# Speed restrictions, maximum safe speed and automatic train protection (ATP) speed supervision

AUTHORS:

Dr Daniel Woodland
MEng (Hons), CEng, FIRSE
***Ricardo Rail***

Joss Apps
BEng (Hons), CEng, FIMechE,
***Ricardo Rail***

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## SUMMARY

In this article the authors consider the main reasons why speeds may need to be limited during operation and the methods used to determine permissible speeds and maximum train speeds on UK railways. They then consider the implications that introduction of comprehensive ATP systems should have on definition of maximum safe, (emergency), speeds, (EVmax), to facilitate optimum usage of the rail infrastructure under ATP supervision.

## INTRODUCTION

In normal operation, a train's speed must not exceed either the safe limit, (before, say, derailment may occur), or the comfort limit, (where passengers may be bounced about or otherwise experience unacceptablediscomfort).
These characteristics can between them be defined as Vmax for the particular train type at any given location.

Since ATP systems are provided as safety systems, they must ensure that unsafe levels of overspeeding do not occur. At the same time, in order to support efficient operation of the railway, they must not be overly restrictive in constraining a driver's normal, (safe), driving behaviour.

If an ATP system is to prevent the train speed from reaching unsafe levels, it must:

- Allow for delays in brake application once an intervention has been made;
- Allow for the system's own processing delays;
- Allow for worst case acceleration of the train during these delay periods.

It must, therefore, initiate an intervention at a speed well below the actual safe limit.
In addition to the constraints imposed by safety, many operators also require ATP systems to:

- Provide a warning to the driver if he/she is detected as overspeeding;
- Allow the driver some reaction time following a warning before intervention occurs.

If such facilities are provided, the speed at which warnings must be initiated will be even further below the actual safe limit. However, in order to ensure efficient operation, such warnings are generally required to commence only once overspeeding has occurred, (i.e. the train is travelling at a speed which exceeds the maximum 'authorised' or 'permissible' speed).

At this point, the implementation of ATP supervision starts to look like it will have a significant, (detrimental), impact on operating speeds if drivers want to avoid intervention. Fortunately, however, the permissible speeds applied to the railway are not set at the maximum safe and comfortable speed for travel, (Vmax). In general, whilst a line speed or Permanent Speed Restriction, (PSR), will be based on an assessment of the track topography, (and condition), and perceived acceptability, (safety / comfort of ride), of movement at a given speed, that assessment is made qualitatively, based on, (conservative), 'Engineering Judgement' and it will be formally defined as a nice rounded, (down), number that can be easily displayed, read and understood from trackside signage and route descriptions.

Thus, the PSR is in fact significantly below the Vmax. In degraded conditions, these may be superseded by a lower Temporary Speed Restriction, (TSR), or Emergency Speed Restriction, (ESR), in order to protect against

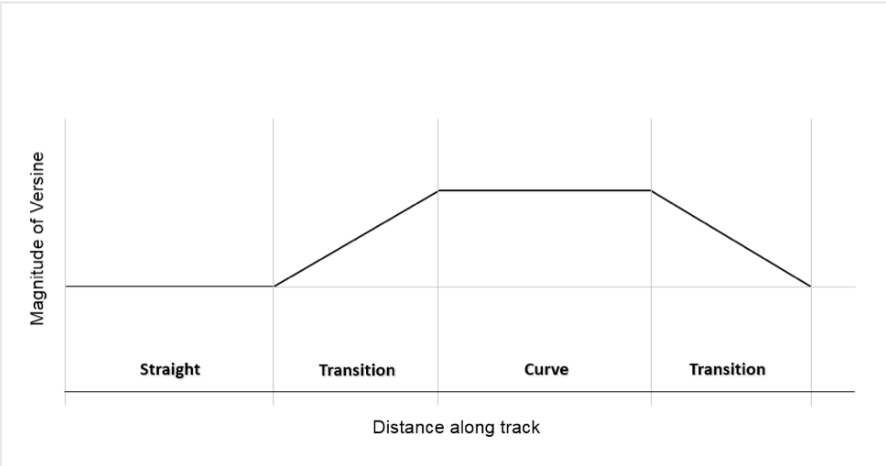


Figure 2 1: – Track curvature described by versine measurement concerns that operation at the PSR is no longer safe, pending remedial works - but the basis of calculation for a TSR / ESR is similarly qualitative.

On the mainline railway maintained by Network Rail there are several differential PSRs; probably the most significant is that for Sprinter trains, ('track friendly' trains, allowed to operate at higher PSR compared to non-Sprinters passenger rolling stock and freight). Differential PSRs recognise that there are differences between train types.

Many PSRs exist on the basis of 'grandfather rights' and modern engineers would be hard set to justify quite why they are at the speed defined, however, clearly, absence of incidents over time shows that they haven't been set too high. Similarly, TSRs / ESRs are often set based on 'broad brush' assessments of the type of problem being experienced.

