Railway Systems Engineering & Rail Infrastructure Technology

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Railroad Engineer

A railroad engineer's workplace on a German ICE-Train

A **railroad engineer**, **locomotive engineer**, **train operator**, **train driver** or **engine driver** is a person who drives a train on a railroad. The engineer is in charge of and responsible for the locomotive(s) as well as the mechanical operation of the train, train speed, and all train handling.

On many US railroads, the career progression is one that starts as an assistant (brakeman), conductor and finally, engineer. In the United States the engineer is required to be certified and re-certified every 2–3 years.

In India, an engine driver starts as a *Diesel Assistant* or *Electrical Assistant* (in case of electric locomotives). They then get promoted on a scale: B, A, and A Special. An 'A Special' driver drives the faster, more important trains.

In the United States, Canada, and New Zealand, train drivers are known as "locomotive engineers". In the United Kingdom, South Africa, and Australia, they are known as "train drivers", "engine drivers", "locomotive drivers", or "locomotive operators".

Duties

The cab of a CountryLink Xplorer diesel multiple unit

An engineer is responsible for preparing equipment for service, checking paperwork and the condition of the locomotives. Their duties require that they control acceleration, braking and handling of the train underway. They must know the physical characteristics of the railroad, including passenger stations, the incline and decline of the right-of-way and speed limits. Along with the conductor, the engineer monitors time to not fall behind schedule, nor leave stations early. The train's speed must be reduced when following other trains, approaching route diversions, or regulating time over road to avoid arriving too early. The engineer assumes the duties of the conductor if the conductor is incapacitated.

The locomotive engineer is required to have an intimate knowledge of track geometry including signal placement so as to be able to safely control their train.

Maintaining concentration is of critical importance in this role.

Train handling

A workplace in Rigi cogwheel electric train

Train dynamics can be extreme and therefore an engineer must be familiar with train handling techniques so as to avoid train partings, derailments and not exceeding line speed.

Freight trains typically have different train forces from passenger trains. A typical freight train may have 500 tonnes of locomotive weight at the front. That may be followed by 1500m of wagons. The wagons may or may not be uniformly loaded and may brake differently.

Severe brake applications can combine with these factors to cause a train parting. Therefore good train handling practice for freight trains is usually to keep the consist (rail vehicles which make up a train) stretched. This is achieved by keeping the consist in power while a brake application is made and by bleeding the air off the locomotives brakes before they apply. It is not possible to do this with the use of dynamic brake, which presents its own train handling challenges.

When there are multiple locomotives, some may be set up to brake like wagons instead of locomotives, as too many locomotives on the front of the train (all with brakes bled off) would require too heavy an application from the rest.

On shorter passenger trains, this is even more noticeable, requiring the first application of the brake to be bled off on the locomotive, applying locomotive brakes with subsequent increases in application. The length and make-up of the slowing or stopping distance dictates just how much locomotive brake application should be allowed to apply.

The use of dynamic brake can result in a severe slack action, When engaged run in is highly possible if brought in at an inappropriate time (regarding track geometry and train speed) and if disengaged at an inappropriate time can result in a run out. Both can potentially snap train drawgear.

Straightlining is a potential cause of derailment that train handling techniques must take into account in order to reduce the likelihood of occurrence. When a train rounds a curve basic physics dictates the trailing wagons in the consist will try to take the shortest route and the flange on some of the wheels within the consist could potentially fail to prevent this occurring with the resultant effect being a derailment.

Track geometry is also critical to train handling. It is desirable to have brakes releasing at the bottom of steep grades rather than applied. And at the top of a steep grade it is desirable to have a fully charged brake pipe.

Serial braking is where a train descends a grade on the air brake alone. The brake pipe application is gradually increased to slow down and if required (depending on the weight of the train and on the grade) stop the train so as to allow the locomotive compressors to recharge the brake pipe throughout the consist. In these cases it is permissible to use the locomotive brakes (which are independent of the train brake and charged through the main reservoir directly) to hold the train (In some cases the weight of the trailing consist will not be held on the locomotive brakes alone) slowing the rate of acceleration and giving more time to recharge the brake pipe to give a better application in the next subsequent train brake application. A runaway can occur if a brake application is required before the train pipe has recharged (as happened at Cima Hill in the United States).

A split reduction is where a train brake application is made and gradually increased as the train descends the grade. It is different to serial braking in that with Serial Braking the application is released, the brake pipe recharged then reapplied.

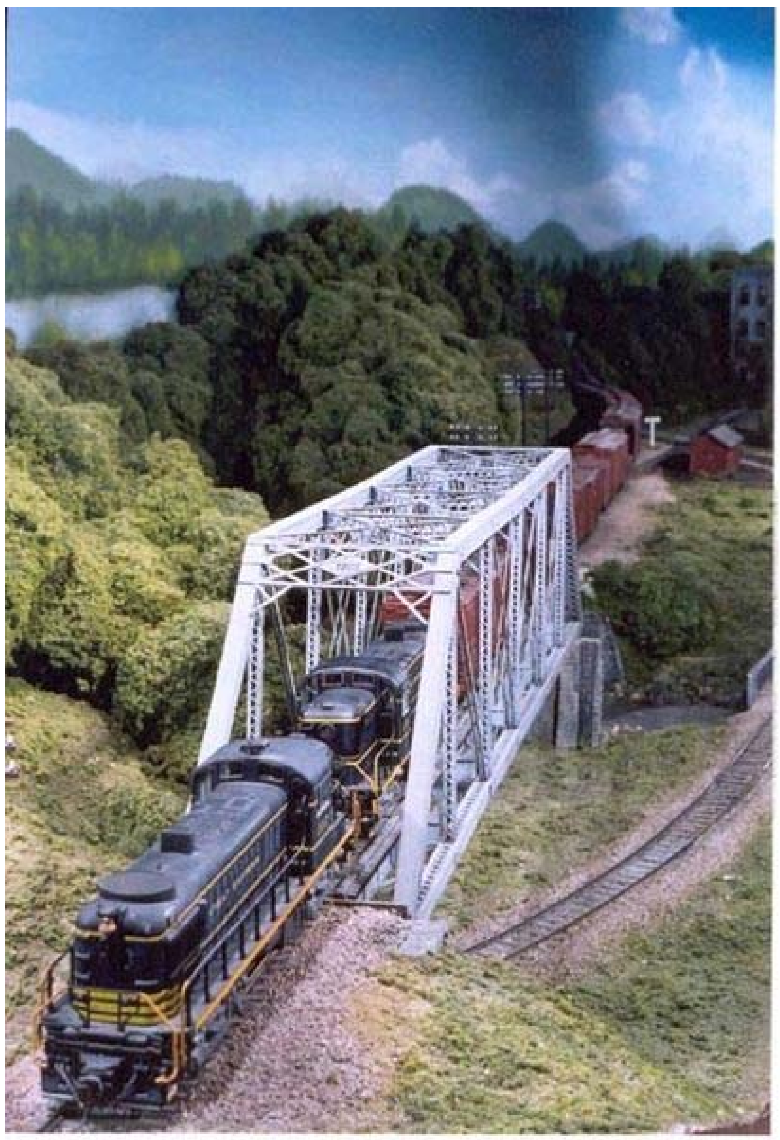
The dynamic brake when operable slows down the rate of acceleration and allows longer for a train brake pipe to be recharged before being required to be re applied. When a train descends a grade utilizing both the dynamic and air brakes the procedure is known as 'maintaining braking'.

In the case of severe grades (for example the Westmere Bank in New Zealand, which is a 1:33 grade with a 40 km/h (25 mph)speed limit) a trains allowable speed is lower for a train that doesn't have dynamic brake than for one that does.

In freight train marshalling yards the wagon brakes are sometimes bled off so they can be easily loose shunted. However when a shunt locomotive moves large numbers of wagons around with no brakes the locomotive must brake for the entire train. This can result in severe slack action and wheel slip. Damage to goods and rolling stock is possible. Also, with unbraked wagons there is potential for a runaway.

Chapter- 2

Rail Transport Modelling



HO scale model railroad.

A scale model of Berlin's Bahnhof Zoo at the LOXX Berlin model railway

A Japanese HOe scale model railroad.

The Miniatur Wunderland in Hamburg/Germany - the largest model railway in the world.

One of the smallest (Z scale, 1:220) placed on the buffer bar of one of the largest (live steam, 1:8) model locomotives.

HO scale (1:87) model of a North American center cab switcher shown with a pencil for size.

Z scale (1:220) scene of a 2-6-0 steam locomotive being turned with a scratch-built Russell snow plow parked on a stub (Val Ease Central Railroad).

Railway modelling (UK, Australia, Ireland and Canada) or **model railroading** (US) is a hobby in which rail transport systems are modelled at a reduced scale. The scale models include locomotives, rolling stock, streetcars, tracks, signalling, and roads, buildings, vehicles, model figures, lights, and features such as streams, hills and canyons.

The earliest model railways are the 'carpet railways' in the 1840s. Electric trains appeared around the turn of the 20th century. But these were crude likenesses. Model trains today are more realistic. Today modellers create model railway / railroad layouts, often recreating real locations and periods in history.

General description

Involvement ranges from possession of a train set to spending hours and large sums on a large and exacting model of a railroad and the scenery through which it passes, called a "layout". Hobbyists, called "model railroaders" or "railway modellers", may maintain models large enough to ride. Modellers may collect model trains, building a landscape for the trains to pass through, or operate their own railroad in miniature.

Some older scale models reach high prices.

