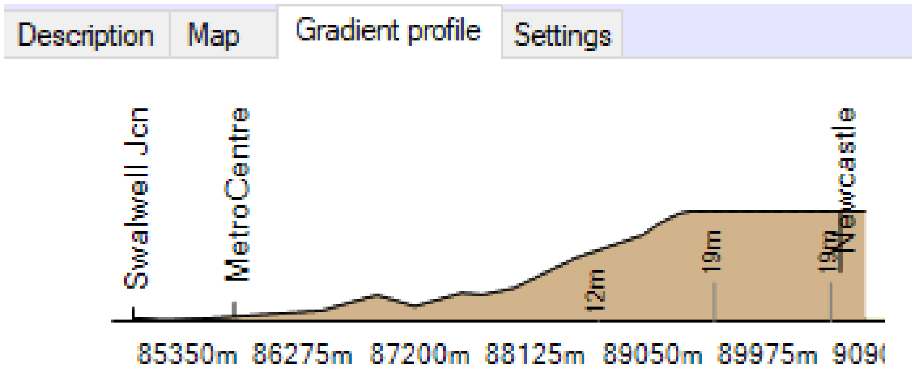


Figure 2: Gradient profile for the given route

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 ($\mu_{\text{min}}$) 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 $\mu$ 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$^{\mathbf{2}}$ brake rate. Under leafy conditions, where $\mu$ can fall to 0.01–0.03, the maximum achievable deceleration drops to 0.10–0.29 m/s$^{\mathbf{2}}$, which is below the 0.45 m/s$^{\mathbf{2}}$ requirement, so the train can no longer be guaranteed to stop within the same 200 m envelope.