Indeed, during a lecture to the eighth IEE vacation school on Railway Signalling and Control Systems, it was noted that "generally speed restrictions are imposed either for comfort or to reduce wear and tear. There is usually a substantial margin for error. In the case of track-based speed restrictions the overturning speed is typically 50% above the speed limit"[8]. Any such 'margin' between the permissible and safe speeds of travel for a train may provide 'room for manoeuvre' in the development of ATP speed supervision criteria.

On which thought we arrive at a new idea… when it comes to ATP implementation, it is not only the case that the permissible speed (PSR / ESR / TSR) is below the speed that needs to be 'protected', but even the Vmax, (which allows for comfort as well as safety), could be exceeded in a worst-case scenario without compromise to safety. Thus, for ATP supervision the real speed of interest is that which a vehicle could be permitted to achieve in emergency conditions, (ie worst-case speed that could be permitted before ATP intervention brings speed under control) – or an Emergency Vmax, (EVmax). On this realisation, the feasibility of implementing an ATP system without detriment to current operating speeds suddenly becomes apparent.

In this article, the authors consider the main reasons why speeds may need to be limited during operation and the methods used to determine permissible speeds and maximum train speeds on UK railways. They then consider the implications that the introduction of comprehensive ATP systems should have on the definition of maximum safe, (emergency), speeds, (EVmax), in order to facilitate optimum usage of the rail infrastructure under ATP supervision.

## TRACK ALIGNMENT

A number of the reasons for setting speed restrictions relate to the alignment of the track. In order to assist the reader's understanding, the authors will begin by briefly considering the subject of track alignment in order to define the terms that will be used in the subsequent discussion.

In plan view, track consists of straight, curved and transitional sections designed to ensure safety against derailment and maintaining comfort for passengers. For low speed train operation, transitions are not necessary. However, as speed increases, transitions between straight and curves are required. A common method for setting out track alignment is by versine as this can measured using simple chord and offset process, (**figure 2-1**).

As a train travels around such a curve, it is necessary to rotate the vehicles which naturally tend to continue in a straight line. This rotation is achieved as the result of a centripetal force acting inwards towards the centre of the curve, exerted on the train's wheelset by interaction with the track, (**figure 2-2**).

In accordance with Newton's third law of motion, the track experiences a reaction that is equal and opposite to the centripetal forces that it is exerting on the wheelsets.

This reaction, known as the centrifugal force, therefore acts horizontally outwards from the curve, with a magnitude equal, (but opposite), to the centripetal force and given by:

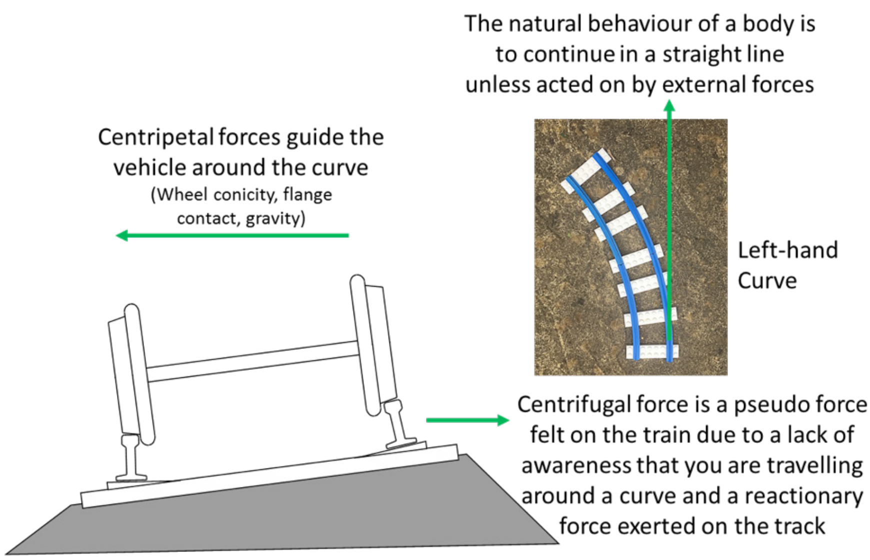


Figure 2-2: Forces experienced on a curve

$$Centrifugal\ Force = \frac{MV^2}{R}\ [N]$$

Where M is the vehicle mass (kg), V the speed (m/s) and R the radius of the curve (m). (Equation 2-1).