Layouts vary from a circle or oval of track to realistic, real places modeled to scale. One of the largest is in the Pendon Museum in Oxfordshire, UK, where an EM gauge (same 1:76.2 scale as 00 but with more accurate track gauge) model of the Vale of White Horse in the 1930s is under construction. The museum also houses one of the earliest scenic models - the Madder Valley layout built by John Ahern. This was built in the late 1930s to late 1950s and brought in realistic modelling, receiving coverage on both sides of the Atlantic in the magazines *Model Railway News* and *Model Railroader*. Bekonscot in Buckinghamshire is the oldest model village and includes a model railway, dating from the 1930s. The world's largest model railroad in H0 scale is the Miniatur Wunderland in Hamburg, Germany. The largest live steam layout, with 25 miles (40 km) of track is *Train Mountain* in Chiloquin, Oregon, U.S..

Model railroad clubs exist where enthusiasts meet. Clubs display models for the public. One specialist branch concentrates on larger scales and gauges, commonly using track gauges from 3.5 to 7.5 inches (89 to 191 mm). Models in these scales are usually hand-built and powered by live steam, or diesel-hydraulic, and the engines are often powerful enough to haul dozens of human passengers. Often railways of this size are called miniature railways. List of model railroad clubs.

The Tech Model Railroad Club (TMRC) at MIT in the 1950s pioneered automatic control of track-switching by using telephone relays.

The oldest society is The Model Railway Club (established 1910), near Kings Cross, London, UK. As well as building model railways, it has 5,000 books and periodicals. Similarly, The Historical Model Railway Society at Butterley, near Ripley, Derbyshire specialises in historical matters and has archives available to members and non-members.

Scales and gauges

The size of engines depends on the scale and can vary from 700 mm (27.6 in) tall for the largest ridable live steam scales such as 1:8, down to matchbox size for the smallest in Z-scale (1:220). However, there is another scale that was introduced in 2007 that is also commercially available. Called T Gauge, it is 3 mm (0.118 in) gauge track and is a scale of 1:450, basically half the size of Z scale. A typical H0 (1:87) engine is 50 mm (1.97 in) tall, and 100 to 300 mm (3.94 to 11.81 in) long. The most popular scales are: G gauge, Gauge 1, O gauge, S scale, HO gauge (in Britain, the similar 00), TT scale, and N scale (1:160 in the United States, but 1:144 in the UK). There is growing interest in Z scale and T Gauge. HO and OO are the most popular. Popular narrow-gauge scales include Sn3, HOn3 Scale and Nn3, which are the same in scale as S, H0 and N except with a narrower spacing between the tracks (in these examples, a scale 3 ft (914 mm) instead of the 4 ft 8 ½ in (1,435 mm) standard gauge).

The largest common scale is 1:8, with 1:4 sometimes used for park rides. G scale (Garden, 1:24 scale) is most popular for backyard modelling. It is easier to fit a G scale model into a garden and keep scenery proportional to the trains. Gauge 1 and Gauge 3 are also popular for gardens. O, S, HO, and N gauge are more often used indoors. Lionel trains in 0 scale (1:48 scale) are popular toys. S refers to 1:64 scale.

The words *scale* and *gauge* seem at first interchangeable but their meanings are different. *Scale* is the model's measurement as a proportion to the original, while *gauge* is the measurement between the rails.

At first, model railways were not to scale. Manufacturers and hobbyists soon arrived at *de facto* standards for interchangeability, such as gauge, but trains were only a rough approximation to the real thing. Official scales for the gauges were drawn up but not at first rigidly followed and not necessarily correctly proportioned for the gauge chosen. O (zero) gauge trains, for instance, operate on track too widely spaced in the United States as the scale is accepted as 1:48 whereas in Britain 0 gauge uses a ratio of 43.5:1 or 7 mm/1 foot and the gauge is near to correct. British 00 standards operate on track significantly too narrow. The 4 mm/1 foot scale on a 16.5 mm (0.650 in) gauge corresponds to a track gauge of 4 ft 1 ½ in/1,257 mm, 7 inches / 178 millimetres undersized). 16.5 mm (0.650 in) gauge corresponds to 4 ft 8 ½ in (1,435 mm) standard gauge in H0 (half zero) 3.5 mm/1 foot or 1:87. Most commercial scales have standards that include wheel flanges that are too deep, wheel treads that are too wide, and rail tracks that are too large.

Later, modellers became dissatisfied with inaccuracies and developed standards in which everything is correctly scaled. These are used by modellers but have not spread to mass-production because the inaccuracies and overscale properties of the commercial scales ensure reliable operation and allow for shortcuts necessary for cost control. The finescale standards include the UK's P4, and the even finer S4, which uses track dimensions scaled from the prototype. This 4 mm:1 ft modelling uses wheels 2 mm (0.079 in) or less wide running on track with a gauge of 18.83 mm (0.741 in). Check-rail and wing-rail clearances are similarly accurate.

A compromise of P4 and 00 is 'EM' which uses a gauge of 18.2 mm (0.717 in) with more generous tolerances than P4 for check clearances. It gives a better appearance than 00 though pointwork is not as close to reality as P4. It suits many where time and improved appearance are important.

Couplers and connectors

In addition to different scales, there are also different types of couplers for connecting cars, which are not compatible with each other.

In H0, the Americans standardized on horn-hook, or X2F couplers, though these have largely given way to working knuckle couplers (Kadee) which are a close approximation to the "automatic" couplers used on the prototype there and elsewhere. Also in H0, the European manufacturers have standardized, but on a coupler mount, not a coupler: many varieties of coupler can be plugged in (and out) of the NEM coupler box. None of the popular couplers has any resemblance to the prototype three-link chains generally used on the continent. For English modelers, whose most popular scale is 00, the normal coupler is a tension-lock coupler, which, again has no pretense of replicating the usual prototype three-link chain couplers.

Other scales have similar ranges of non-compatible couplers available.

It must be emphasized that, in all scales, couplers can be exchanged, with varying degrees of difficulty.

Landscaping

A HOe scale layout, 47 × 32 cm (18.5 × 12.6 in) in size.

The landscape in this N scale town includes weathered buildings and tall uncut grass.

Some modellers pay attention to landscaping their layout, creating a fantasy world or modelling an actual location, often historic. Landscaping is termed "scenery building" or "scenicking".

Constructing scenery involves preparing a sub-terrain using a wide variety of building materials, including (but not limited to) screen wire, a lattice of cardboard strips, or carved stacks of expanded polystyrene (styrofoam) sheets. A scenery base is applied over the sub-terrain; typical base include casting plaster, plaster of Paris, hybrid paper-pulp (papier-mâché) or a lightweight foam/fiberglass/bubblewrap composite as in Geodesic Foam Scenery. The scenery base is covered with ground cover, which may be ground foam, colored sawdust, natural lichen, or commercial scatter materials for grass and shrubbery. Buildings and structures can be purchased as kits, or built from cardboard, balsa wood, basswood, paper, or polystyrene or other plastic. Trees can be fabricated from materials such as Western sagebrush, candytuft, and caspia, to which adhesive and model foliage are applied; or they can be bought ready-made from specialist maunfacturers. Water can be simulated using polyester casting resin, polyurethane, or rippled glass. Rocks can be cast in plaster or in plastic with a foam backing. Castings can be painted with stains to give coloring and shadows.

Weathering

Weathering refers to making a model look used and exposed to weather by simulating dirt and wear on real vehicles, structures and equipment. Most models come out of the box looking new, because unweathered finishes are easier to produce and many collectors want models to look pristine. Also, the wear a freight car or building undergoes depends not only on age but where it is used. Rail cars in cities accumulate grime from building and automobile exhaust, while cars in deserts may be subjected to sandstorms which etch or strip paint. A model that is weathered would not fit as many layouts as a pristine model which can be weathered by its purchaser.

Weathering purchased models is common. At the least, weathering aims to reduce the plastic-like finish of scale models. The simulation of grime, rust, dirt, and wear add realism. Some modelers simulate fuel stains on tanks, or corrosion on battery boxes. In some cases, evidence of accidents or repairs may be added, such as dents or freshly-painted replacement parts, and weathered models can be nearly indistinguishable from their prototypes when photographed appropriately.

Methods of power

The sugar-cube sized electric motor in a Z scale model locomotive. The entire engine is only 50 mm (2") long.

Model of WP Steam Locomotive(1:3 size) at Guntur, India.

Model railway engines are generally operated by low voltage DC electricity supplied via the tracks, but there are exceptions, such as Märklin and Lionel Corporation, which use AC.

Most early models for the toy market were powered by clockwork and controlled by levers on the locomotive. Although this made control crude the models were large and robust enough that grabbing the controls was practical. Various manufacturers introduced slowing and stopping tracks that could trigger levers on the locomotive and allow station stops. Other locomotives, particularly large models, used steam. Steam or clockwork driven engines are still sought by collectors.

Early electrical models used a three-rail system with the wheels resting on a metal track with metal sleepers that conducted power and a middle rail which provided power to a skid under the locomotive. This made sense at the time as models were metal and conductive. Modern plastics were not available and insulation was a problem. In addition the notion of accurate models had yet to evolve and toy trains and track were crude tinplate.

As accuracy became important some systems adopted two-rail power in which the wheels were isolated and the rails carried the positive and negative supply or two sides of the AC supply. Other systems such as Märklin instead used fine metal studs to replace the central rail, allowing existing three-rail models to use more realistic track.

Although DC with the positive and negative charges on the two rails is the most common method, Märklin and Lionel use AC on the three-rail system. American Flyer used AC power on two-rail track.

Early electric trains ran on batteries because few homes in the late 19th and early 20th centuries had electricity. Today, inexpensive train sets on batteries are again common but regarded as toys seldom used by hobbyists. Battery power is used by many garden railway and larger scale systems because of the difficulty in obtaining reliable power supply through the rails outdoors and because the high power consumption and thus current draw of large scale garden models is more easily and safely met with lead acid batteries.

Engines powered by Live steam are often built in large, outdoor gauges, and are available in Gauge 1, G scale, 16 mm scale and can be found in 0 and H0. Hornby Railways produce live steam locomotives in 00, based on designs first arrived at by an amateur modeller. Other modellers have built live steam models in H0/00, 009 and N, and there is one in Z in Australia.

Occasionally gasoline-electric models, patterned after real diesel-electric locomotives, come up among hobbyists and companies like Pilgrim Locomotive Works have sold such locomotives. Large-scale petrol-mechanical and petrol-hydraulic models are available but unusual and pricier than the electrically powered versions.

Scratch building

Modern manufacturing techniques mean mass produced models achieve a high degree of precision and realism. In the past this was not the case and scratch building was very common. Simple models are made using cardboard engineering techniques. More sophisticated models can be made using a combination of etched sheets of brass and low temperature castings. Parts that need machining, such as wheels and couplings are bought in. Etched kits are still popular, still accompanied by low temperature castings. These kits produce models that are not covered by the major manufacturers or in scales that are not in mass production. Laser machining techniques have extended this ability to thicker materials for scale steam and other locomotive types.

Control

Coin-operated model train layout in Germany

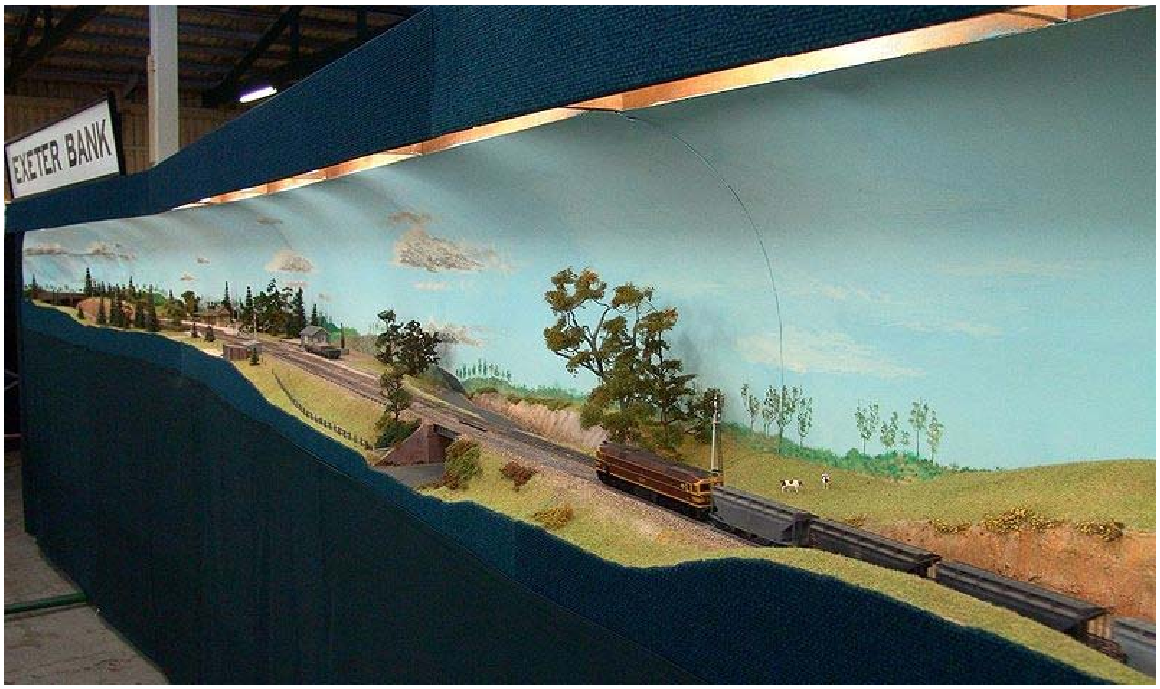
The first clockwork (spring-drive) and live steam locomotives ran until out of power, with no way for the operator to stop and restart the locomotive or vary its speed. The advent of electric trains, which appeared commercially in the 1890s, allowed control of the speed by varying the current or voltage. As trains began to be powered by transformers and rectifiers more sophisticated throttles appeared, and soon trains powered by AC contained mechanisms to change direction or go into neutral gear when the operator cycled the power. Trains powered by DC can change direction by reversing polarity.

Electricity permits control by dividing the layout into isolated blocks, where trains can be slowed or stopped by lowering or cutting power to a block. Dividing a layout into blocks permitted operators to run more than one train with less risk of a fast train catching and hitting a slow train. Blocks can also trigger signals or other accessories, adding realism or whimsy. Three-rail systems often insulate one of the common rails on a section of track, and use a passing train to complete the circuit and activate an accessory.

Many modern railways are computer-controlled. The industry standard command system is Digital Command Control (DCC). The advantages to DCC are that instead of controlling the voltage to the track, small circuit cards, or decoders, hidden inside the piece of equipment allowing control of the individual locomotive. This allows more realistic operation, in that the modeler can control individual locomotives on the same stretch of track. Some DCC decoders generate sounds through a speaker also hidden inside. Less common closed proprietary systems also exist.

In large scales, particularly for garden railways, radio control and DCC in the garden has become popular.

Model railway manufacturers



Exeter Bank: An HO-scale Australian model railway

An O-scale Australian model railway

A propane fired 1:8 scale live steam train running on the Finnish Railway Museum's miniature track.

A model train running on the Willans Hill Model Railway miniature track in Wagga Wagga, New South Wales, Australia.

- Airfix
- American Flyer
- AR Kits
- Arnold
- Athearn
- Atlas Model Railroad
- Auhagen
- Bachmann Industries
- Bassett-Lowke
- Bavaria
- Bemo
- Bing
- Bowser Manufacturing
- Bachmann
- Broadway Limited Imports (BLI)
- Dapol
- Exley
- Faller
- Ferris (defunct)
- Lesney (Matchbox)
- Lehmann Gross Bahn
- Life Like
- Lima
- Lionel
- Marx
- Mainline
- Mantua, later Tyco Toys
- Märklin
- Mehano
- Merkur (toy)
- Merten
- Modemo (Hasegawa)
- MTH Electric Trains
- Noch
- Peco
- Piko
- Playmobil
- President's Choice

- Fleischmann
- Fulgurex
- G .& R. Wrenn Ltd
- Graham Farish ("Grafar")(Owned by Bachmann Branchline)
- Great West Models
- HAG
- Heljan
- Herpa
- Hornby
- Ibertren
- JMRI
- Jouef
- Kato
- Kemtron Corporation (defunct 1964)
- Klein Modellbahn
- Kleinbahn
- Lego
- Lemaco
- Rapido
- Rivarossi
- Roco
- Rocrail
- Rokal
- Tomix
- Tillig
- Tri-ang Railways
- Trix/Minitrix
- USA Trains
- Varney
- Viessmann
- Vollmer
- Walthers
- Williams
- Woodland Scenics
- Worsley Works

Famous model railroaders

Model train display at Chicago's Museum of Science and Industry

A model railway based on a fictional location in the United States.

Layout standards organizations

Several organizations exist to set standardizations for connectability between individual layout sections (commonly called "modules"). This is so several (or hundreds, given enough space and power) people or groups can bring together their own modules, connect them together with as little trouble as possible, and operate their trains. Despite different design and operation philosophies, different organizations have similar goals; standardized ends to facilitate connection with other modules built to the same specifications, standardized electricals, equipment, curve radii.

- NTRAK, standardized 3-track (heavy operation) mainline with several optional branchlines. Focuses on Standard Gauge, but also has specifications for Narrow Gauge. Due to its popularity, it can be found in regional variations, most notably the Imperial-to-Metric measurement conversions. Tends to be used more for 'unattended display' than 'operation'.
- FREMO, a European-based organisation focusing on a single-track line, HO Scale. Also sets standards for N Scale modules. Standards are considerably more flexible in module shape than NTRAK, and has expanded over the years to accommodate several scenery variations.
- oNeTRAK, operationally similar to FREMO, standardises around a single-track mainline, with modules of varying sizes and shapes. Designed with the existing NTRAK spec in mind, is fully compatible with such modules.
- Z-Bend Track, uses a double track mainline running down both sides of a module. Modules can be of any length, or width in the middle and any overall shape. The

"standard" called Z-Bend Track only applies to the last five inches (12.7 cm) of the module's interface to other modules, the electrical interface and the module height.

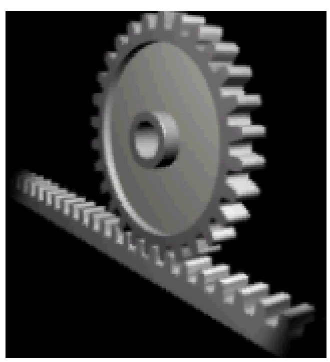
- ausTRAK, N Scale, two-track main with hidden third track (can be used as NTRAK's third main, as a return/continuous loop, or hidden yard/siding/on-line storage). Australian scenery and rolling stock modelled in Standard Gauge.
- NMRA, National Model Railroad Association, the largest organization devoted to the development, promotion, and enjoyment of the hobby of model railroading.
- MOROP, European Union of Model Railroad and Railroad Fans, the European standardization organisation.
- sTTandard, Polish TT-scale (1:120) modules organization.
- N-orma, Polish N-scale (1:160) modules organization.

Chapter- 3

Rack Railway

Rack railway track using the Lamella system rack.