If both rails of the track are horizontally aligned, objects within the vehicle will also experience deflection from the straight-line motion and the consequent centrifugal reaction to the curving forces. This reaction will cause the objects within the vehicle to tend to slide outwards. If one of the objects is a passenger, this will cause an uncomfortable sensation as if he/she were being pushed over. Cant is therefore applied to the track in order to reduce the effects of centrifugal forces. Cant is the difference in vertical level across the track gauge. It is measured in mm at the railhead centres or contact rolling point of each rail, or as an angle between the plane of the track and the horizontal, (**see figure 2-2**). If the track is canted inwards, the centrifugal force becomes resolved into two components, one perpendicular to the vehicle floor and the other parallel to it. Similarly, the forces produced by the mass of the train also become resolved into two components, one perpendicular to the vehicle floor and the other parallel to it in the opposite direction to the centrifugal forces, (**see figure 2-2**). The two forces parallel to the vehicle floor therefore act against each other, reducing the effects of lateral acceleration on passenger comfort.

As the forces due to the vehicle mass are constant but the centrifugal forces are dependent on the speed and curve radius, it is possible to design a curve with a level of cant that causes the perpendicular force components to cancel each other out at a given speed. This cant is referred to as the 'equilibrium cant' which, when achieved, produces no sensation of lateral force for passengers on the train.

Unfortunately, since the equilibrium cant can only exist at one speed on a particular curve, most trains will travel around the curve at a higher or lower speed. This causes a deficiency or excess of cant, in both cases leading passengers to experience the sensation of lateral forces. If the cant excess or deficiency becomes too high, the train may become liable to wheel flange climb and subsequent derailment or overturning. Interestingly, flange climb derailments tend to occur at low speed not high speed; and long before the limit of reasonable comfort for passengers and the driver will be reached. A balance must therefore be found in selecting suitable levels of cant and determining line speeds.

Cant deficiency and excess are measured either in terms of the angle, (in degrees), or the distance, (in mm), by which they differ from the equilibrium cant, rather than the speed differential that they represent, (**figure 2-3**).

If the track on a simple curve is canted and the straight track to which it is joined is not, a cant gradient is introduced across the join.

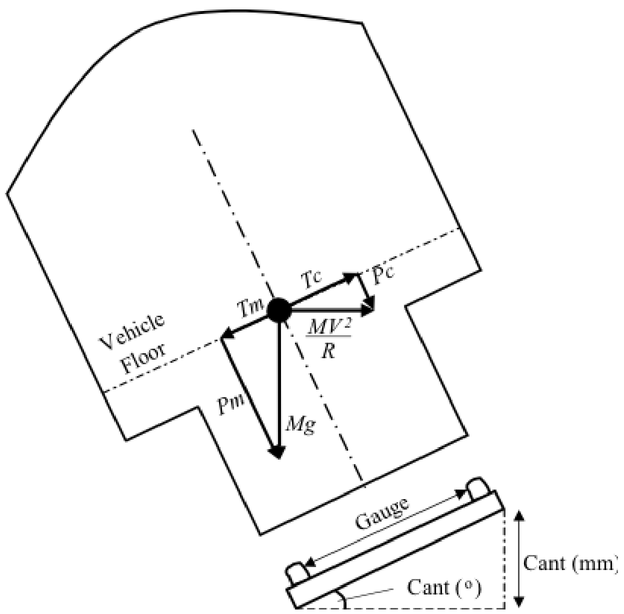


Figure 2 3: Weight and centrifugal forces on canted track[5 p97]

This can cause a sudden jerk in the train's movement, affecting both passenger comfort and safety. In order to avoid this occurrence, a transitional section is included in between the circular arc or the curve and the straight track to change both the horizontal curvature and track cant gradually and uniformly. "The nature of the transition curve is probably the most important design feature of a railway alignment for high speed passenger vehicles as it has the greatest influence on passenger comfort"[3 p14].

Horizontal curves are not the only element of track alignment to consider. Railways also require gradients. As with horizontal transitions, vertical curves are used to minimise the transient effects of changes in acceleration where sections of track with different gradients join.

They must limit the rate of change and value of vertical acceleration experienced by passengers to a comfortable value, limit wheel unloading during the transition, prevent excessive compression of the springs of the inner axles of any vehicles with three or more fixed axles and maintain track clearance, (to avoid 'grounding').

However, "in the context of rail speed increases, vertical radii could be considered less important than horizontal curves"[3 p15]. They will not, therefore, be expanded upon here.

## THE NEED FOR LIMITING SPEEDS

The speed of a rail vehicle can affect both the comfort and safety of passengers through a number of mechanisms. Each of these mechanisms raises the need for limiting speeds in certain circumstances, for certain vehicles or at certain locations. In order to consider the relevant mechanisms and their effects, the authors have identified five reasons why speed may need to be limited, each of which will be considered in turn.

### PASSENGER COMFORT

The basis for most track geometry and line speed limits is passenger comfort.