Schneeberg cog railway steam locomotive, with tilted boiler, on level track.



functioning of the rack and pinion.

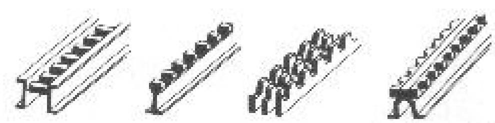
A **rack-and-pinion railway** (also **rack railway**, **cog railway**) is a railway with a toothed rack rail, usually between the running rails. The trains are fitted with one or more cog wheels or pinions that mesh with this rack rail. This allows the trains to operate on steep gradients.

Most rack railways are mountain railways, although a few are transit railways or tramways built to overcome a steep gradient in an urban environment.

The first cog railway was the Middleton Railway between Middleton and Leeds in West Yorkshire, England, UK, where the first commercial steam locomotive, *Salamanca*, ran in 1812. This used a rack and pinion system designed and patented in 1811 by John Blenkinsop.

The first mountain cog railway was the Mount Washington Cog Railway in the US state of New Hampshire, which carried its first fare-paying passengers in 1868 and reached the summit of Mount Washington in 1869. The first mountain rack railway in continental Europe was the Vitznau-Rigi-Bahn on Mount Rigi in Switzerland, which opened in 1871. Both lines are still running.

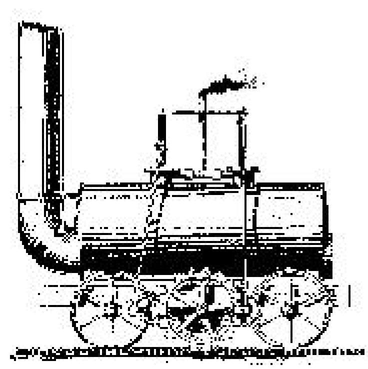
Rack systems



Different rack systems: from the left, Riggenbach, Strub, Abt and Locher.

A number of different rack systems have been developed. Today, the majority of rack railways use the Abt system.

Blenkinsop



Blenkinsop rack and pinion with teeth on outer side of one rail only

Thinking that the friction of metal wheels on metal rails would be too low, John Blenkinsop built his locomotives for the Middleton Railway in 1812 with a 20 teeth, 3 feet (915 mm) diameter cog wheel (pinion) on the left side that engaged in rack teeth (two teeth per foot) on the outer side of the rail, the metal "fishbelly" edge rail with its side rack being cast all in one piece, in three feet (one yard) lengths. While Blenkinsop's system remained in use for 25 years on the Middleton Railway, it remained a curiosity because simple friction was found to be sufficient for railroads operating on level ground. One wonders how the Blenkinsop rack dealt with pointwork.

With the exception of some early Morgan rack installations, all other rack systems place the rack rail halfway between the running rails.

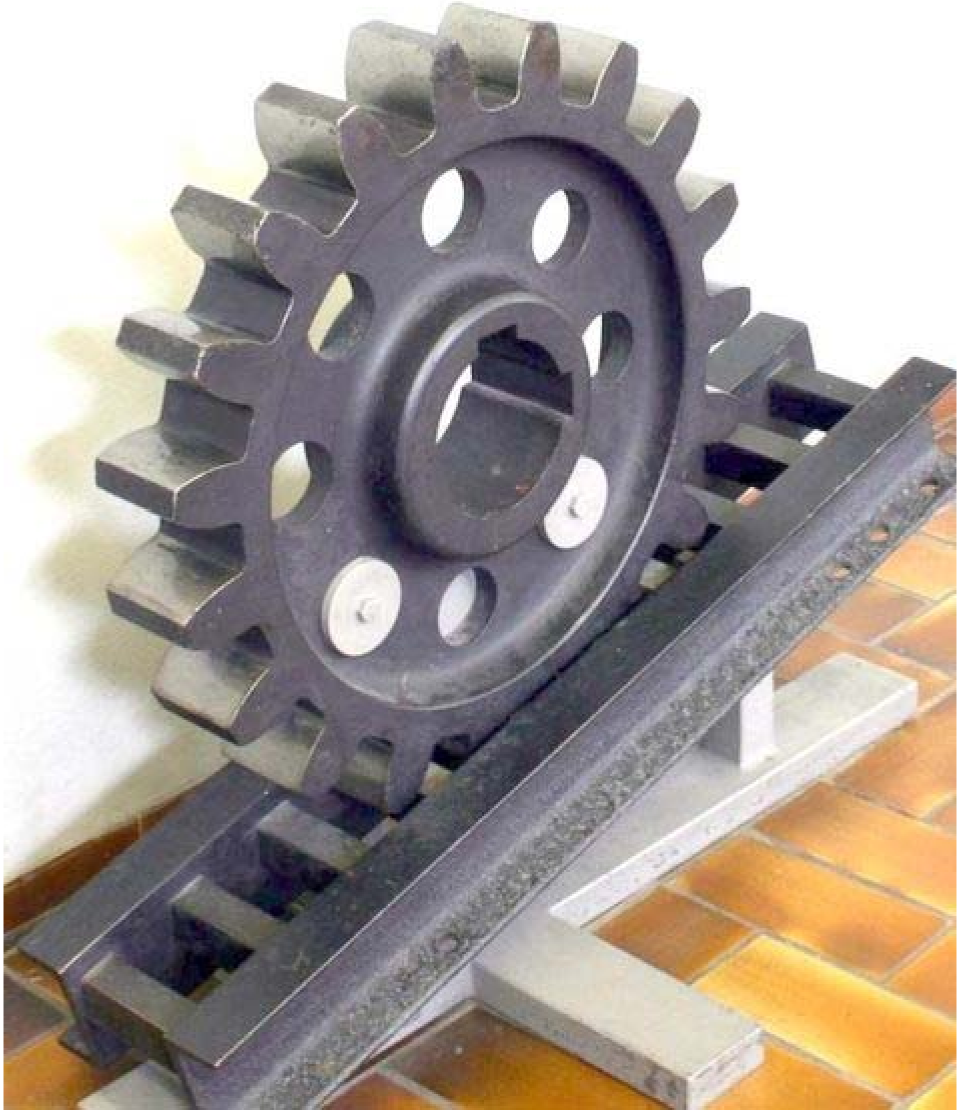
Stephenson

George Stephenson grouped the steep gradients on either side of Rainhill and from Liverpool down to the wharfs, just in case cable haulage was necessary. In the event, only the wharf line needed cable haulage for a few decades.

Marsh

The first successful rack railway in the US was the Mount Washington Cog Railway, developed by Sylvester Marsh. Marsh was issued a U.S. patent for the general idea of a rack railway in September 1861, and in January 1867 for a practical rack where the gear teeth take the form of rollers arranged like the rungs of a ladder between two L-shaped wrought-iron rails. The first public trial of the Marsh rack on Mount Washington was made on August 29, 1866, when only one quarter of a mile (half a kilometer) of track had been completed. The Mount Washington railway opened to the public on August 14, 1868. The pinion wheels on the locomotives had deep teeth that ensure that at least two teeth are engaged with the rack at all times - this measure helps reduce the possibility of the pinions riding up and out of the rack.

Riggenbach



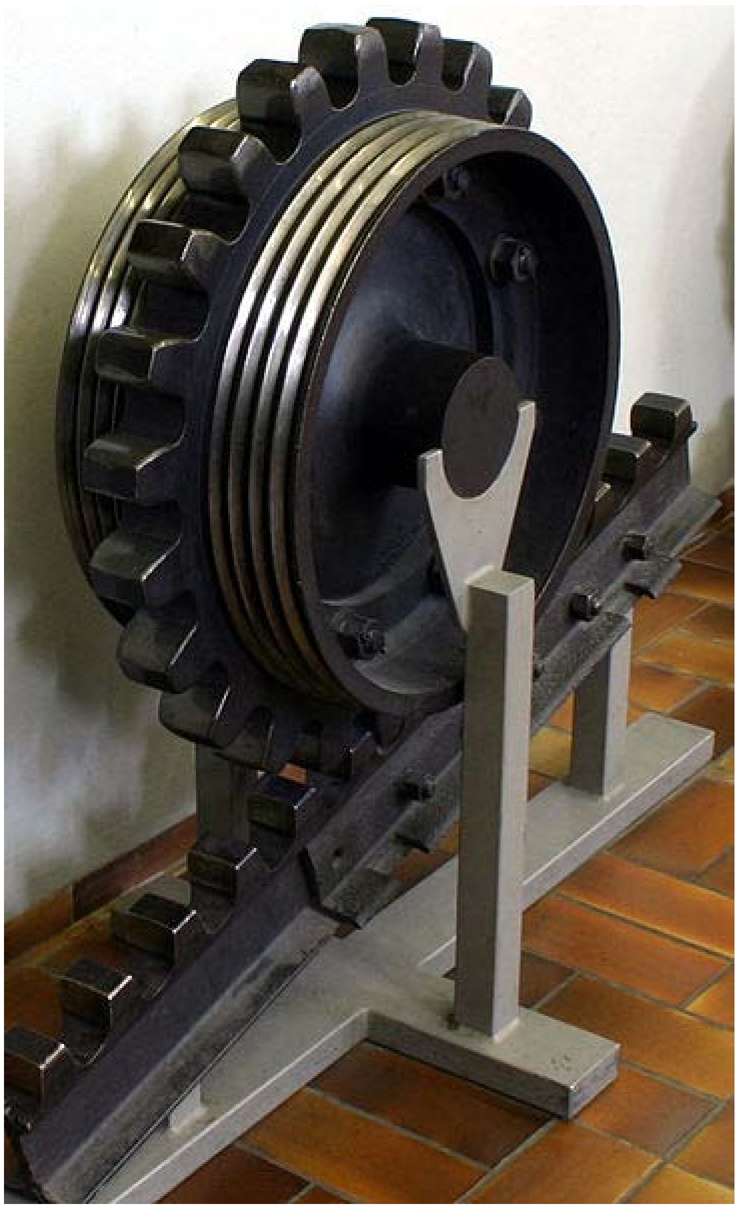
The Riggenbach rack system

The Riggenbach rack system was invented by Niklaus Riggenbach working at about the same time as, but independently from Marsh. Riggenbach was granted a French patent in 1863 based on a working model which he used to interest potential Swiss backers. During this time, the Swiss Consul to the United States visited Marsh's Mount Washington Cog Railway and reported back with enthusiasm to the Swiss government. Eager to boost tourism in Switzerland, the government commissioned Riggenbach to build a rack railway up Rigi Mountain. Following the construction of a prototype locomotive and test track in a quarry near Bern, the Vitznau-Rigi-Bahn opened on 22 May 1871.