The effect of speed in increasing centrifugal forces has already been considered earlier under TRACK ALIGNMENT. In terms of static and quasi-static lateral forces, it is the lack or excess of cant that is most felt by passengers. A 110mm cant deficiency at the wheelset corresponds to 0.72m/s2 lateral acceleration. Allowing for vehicle body roll in the suspension, this is generally increased to 1m/s2 as felt by the passenger. For a tilting train running at 300mm cant deficiency with a tilt compensation of 75%, (50% after allowing for body roll), the passenger still feels no more than 1m/s2[6pE11/3]. Hence, some of the adverse effects of lateral accelerations on passenger comfort can be overcome by operating tilting trains - enabling them to run comfortably around curves at higher speeds.

Another significant factor, contributing to the lateral jerk experienced by passengers is the rate of change of cant, (a measure of the rotation of the car body and the passengers within it). A European pre-norm suggests that a roll rate of 8o/s makes less than 1 in 10 people feel uncomfortable. The current UK limiting value for conventional trains is 3.4o/s and for tilting trains is 4.2o/s[6 pE11/4].

In 1984 a high-speed train was run on a curved route at speeds of up to 30% above the normal curve speeds. The study found that at normal operating speeds 12% of standing and 3% of seated passengers were dissatisfied with the ride comfort and that this dissatisfaction doubled when the line speed was increased by 10 mph[3 p22].

Passengers are also subjected to random dynamic accelerations caused by track irregularities, which can cause physical weariness. Sensitivity to such irregularities has been found to be greater on curved than on straight track and to reach a maximum at vibration frequencies in the order of 5 Hz[3 p23;9 pp35-6].

DERAILMENT

The derailment of a train can result from a number of causes. Those that can be speed related include:

- Flange climb: the flangeway clearance on a wheelset typically allows 7 to 10mm of lateral displacement to occur before the flange contacts with the rail. However, on tight curves this allowance may be insufficient to prevent the flange making contact with the rail. If the flange becomes unable to slide past the rail for a finite distance when this occurs, (typically for a couple of metres), the wheel will climb up the rail, ultimately derailing the train. It is more likely that this will occur if there is a high lateral force between the wheel and rail, often on curves less than 200m radius where speed is low
- Dynamic reaction to track geometry: if cyclic features in the track, (such as dips in the rail at joints and welds), excite the suspension of freight wagons into resonance, they can start to bounce violently; possibly right off the rail. Where cyclic conditions occur, the speed of vehicles needs to be restricted to ensure they cannot reach their natural frequencies, which will be dependent on both vehicle type and loading; occurring at lower speeds for fully loaded vehicles, but more violently for unloaded vehicles
- Gauge spreading: on curved track with relatively high lateral curving forces the gauge can become excessively widened. If this occurs, the wheels drop off the rail into the four foot. Gauge spread develops over time and the speed of an individual train is not generally a significant factor, but the lateral forces exerted by all trains increase in proportion to the square of the speed, making gauge spreading more likely on lines with higher permissible speeds;
- Track shifting: If the transverse forces generated by a passing vehicle exceed the track transverse resistance, the track will shift, which can cause derailment. The transverse track resistance depends on the type of sleepers and track maintenance used. (It is worth noting that application of ballast shoulders on high speed curves improves the resistance.) It is highest on concrete sleepers with mechanical means of maintenance and lowest on track with timber sleepers and manual maintenance. In all cases, it is lowest just after track maintenance, which

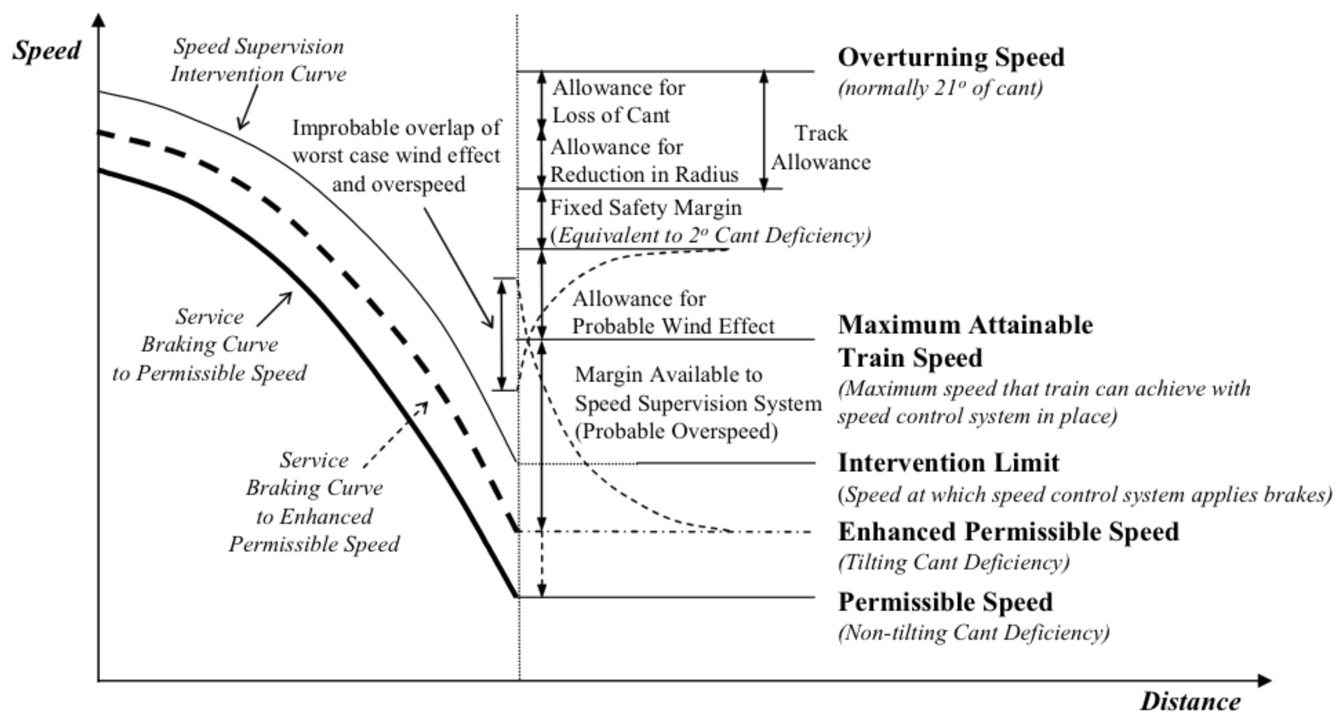


Figure 3-1: Determining the safe limit of permissible and enhanced permissible speeds[12 pp24-25; 4 p14]

- destabilises the track. Transverse forces are produced by unbalanced centrifugal acceleration on curves as well as the dynamic effects of track and rolling stock defects. This form of derailment is, therefore, more likely at high speeds.

*It is worth noting that application of Ballast Shoulders on high speed curves improves the resistance.*

Where there is significant risk of any of these derailment modes occurring, speeds may need to be limited; either on a permanent or temporary basis.

OVERTURNING

When a train is subjected to high lateral forces, it is at risk of overturning. This can occur under three conditions:

- At high speeds on curved track a combination of overspeed, curve misalignment, cant loss and cross wind can result in excessive cant deficiency and unloading of the inner rail
- Lightweight empty wagons standing still or with a displaced freight load can experience unloading of the outer rail on track with high cant and an unfavourable cross wind
- Unloading of the outer rail can also occur when a train failure results in the brakes at the rear of a train failing to release[3 p33].

In general, the main track related factors influencing the overturning of a train are the design cant and curve radius.

Rail group standards in the UK require vehicles to be designed with mass distribution and suspension characteristics that allow them to travel around smooth curves at constant speed without rolling over at not less than 16.5° cant deficiency for freight vehicles designed to operate at up to 75mph and not less than 21° cant deficiency for all other vehicles[1 p8].

When it is considered that the maximum cant deficiency permitted for a conventional train on UK main line infrastructure is 150mm, (5.74°), it can be seen that there is, at worst, a margin of 15° cant deficiency between the train's permissible speed and its roll-over resistance. This margin is reduced to 9° cant deficiency for tilting trains, which are permitted to operate at cant deficiencies of up to 12°[11 p23]. The INF TSI allows for higher cant at 180mm for all services and 190mm for passenger only lines. Whilst a trial at 200mm track cant is applied at Cullompton, this required special permission and restriction of the types of freight vehicles using the site[10 p28].

A train travelling at a nominal design cant deficiency may experience significantly higher cant deficiency in practice, due to the effects of imperfect wheel condition, track irregularities, (especially in cant and curve radius), wind and possible over speeding of the train. Factors such as these reduce the effective margin to overturning and must, therefore, be accounted for in the design of appropriate track, trains and speed limits.

The track irregularities experienced on UK main line railways have been measured by track recording coaches. From the measurements taken, it has been concluded that for a design curve radius of less than 3000m, the minimum curve radius expected is 80% of the design radius. For curves with radii of 3000m or greater, the minimum expected is 70% of design radius. In most cases, deviation in cant is less than 10mm, (0.38° cant deficiency)[4 p3]. Fixed allowances can, therefore, be made for these factors in determining speed restrictions.

However, if all of the effects that could lead to a train overturning were considered to act simultaneously, the permissible speed that could be considered acceptable would be very restrictive. Therefore, probabilities of wind speed and overspeed, which represent the most significant factors in overturning risk, are considered, rather than absolute values. To this end, the calculation of permissible speeds on UK main lines includes:

- Fixed allowances for reduction in curve radius and loss of cant
- Probabilistic allowances for overspeed and the effects of wind
- A fixed safety margin of 2° cant, (an allowance for inaccuracies in the calculation of other allowances)

An example of how this is done is given in EVMAX DEFINITION.