The Riggenbach system is similar in design to the Marsh system. It uses a ladder rack, formed of steel plates or channels connected by round or square rods at regular intervals. The Riggenbach system suffers from the problem that its fixed ladder rack is more complex and expensive to build than the other systems.

Following the success of the Vitznau-Rigi-Bahn, Riggenbach established the *Maschinenfabrik der Internationalen Gesellschaft für Bergbahnen* (IGB) - a company that produced rack locomotives to his design.

Strub

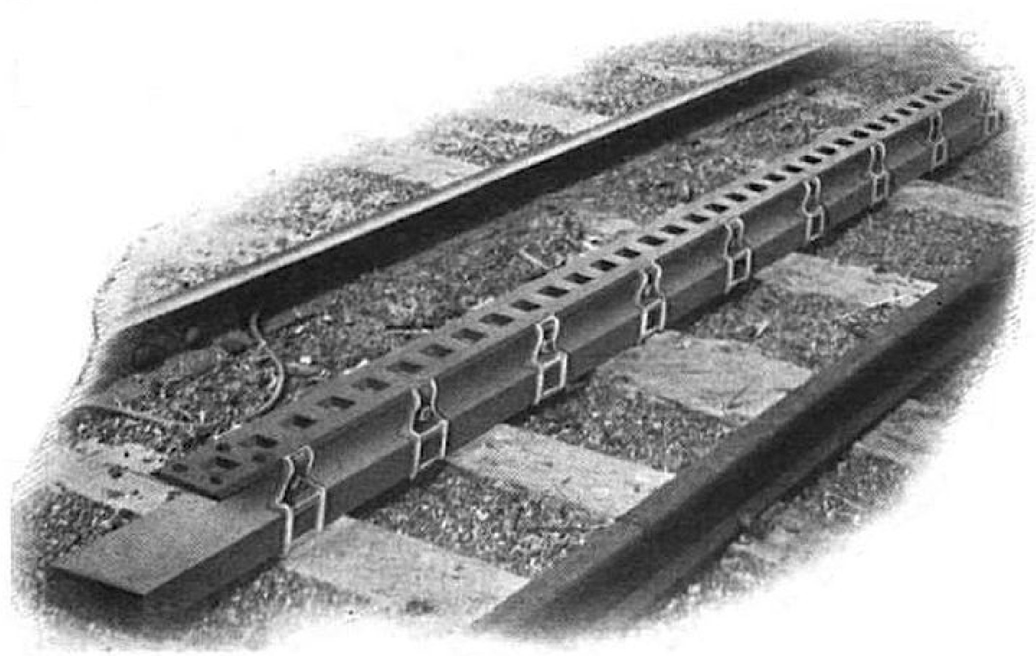


The Strub rack system

The Strub rack system was invented by Emil Strub in 1896. It uses a rolled flat-bottom rail with rack teeth machined into the head approximately 100 mm apart. Safety jaws fitted to the locomotive engage with the underside of the head to prevent derailments and serve as a brake. Strub's US Patent, granted in 1898, also includes details of how the rack rail is integrated with the mechanism of a turnout.

The best-known use of the Strub system is on the Jungfraubahn in Switzerland. It is the simplest rack system to maintain and has become increasingly popular.

Morgan

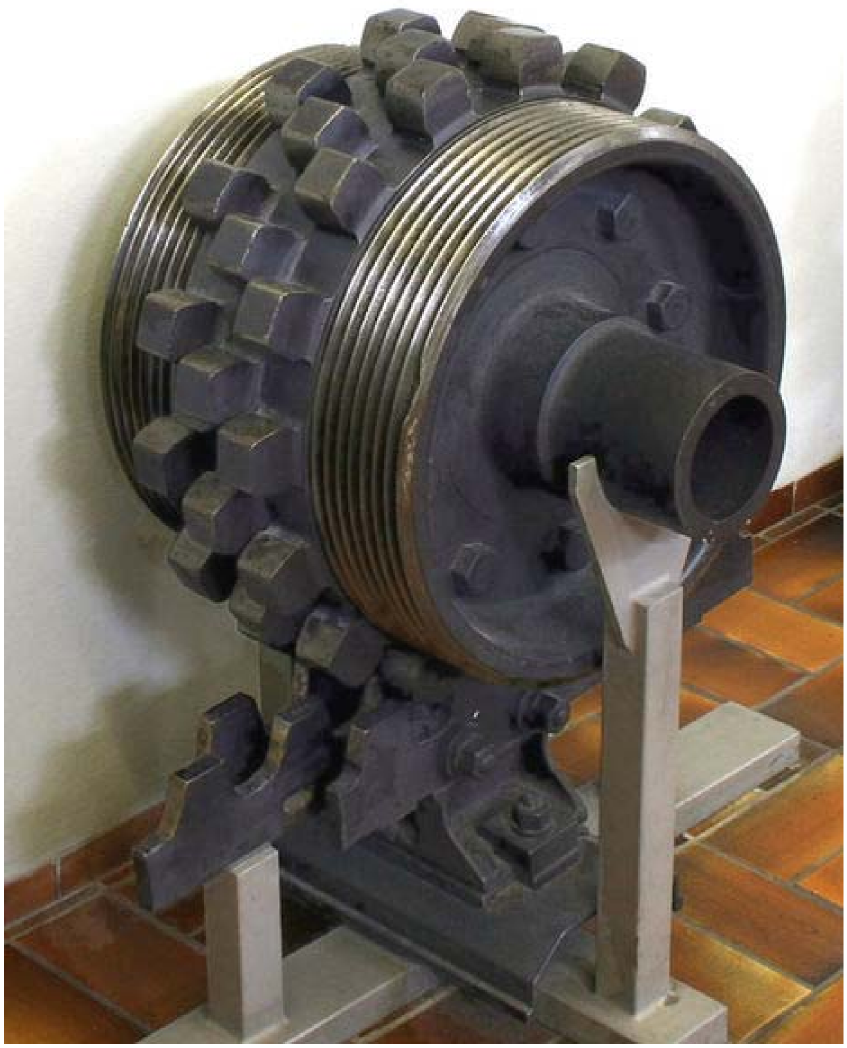


The non-powered variant of the Morgan rack, from the 1919 Goodman catalog.

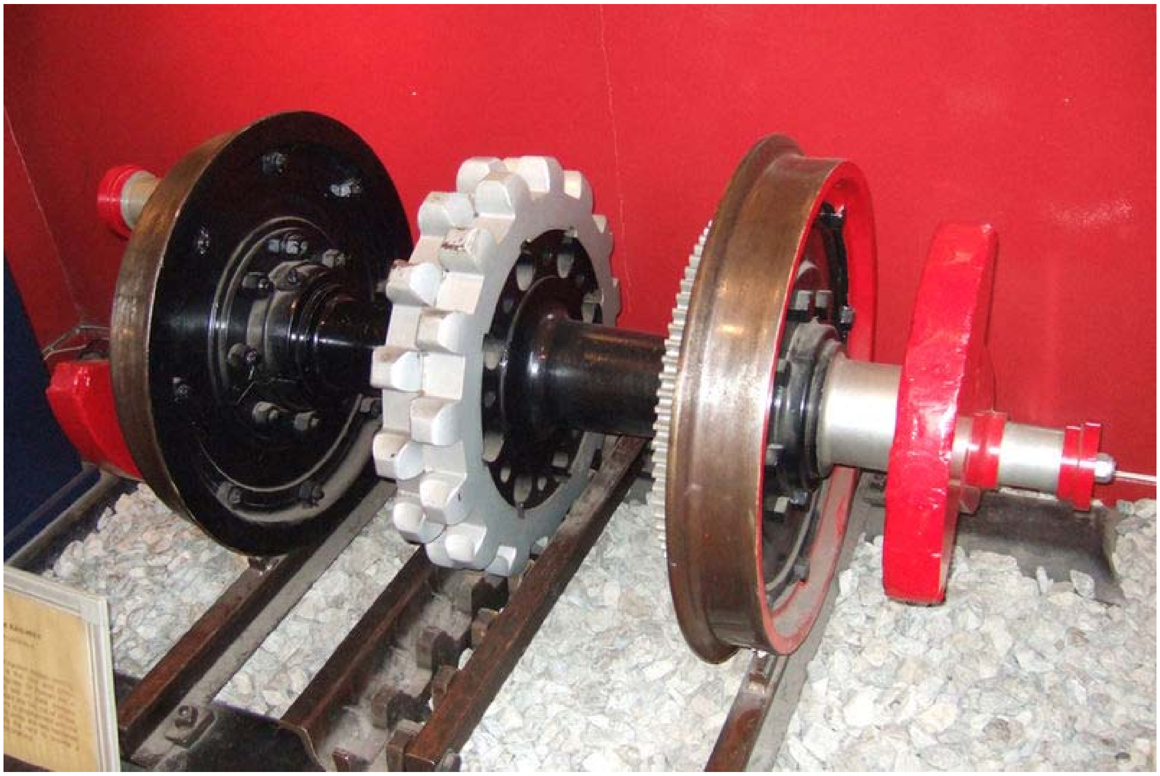
In 1900, E. C. Morgan of Chicago received a patent on a rack railway system that was mechanically similar to the Riggenbach rack, but where the rack was also used as a third rail to power the electric locomotive. Morgan went on to develop heavier locomotives and with J. H. Morgan, turnouts for this system. In 1904, he patented a simplified but compatible rack, where the teeth on the engine pinions engaged square holes punched in a bar-shaped center rail. J. H. Morgan patented several alternative approaches to building turnouts for use with this new rail. Curiously, Morgan recommended an off-center rack in order to allow clear passage for pedestrians and animals walking along the tracks. Some photos of early Morgan installations show this. A simplified rack mounting system could be used when the Morgan rack was not used for third-rail power and the Morgan rack offered interesting possibilities for street railways. The Morgan rack was good for grades of up to 16 percent.

The Goodman Equipment Company began marketing the Morgan system to mining companies, and it saw widespread use in many mines, particularly where steep grades were encountered underground. By 1907, Goodman had offices in Cardiff, Wales to serve the British market. Between 1903 and 1909, the McKell Coal and Coke company in Raleigh County, West Virginia, installed 35,000 feet (10,700 m) of Morgan rack/third-rail track in its mines. The Morgan system saw limited use on one common carrier railroad in the United States, the Chicago Tunnel Company a narrow gauge freight carrier that had one steep grade in the line up to their surface disposal station on the Chicago lakefront.

Abt



Abt rack system



Abt rack system

The Abt system was devised by Roman Abt, a Swiss locomotive engineer. Abt worked for Riggenbach at his works in Olten and later at his IGB rack locomotive company. In 1885 he founded his own civil engineering company.

During the early 1880s, Abt worked to devise an improved rack system that overcame the limitations of the Riggenbach system. In particular, the Riggenbach rack was expensive to manufacture and maintain and the switches were complex. In 1882 Abt designed a new rack using solid bars with vertical teeth machined into them. Two or three of these bars are mounted centrally between the rails, with the teeth offset. The use of multiple bars with offset teeth ensures that the pinions on the locomotive driving wheels are constantly engaged with the rack. The Abt system is cheaper to build than the Riggenbach because it requires a lower weight of rack over a given length. However the Riggenbach system exhibits greater wear resistance than the Abt.

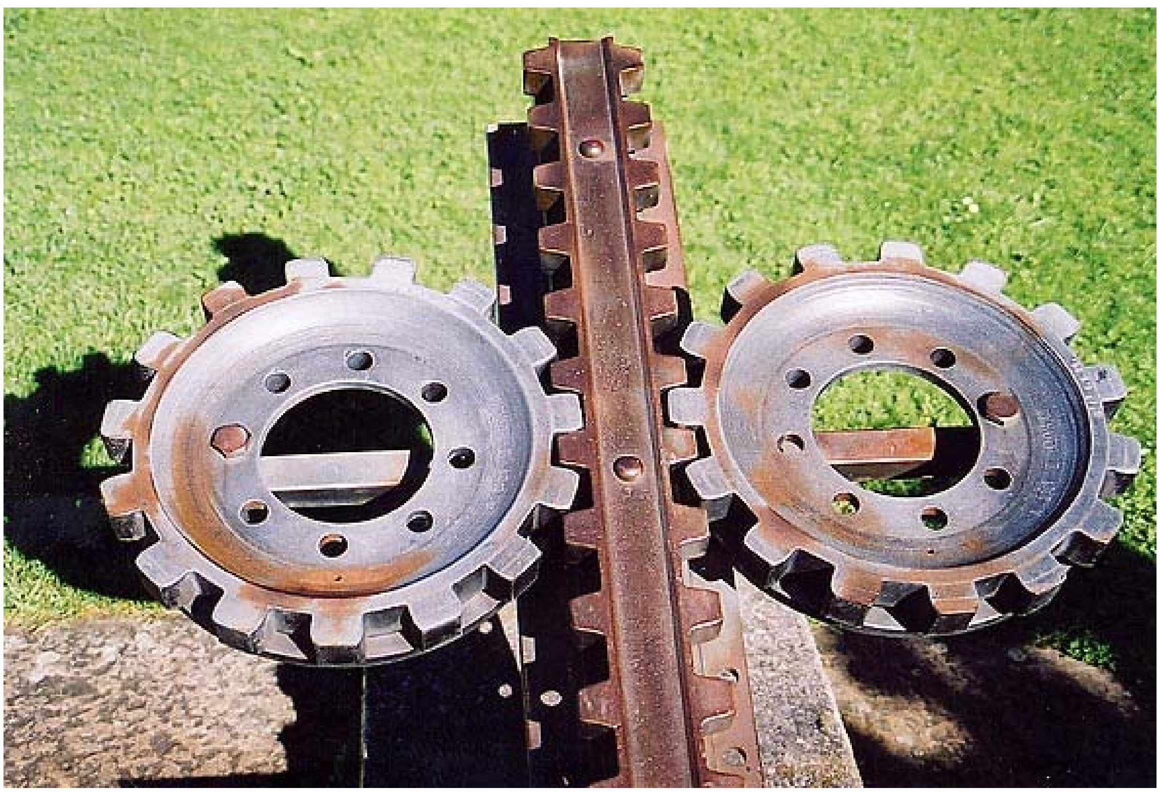
Abt also developed a system for smoothing the transition from friction to rack traction, using a spring-mounted rack section to bring the pinion teeth gradually into engagement.

The first use of the Abt system was on the Harzbahn in Germany which opened in 1885.

The pinion wheels can be mounted on the same axle as the rail wheels (as in the picture at right), or driven separately. The steam locomotives on the Mount Lyell Mining and Railway Company had separate cylinders driving the pinion wheel as do the 'X' Class locomotives on the Nilgiri Mountain Railway.

Locher

Locher rack system



Locher Rack system (seen from above)

The Locher rack system, invented by Eduard Locher, has gear teeth cut in the sides rather than the top of the rail, engaged by two cog wheels on the locomotive. This system allows use on steeper grades than the other systems, whose teeth could jump out of the rack. It is used on the Pilatus Railway.

Locher set out to design a rack system that could be used on gradients as steep as 1 in 2 (50%). The Abt system - the most common rack system in Switzerland at the time - was limited to a maximum gradient of 1 in 4 (25%). Locher showed that on steeper grade, the Abt system was prone to the driving pinion over-riding the rack causing potentially catastrophic derailments, as predicted by Dr. Abt. To overcome this problem and allow a rack line up the steep sides of Mt. Pilatus, Locher developed a rack system where the rack is a flat bar with symmetrical, horizontal teeth. Horizontal pinions engage the centrally-mounted bar, both driving the locomotive and keeping it centered on the track.

This system provides very stable attachment to the track, also protecting the car from toppling over even under the severest cross winds. Such gears are also capable to lead the car, so even flanges on running wheels are optional. The biggest shortcoming of the system seems that the ordinary railway switch is not possible and a transfer table or other complex device must be used where it is needed to branch the track.

Following tests, the Locher system was deployed on the Pilatus Railway which opened in 1889. No other public railway uses the Locher system, although some European coal mines use a similar system on steeply graded underground lines.

Lamella

Joint between Riggenbach and Strub

The Lamella system (also known as the Von Roll system) was developed by the Von Roll company after the rolled steel rails used in the Strub system became unavailable. It is formed from a single blade cut in a similar fashion to the Abt system but typically wider than a single Abt bar. The Lamella rack can be used by locomotives designed for use on the Riggenbach or the Strub systems and some railways use rack from multiple systems. The St. Gallen Gais Appenzell Railway in Switzerland has sections of Riggenbach, Strub and Lamella rack.

Most of the rack railways built from the late 20th century onwards have used the Lamella system.

Rack-and-adhesion systems / Pure rack systems

Rack-and-adhesion systems use the cog drive only on the steepest sections and elsewhere operate as a regular railway. Others, the steeper ones, are rack-only. On the latter type, the locomotives' wheels are generally free-wheeling and despite appearances do not contribute to driving the train. In this case the racks continue also in the horizontal parts, if any.

Fell

The Fell mountain railway system is not strictly speaking a rack railway since there are no cogs with teeth. Rather, this system uses a smooth raised centre rail between the two running rails on steep lines which is gripped on both sides to improve friction. Trains are propelled by wheels or braked by shoes pressed horizontally onto the centre rail, as well as by means of the normal running wheels.

Switches

Railroad switch at von Roll system rack railway (Štrbské Pleso, Slovakia).

Rack railway switches are as varied as rack railway technologies, for optional rack lines such as the Zentralbahn in Switzerland and the West Coast Wilderness Railway in

Tasmania it is convenient to only use switches on sections flat enough for adhesion (for example, on a pass summit). Other systems which rely on the rack for driving (with the conventional rail wheels undriven) such as the Dolderbahn in Zurich, Štrbské Pleso in Slovakia and the Schynige Platte rack railway instead must switch the rack rail. The Dolderbahn switch works by bending all three rails, an operation that is performed every trip as the two trains pass in the middle.