PERMISSIBLE FORCES

As a train travels along the railway it exerts vertical, lateral and longitudinal forces on the track and its support structures, causing fatigue in their materials and deterioration of the track geometry.

The longitudinal forces on the rail result from acceleration and deceleration during train operation. They are dependent on both train design and operating speeds and must be considered in the setting of speed limits and restrictions so as not to generate forces which could damage the structural integrity of the rails, track and infrastructure. Longitudinal forces are particularly taken into account in the design of bridges on railway lines.

When subjected to vertical forces, the behaviour of the rails and sleepers is elastic, while that of the ballast and the subgrade is elastoplastic.

The vertical forces produced by the passage of a train consist of four components:

- The normal static load of the wheel
- The quasi-static load resulting from cant deficiency in curves
- The random, (dynamic), overload caused by rail to wheel interaction of un-sprung mass when the train runs over variations in the vertical alignment of the rail, (high frequency 20-150Hz)
- The random (dynamic) overload caused by rail to wheel interaction of sprung mass, (low frequency 0-20Hz)[9 p36].

All four components are influenced by the train's design, whether directly by its mass or as a result of its suspension arrangements. The quasi-static and dynamic forces are also influenced by track design / quality and train speed.

Rail Group standards in the UK require vehicles to be capable of negotiating a vertical ramp equivalent to a dipped rail joint on straight track at their maximum design operating speed without exceeding a total vertical force, (static and dynamic), of 322kN per wheel[2 p7]. Vertical forces must also be considered in the setting of speed limits and restrictions so that trains will not generate forces that could damage the structural integrity of the rails, track and infrastructure, (including bridges and viaducts), over the normal range of vertical track irregularities at normal operating speeds.
Just as with longitudinal forces, the lateral forces on the rail also result from several causes:

- Inclination of the wheel / rail contact patch, (occurring particularly where wheel conicity is high – whether by design or following wear)
- Creep forces across the contact patch
- Dynamic instability, (hunting)
- Lateral curving, (centrifugal) forces
- Inertial forces generated at track irregularities.

Railway Group standards require vehicles to be designed so as not to generate lateral forces that could jeopardise the structural integrity of the rails and track. The maximum permitted lateral force is given by:

$((M / 3) + 10)$ kN ,

Where M is the static load[2 p8].
(Equation 3-1)

In the UK, conventional trains are not permitted to operate at more than 150mm cant deficiency and the static and quasi static forces that occur when operating under these conditions account for only 25% of the lateral force limits. For tilting trains, which can operate at up to 300mm cant deficiency, the static and quasi-static forces are far more significant, accounting for 50% of the lateral force limits[6 pE11/2]. The dynamic component of the lateral forces can be controlled by maintaining track to sufficient quality, designing trains with sufficient suspension and by limiting train speeds.

### TRAIN SEPARATION / BRAKING DISTANCES

The final need for limiting train speeds that will be considered in this paper is the requirement to keep trains separated by safe braking distances.

Some sections of line, (particularly straight plain line sections), are physically capable of safely supporting operating speeds far higher than the speeds that are actually permitted over them. Where this is the case, it would be physically possible to set a higher permitted speed. However, for a section of line with an existing signalling layout, the line speed can only be increased for trains capable of sufficient braking performance to stop the train from the higher speed within the distances required by the signal spacing, otherwise safe train separations cannot be guaranteed. It is likely, therefore, that any increase in permitted speeds would need to be accompanied by an improvement in braking performance.
For a new section of line, (or one undergoing resignalling), it would be possible to design the new signalling to support any desired speed of operation, whilst maintaining adequate separation between trains. However, the need for longer braking distances from the higher speeds would result in a reduction in the headway that could be achieved on that section as the permitted speeds were increased. The train headway required to deliver the desired capacity on the line, the train's braking performance and the design of any signalling layout are all factors that must, therefore, also be considered in setting permissible speeds for a section of line.

## SPEED SUPERVISION

Returning to the starting point of this article: If we are considering the introduction of a comprehensive ATP system that will guarantee safety of operation, (avoidance of over speeding risk), then we need to think not just about why speed needs to be restricted, but also how that relates to the ATP system supervision criteria. Whilst this was considered at high level in the article's introduction, more detailed consideration is warranted.

### PROBABILITY OF OVERSPEEDING

The permitted speeds in use on British main line railways have generally been set on the basis of assumed manual driving without speed supervision. Therefore, some level of over speeding has been assumed in setting them.

According to a now withdrawn Rail Group standard from the 'Railtrack' days, (GO/RT 3253), train-operating companies were required to carry out checks on the speeds of their trains. In so doing, any incidence of the permissible speed being exceeded by more than 3mph had to be reported to Railtrack as quickly as possible.

The action to be taken beyond this depended on the level of overspeed:

- If the permissible speed was exceeded by 4mph (6km/h), the driver was to be informed and the facts recorded
- If exceeded by 6 to 10mph, (10 to 16km/h), the driver was to be informed and interviewed at the first scheduled stopping point where a competent person could establish both the facts and the driver's fitness to continue duty
- If exceeded by 11mph, (18km/h), or more, Railtrack were to arrange for the train to be stopped at the first available point where the driver could be informed of the infringement and interviewed by a competent person to establish both the facts and the driver's fitness to continue duty[7 p5].

Whilst that particular standard has now been withdrawn, (as its content was deemed outside the scope of rail group standards, and more fitting for each operator to decide their own response), some explanation of the criteria used within it can be found in the still current GE/RC 8517[10], where it is noted that:

- A mechanical speedometer typically requires a tolerance for driver control of 4km/h
- Below 160km/h, speed measurement precision is typically 6km/h[11 p33].

A driver's real speed could, therefore, be 10km/h above the permissible speed before it is reasonable to assume that he/she is over speeding. On top of that, it is also entirely possible that in a 'human' controlled process, drivers will, on-occasion, 'over speed' - either due to misjudgement, inattention or deliberate intent.

Existing operations require driving at the signed PSR / TSR / ESR. In consequence, the signed speed must be set sufficiently below the actual maximum safe speed, (EVmax), so as to ensure that at least the occurrences of misjudgement and inattention will not result in an unsafe condition. Then, of course, there is also the need for meaningful signage, (already discussed), so the EVmax must be converted into a '(probably) safe maximum driving speed' and then rounded down to the nearest PSR/TSR speed that can be signed . In the process, there is usually a fair margin for error…or would be if that was actually how the PSR / TSR was calculated. As noted in the introduction, however, there is not so much science applied to the process. Engineering Judgement and 'gut feel' are applied in liberal quantities; backed up extensively by experience and 'grandfather rights'. Better safe than sorry. Therefore, as long as the PSR / TSR is set low enough, there should never be any issues.

*Speed restrictions on UK main line railways are always quoted in 5mph (8km/h) intervals [6 pE11/4]. This is done to assist drivers in remembering the permitted speed for the section of track they are travelling over. Whilst trains are driven on the basis of route knowledge, or on the basis of limited aspect speed signalling through lineside signals, this is a necessary simplification.*

## THE EFFECT OF ATP ON SPEED RESTRICTIONS

With the introduction of ATP, the considerations change somewhat. We still have the objective of driving at the PSR / TSR and we still want to avoid any possibility of exceeding the EVmax value. However, in ensuring that we no longer need to make 'assumptions' about the maximum over speed that could be inadvertently achieved by a human driver, instead, it becomes necessary to consider the speed supervision criteria that will be used in determining warning and intervention limits on-board the train and the 'margin' that these impose between the EVmax and maximum target driving speed. So long as the target driving speed is at least this 'margin' below the EVmax, that target can be safely applied. In theory, there is no need to sign the speed limit; and thus no need to 'round' the signed speed. Hence introduction of ATP systems should enable an Enhanced Permissible Speed of operation, (EPS).

If this sounds too good to be true…it almost is. There are a couple of catches. Firstly, the simplistic approach to defining an EPS for ATP protected operation assumes that we actually know how to determine the EVmax in a rigorous / scientific manner. Secondly, it requires us to define ATP supervision 'margins' that will avoid intervention, including scaring the driver into operating at a slower speed by issuing warnings, when the driver is correctly controlling the train's speed, whilst also 'guaranteeing' that the ATP will be able to intervene before the EVmax is exceeded.

### ATP SUPERVISION 'MARGINS'

The second of these issues is actually the easier to address. In doing so, tolerances including the accuracy of speed measurement, (such as wheel diameter calibration, slip and slide, sensor accuracy, and the dynamics of controlling the train's speed, (such as delays in traction cut off and brake application), must be accounted for.

As an example of this, if the driver of a class 390 realised that his/her train was exceeding the permitted speed the train's speed could continue to rise by 9.3km/h before he/she would be able to bring the train's speed under control under worst case conditions. This figure is based on:

- 2s allowance for driver reaction
- 1s delay in traction cut off
- Maximum 3% down gradient
- 4s brake build up delay, consisting of 2s delay to start of application, followed by assumed linear build up
- Maximum acceleration 0.44m/s$^2$ below 70km/h, then decreasing linearly to 0.07m/s$^2$ at 230km/h

- Brake Rate 9%g
- 1.6km/h allowance for speed measurement error, (based on a specified maximum speed measurement error of ±0.5km/h ±0.5% of speed, with maximum speed of 225km/h).