The geometry of the rack system has a large impact on the construction of turnouts. If the rack is elevated above the running rails, there is no need to interrupt the running rails to allow passage of the driving pinions of the engines. Strub explicitly documented this in his U.S. patent. Strub used a complex set of bell-cranks and push-rods linking the throw-rod for the points to the two throw-rods for the moving rack sections. One break in the rack was required to select between the two routes, and a second break was required where the rack rails cross the running rails. These are visible in the photo of the Strub turnout on the Štrbské Pleso railway. Turnouts for the Morgan Rack system were similar, with the rack elevated above the running rails. Most of the Morgan turnout patents included movable rack sections to avoid breaks in the rack, but because all Morgan locomotives had two linked drive pinions, there was no need for a continuous rack. So long as the breaks in the rack were shorter than the distance between the drive pinions on the locomotive, the rack rail could be interrupted wherever there was need to cross over a running rail.

Turnouts are far more complex when the rack is at or below the level of the running rails. Marsh's first rack patent shows such an arrangement, and the original Mount Washington Cog Railroad he built had no turnouts. It was not until 1941 that a turnout was constructed on this line. The new turnouts installed on the Mount Washington line in 200? are essentially transfer tables.

Cog locomotives

Vertical boiler locomotive Arth–Rigi Railway

Rittnerbahn early electric cog locomotive and carriage

Originally almost all cog railways were powered by steam locomotives. The steam locomotive needs to be extensively modified to work effectively in this environment. Unlike a diesel locomotive or electric locomotive, the steam locomotive only works when its powerplant (the boiler, in this case) is fairly level. The locomotive boiler requires water to cover the boiler tubes and firebox sheets at all times, particularly the crown sheet, the metal top of the firebox. If this is not covered with water, the heat of the fire will soften it enough to give way under the boiler pressure, leading to a catastrophic failure.

On rack systems with extreme gradients, the boiler, cab and general superstructure of the locomotive are tilted forward relative to the wheels so that they are more or less horizontal when on the steeply graded track. These locomotives often cannot function on level track, and so the entire line, including maintenance shops, must be laid on a gradient. This is one of the reasons why rack railways were among the first to be electrified and most of today's rack railways are electrically powered. In some cases, the vertical boiler can be used that is less sensitive for the track gradient.

On a rack-only railroad locomotives always push their passenger cars for safety reasons since the locomotive is fitted with powerful brakes, often including hooks or clamps that grip the rack rail solidly. Some locomotives are fitted with automatic brakes that apply if the speed gets too high, preventing runaways. Often there is no coupler between locomotive and train since gravity will always push the passenger car down against the locomotive. Electrically powered vehicles often have electromagnetic track brakes as well.

The maximum speed of trains operating on a cog railway is very low, generally from 9 to 25 km/h depending on gradient and propulsion method. Because the Skitude has gentler gradients than typical, its speeds are higher than typical.

Chapter- 4

Railway Signalling

A gantry of British semaphore signals seen from the cab of a steam locomotive

Railway signalling is a system used to control railway traffic safely, essentially to prevent trains from colliding. Being guided by fixed rails, trains are uniquely susceptible to collision; furthermore, trains cannot stop quickly, and frequently operate at speeds that do not enable them to stop within sighting distance of the driver. In the UK, the Regulation of Railways Act 1889 introduced a series of requirements on matters such as the implementation of interlocked block signalling and other safety measures as a direct result of the Armagh rail disaster in that year.

Most forms of train control involve movement authority being passed from those responsible for each section of a rail network (e.g., a signalman or stationmaster) to the train crew. The set of rules and the physical equipment used to accomplish this determine what is known as the *method of working* (UK), *method of operation* (US) or *safeworking* (Aus.). Not all these methods require the use of physical signals and some systems are specific to single track railways.

The earliest rail cars were first hauled by horses or mules. A mounted flagman on a horse preceded some early trains. Hand and arm signals were used to direct the “train drivers”. Foggy and poor-visibility conditions gave rise to flags and lanterns. Wayside signalling dates back as far as 1832, and used elevated flags or balls that could be seen from afar.

Timetable operation

The simplest form of operation, at least in terms of equipment, is to run the system according to a timetable. A fixed schedule is drawn up with which every train crew must be familiar. Trains may only run on each section of track at their scheduled time, during which they have 'possession' and no other train is permitted to use the same section.

When trains are running in opposite directions on a single-track railroad, meeting points ("meets") are scheduled, at which each train must wait for the other at a passing place. Neither train is permitted to move before the other has arrived. In the US the display of two green flags (green lights at night) is an indication that another train is following the first and the waiting train must wait for the next train to pass. In addition, the train carrying the flags gives eight blasts on the whistle as it approaches. The waiting train must return eight blasts before the flag carrying train may proceed.

The timetable system has several disadvantages. First, there is no positive confirmation that the track ahead is clear, only that it is scheduled to be clear. The system does not allow for engine failures and other such problems, but the timetable is set up so that there should be sufficient time between trains for the crew of a failed or delayed train to walk far enough to set up warning flags, flares, and *detonators* or *torpedoes* (UK and US terminology, respectively) to alert any other train crew.

A second problem is the system's inflexibility. Trains cannot be added, delayed, or rescheduled without advance notice.

A third problem is a corollary of the second: the system is inefficient. To provide flexibility, the timetable must give trains a broad allocation of time to allow for delays, so the line is in the possession of each train for longer than is otherwise necessary.

Nonetheless, this system permits operation on a vast scale, with no requirements for any kind of communication that travels faster than a train. Timetable operation was the normal mode of operation in North America in the early days of the railroad.

Timetable and train order

With the advent of the telegraph in 1851, a more sophisticated system became possible because this provided a means whereby messages could be transmitted ahead of the trains. The telegraph allows the dissemination of any timetable changes, known as *train orders*. These allow the cancellation, rescheduling and addition of train services.

Train crews generally receive their orders at the next station at which they stop, or they are sometimes handed up to a locomotive 'on the run' via a long staff. Train orders allowed dispatchers to set up meets at sidings, force a train to wait in a siding for a priority train to pass, and to maintain at least one block spacing between trains going the same direction.

Timetable and train order operation was commonly used on American railroads until the 1960s, including some quite large operations such as the Wabash Railroad and the Nickel Plate Road. Train order traffic control was used in Canada until the late 1980s on the Algoma Central Railway and some spurs of the Canadian Pacific Railway.

Timetable and train order was not used widely outside North America, and has been phased out in favor of radio dispatch on many light-traffic lines and electronic signals on high-traffic lines. More details of North American operating methods is given below.

Block signalling

British lower-quadrant semaphore stop signal (absolute) with subsidiary arm (permissive) below

Trains cannot collide with each other if they are not permitted to occupy the same section of track at the same time, so railway lines are divided into sections known as *blocks*. In normal circumstances, only one train is permitted in each block at a time. This principle forms the basis of most railway safety systems.

History of block signalling

On double-tracked railway lines, which enabled trains to travel in one direction on each track, it was necessary to space trains far enough apart to ensure that they could not collide. In the very early days of railways, men (originally called 'policemen') were employed to stand at intervals ("blocks") along the line with a stopwatch and use hand signals to inform train drivers that a train had passed more or less than a certain number of minutes previously. This was called "time interval working". If a train had passed very recently, the following train was expected to slow down to allow more space to develop.

The watchmen had no way of knowing whether a train had cleared the line ahead, so if a preceding train stopped for any reason, the crew of a following train would have no way of knowing unless it was clearly visible. As a result, accidents were common in the early days of railways. With the invention of the electrical telegraph, it became possible for staff at a station or signal box to send a message (usually a specific number of rings on a bell) to confirm that a train had passed and that a specific block was clear. This was called the "absolute block system".

Fixed mechanical signals began to replace hand signals from the 1830s. These were originally worked locally, but it later became normal practice to operate all the signals on a particular block with levers grouped together in a signal box. When a train passed into a block, a signalman would protect that block by setting its signal to 'danger'. When an 'all clear' message was received, the signalman would move the signal into the 'clear' position.

The block system came into use gradually during the 1850s and 1860s and became mandatory in the United Kingdom after Parliament passed legislation in 1889 following a number of accidents, most notably the Armagh rail disaster. This required block signalling for all passenger railways, together with interlocking, both of which form the basis of modern signalling practice today. Similar legislation was passed by the United States around the same time.

Not all blocks are controlled using fixed signals. On some single track railways in the UK, particularly those with low usage, it is common to use token systems that rely on the train driver's physical possession of a unique token as authority to occupy the line, normally in addition to fixed signals.

Entering and leaving a manually-controlled block

Before allowing a train to enter a block, a signalman must be certain that it is not already occupied. When a train leaves a block, he must inform the signalman controlling entry to the block. Even if the signalman receives advice that the previous train has left a block, he is usually required to seek permission from the next signal box to admit the next train. When a train arrives at the end of a block section, before the signalman sends the message that the train has arrived, he must be able to see the end-of-train marker on the back of the last vehicle. This ensures that no part of the train has become detached and remains within the section. The end of train marker might be a white disc by day or a steady or flashing red lamp. If a train has entered the next block before the signalman sees that the disc or lamp is missing, he will ask the next signal box to stop the train and investigate.

Permissive and absolute blocks

Under a permissive block system, trains are permitted to pass signals indicating the line ahead is occupied, but only at such a speed that they can stop safely driving by sight. This allows improved efficiency in some situations and is mostly used in the USA, and in most countries is restricted to freight trains only, and may be restricted depending on the level of visibility.

Permissive block working may also be used in an emergency, either when a driver is unable to contact a signalman after being held at a danger signal for a specific time, although this is only permitted when the signal does not protect any conflicting moves, and also when the signalman is unable to contact the next signal box to make sure the previous train has passed, for example if the telegraph wires are down. In these cases, trains must proceed at very low speed (typically 20 mph or less) so that they are able to stop short of any obstruction. In most cases this will not be allowed during times of poor visibility (e.g. fog or falling snow).