If automatic speed supervision is configured to provide a warning prior to brake intervention, the margin between the warning and brake intervention must, therefore, be at least 9.3km/h if the driver is to be allowed to act on the warning without invoking an intervention under all circumstances. This is typical of other train classes, the margin between warning and intervention generally needing to be between 5 and 10km/h[11 p38]. At higher speeds, when trains tend to have poorer acceleration performance, the required margin is smaller. Returning to the example of a class 390, the maximum achievable acceleration at 200km/h is only 0.07m/s2. This reduces the required margin between warning and brake intervention to around 4km/h.

If the warning is to be given only once the train is definitely travelling above the permitted speed, a further margin of 5.5km/h would be required for a class 390, (allowing 4km/h tolerance for driver control and 1.5km/h for possible speed measurement error). The train could, therefore, achieve a speed nearly 15km/h above the permitted speed if the driver applied the brakes on receipt of an overspeed warning under the 'worst case' conditions.

Every ATP system / train type has their own set of margins, but all can be similarly calculated, based on their physical and programmed characteristics.

### EVMAX DEFINITION

Earlier in THE NEED FOR LIMITING SPEEDS, the authors discussed the main reasons that speeds may need to be limited on a railway. Of the factors discussed, the two most significant are passenger comfort and overturning risk.

For a conventional, non-tilting train, the constraints of passenger comfort mean that large margins are available between permissible and overturning speeds during normal operation. Since ATP can do nothing to improve passenger comfort, it appears that the introduction of ATP can have no effect on the setting of permissible speeds. It can only ensure that the speeds determined as acceptable for passenger comfort are not exceeded by too large a margin. However, this is not quite true.

As already noted, permissible speed must always be selected as a safe and comfortable speed and on a 'conventional' railway, (manually driven with no speed supervision), it must always be rounded down to the nearest 5mph, (8km/h), interval. This small reduction will have a minimal effect on journey times at high speed, (up to 3.5% at 200km/h), but could be significant at lower speeds, (for example, up to 14% at 50km/h).

If a railway were to be operated on the basis of in-cab signalling that includes an indication of the permitted speed, it could be possible to refine the permitted speeds to the nearest 1mph, (or 1km/h if the railway were to switch to the standard European units). However, in the opinion of the authors, the methods used for determining speed restrictions are not currently precise enough to make full use of this potential refinement. It is, therefore, unlikely that any significant benefits could be gained by attempts to implement it.

Tilting trains can travel at enhanced permissible speeds, (EPSs), much closer to their overturning speed than conventional trains can reach without causing undue discomfort to passengers. This may mean that the main constraint on tilting train speed is the risk of overturning, rather than passenger comfort. In a similar way, temporary speed restrictions, (TSRs) are sometimes set to mitigate the risks of derailment or overturning in areas of poor infrastructure. Here ATP can have a significant effect on determining safe EPS and TSR values. By reducing the probability of any overspeed, the ATP system reduces the risk of the train attaining overspeed levels that could result in overturning or derailment. The enhanced permissible speeds that can be considered safe for a tilting train and some TSRs for all trains will, therefore, become directly related to the implementation of the ATP's supervision criteria. If the probable overspeed can be reduced, the EPS / TSR can be increased by an equivalent amount without increasing the overturning or derailment risk. An example of this can be seen in **figure 3-1**.

## CONCLUSION

For conventional trains, the predominant factor in determining permanent speed restrictions is passenger comfort. This means that large margins are available between the defined permitted speed and speeds at which overturning and / or derailment become serious concerns. In order to make efficient / effective use of modern ATP systems, we must move away from the current 'PSR / TSR' definitions and identify the true 'EVmax' that must not be exceeded if derailment and overturning are to be avoided. If we succeed in doing this, we will not artificially constrain ATP system performance, and thus driving under its supervision and may even be able to enhance permitted speeds in some areas.

## ABBREVIATIONS

| | |
|---|---|
| ATP | Automatic Train Protection |
| EPS | Enhanced Permissible Speed |
| ESR | Emergency Speed Restriction |
| g | Acceleration due to gravity (9.81m/s2) |
| M | Vehicle mass (kg) |
| PSR | Permanent Speed Restriction |
| R | Curve radius (m) |
| TSR | Temporary Speed Restriction |
| V | Vehicle speed (m/s) |
| Vmax | Maximum speed a vehicle should achieve in normal operation |
| EVmax | Maximum speed a vehicle can be permitted to achieve in emergency conditions (i.e. worst case speed that could be permitted before ATP intervention brings speed under control) |

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Kerrie Illsley
JOURNAL PRODUCTION EDITOR
Permanent Way Institution
kerrie.illsley@thepwi.org