Even when an absolute block system is implemented, multiple trains may enter a block with authorisation. This may be necessary e.g. in order to split or join trains together, or to rescue failed trains. In giving authorisation, the signalman also ensures the driver knows precisely what to expect ahead, and the driver must operate the train in a safe manner taking this information into account. Generally, the signal will remain at danger, and the driver will be given verbal authority, usually accompanied by a yellow flag, to pass a signal at danger, and the presence of the train in front will be explained. At locations where trains regularly enter occupied blocks, such as stations where coupling takes place, a subsidiary signal, sometimes known as a "calling on" signal, will be provided for these movements, otherwise they are accomplished through train orders.

Automatic block

Under automatic block signalling, signals indicate whether or not a train may enter a block based on automatic train detection indicating whether a block is clear. The signals may also be controlled by a signalman, so that they only provide a *proceed* indication if the signalman sets the signal accordingly and the block is clear.

Fixed block

Most blocks are "fixed", i.e. they include the section of track between two fixed points. On timetable, train order, and token-based systems, blocks usually start and end at selected stations. On signalling-based systems, blocks start and end at signals.

The lengths of blocks are designed to allow trains to operate as frequently as necessary. A lightly-used line might have blocks many kilometres long, but a busy commuter line might have blocks a few hundred metres long.

A train is not permitted to enter a block until a signal indicates that the train may proceed, a dispatcher or signalman instructs the driver accordingly, or the driver takes possession of the appropriate token. In most cases, a train cannot enter the block until not only the block itself is clear of trains, but there is also an empty section beyond the end of the block for at least the distance required to stop the train. In signalling-based systems with closely-spaced signals, this overlap could be as far as the signal following the one at the end of the section, effectively enforcing a space between trains of two blocks.

When calculating the size of the blocks, and therefore the spacing between the signals, the following have to be taken into account:

- Line speed (the maximum permitted speed of each train)
- Gradient (to compensate for longer or shorter braking distances)
- The braking characteristics of trains on that line
- Sighting (how far ahead a driver can see a signal)
- Reaction time (of the driver)

Historically, some lines operated so that certain large or high speed trains were signalled under different rules and only given the right of way if two blocks in front of the train were clear.

Moving block

One disadvantage of having fixed blocks is that the faster trains are allowed to run, the longer the stopping distance, and therefore the longer the blocks need to be, thus decreasing the line's capacity.

Under a moving block system, computers calculate a 'safe zone' around each moving train that no other train is allowed to enter. The system depends on knowledge of the precise location and speed and direction of each train, which is determined by a combination of several sensors: active and passive markers along the track and trainborne tachometers and speedometers (GPS systems cannot be used because they do not work in tunnels.) With a moving block, lineside signals are unnecessary, and instructions are passed directly to the trains. This has the advantage of increasing track capacity by allowing trains to run closer together while maintaining the required safety margins.

Moving block is in use on Vancouver's Skytrain, London's Docklands Light Railway, New York City's BMT Canarsie Line, and London's Jubilee Line. It was supposed to be the enabling technology on the modernisation of Britain's West Coast Main Line which would allow trains to run at a higher maximum speed (140 mph), but the technology was deemed not mature enough, considering the large number of junctions on the line, and the plan was dropped. It forms part of the European Rail Traffic Management System's level-3 specification for future installation in the European Train Control System, which will (at level 3) feature moving blocks that allow trains to follow each other at exact braking distances.

Train detection

Track circuits

One of the most common ways to determine whether a section of line is occupied is by use of a track circuit. The rails at either end of each section are electrically isolated from the next section, and an electrical current is fed to both running rails at one end. A relay at the other end is connected to both rails. When the section is unoccupied, the relay coil completes an electrical circuit, and is energized. However, when a train enters the section, it short-circuits the current in the rails, and the relay is de-energized.

This method does not explicitly need to check that the entire train has left the section. If part of the train is left in the section, that part will continue to be detected by the track circuit.

This type of circuit is used to detect trains, both for the purpose of setting the signal indication and for providing various interlocking functions — for example, not permitting points to be moved when a train is standing over them. Electrical circuits are also used to *prove* that points are in the appropriate position before a signal over them may be cleared. Modern UK trains, and staff working in track circuit block areas, carry operating clips so that, in the event of a derailment fouling an adjacent track, the track circuit can be short-circuited. This places signals on that track to 'danger' and can be used to prevent a collision before the crew is able to contact a signalman.

Axle counters

An alternative method of determining the occupied status of a block is using devices located at its beginning and end that count the number of axles entering and leaving. If the same number leave the block as enter it, the block is assumed to be clear. Although axle counters can provide similar functionality to track circuits, they also exhibit a few other characteristics. In a damp environment an axle counted section can be far longer than a track circuited one. The low ballast resistance of very long track circuits reduces their sensitivity. Track circuits can automatically detect some types of track defect such as a broken rail. In the event of power restoration after a power failure, an axle counted section is left in an undetermined state until a train has passed through the affected section. When a block section has been left in an undetermined state, it may be worked under pilot working. The first train to pass through the section would typically do so at a speed no greater than 20 mph or walking pace in areas of high transition, reverse curvature and may have someone who has a good local knowledge of the area acting as the pilotman. A track circuited section will detect the presence of a train in section immediately.

Fixed signals

On most railways, physical signals are erected at the lineside to indicate to drivers whether the line ahead is occupied and to ensure that sufficient space exists between trains to allow them to stop.

Mechanical signals

Older forms of signal displayed their different aspects by their physical position. The earliest types comprised a board that was either turned face-on and fully visible to the driver, or rotated so as to be practically invisible. While this type of signal is still in use in some countries (e.g. France and Germany), by far the most common form of mechanical signal worldwide is the *semaphore signal*. This comprises a pivoted arm or blade that can be inclined at different angles. A horizontal arm is the most restrictive indication (for 'danger' or 'caution', depending on the type of signal).

To enable trains to run at night, one or more lights are usually provided at each signal. Typically this comprises a permanently-lit oil lamp with movable coloured spectacles in front that alter the colour of the light. The driver therefore had to learn one set of indications for day time viewing and another for night time viewing.

Whilst it is normal to associate the presentation of a green light with a safe condition, this was not historically the case. In the very early days of railway signalling, the first coloured lights (associated with the turned signals above) presented a white light for 'clear' and a red light for 'danger'. Green was originally used to indicate 'caution' but fell out of use when the time interval system was discontinued. A green light subsequently replaced white for 'clear', to address concerns that a broken red lens could be taken by a driver as a false 'clear' indication. It was not until scientists at Corning Glassworks perfected a shade of yellow without any tinges of green or red that yellow became the accepted colour for 'caution'.

Mechanical signals are usually remotely operated by wire from a lever in a signal box, but electrical or hydraulic operation is normally used for signals that are located too distant for manual operation.

Colour light signals

Vertical colour light signal on the Enshū Railway Line in Japan

On most modern railways, colour light signals have largely replaced mechanical ones. Colour light signals have the advantage of displaying the same aspects by night as by day, and require less maintenance than mechanical signals.

Although signals vary widely between countries, and even between railways within a given country, a typical system of aspects would be:

- Green: Proceed at line speed. Expect to find next signal displaying green or yellow.
- Yellow: Prepare to find next signal displaying red.

- Red: Stop.

On some railways, colour light signals display the same set of aspects as shown by the lights on mechanical signals during darkness.

Route signalling and speed signalling

Signalling of British origin generally conforms to the principle of *route signalling*. Most railway systems around the world, however, use what is known as *speed signalling*.

Under **route signalling**, a driver is informed which route the train will take beyond each signal (unless only one route is possible). This is achieved by a *route indicator* attached to the signal. The driver uses his route knowledge, reinforced by speed restriction signs fixed at the lineside, to drive the train at the correct speed for the route to be taken. This method has the disadvantage that the driver may be unfamiliar with a route onto which he has been diverted due to some emergency condition. Several accidents have been caused by this alone. For this reason, in the UK drivers are only allowed to drive on routes that they have been trained on and must regularly 'practice' on lesser used diversionary routes to keep their route knowledge up to date.

Under **speed signalling**, the driver is not informed which route the train will take, but the signal aspect informs him at what speed he may proceed. Speed signalling requires a far greater range of signal aspects than route signalling, but less dependence is placed on drivers' route knowledge.

Approach release

When the train is routed towards a diverging route that must be taken at a speed significantly less than the mainline speed, the driver must be given adequate prior warning.

Under 'route signalling', the aspects necessary to control speed do not exist, so a system known as *approach release* is employed. This involves holding the junction signal at a restrictive aspect (typically 'stop') in order that the signals on the approach show the correct sequence of caution aspects. The driver will brake in accordance with the caution aspect, without necessarily being aware that the diverging route has in fact been set. As the train approaches the junction signal, its aspect may clear to whatever aspect the current track occupancy ahead will permit. Where the turnout speed is the same, or nearly the same, as the mainline speed, approach release is unnecessary.

With speed signalling, the signals approaching the divergence will display aspects appropriate to control the trains speed, so no 'approach release' is required.

Safety systems

The consequence of a driver/engineer failing to respond to a signal's indication can be disastrous. As a result, various auxiliary safety systems have been devised. Any such system will necessitate the installation of trainborne equipment to some degree. Some systems only intervene in the event of a signal being passed at danger. Others include audible and/or visual indications inside the driver's cab to supplement the lineside signals. Automatic brake application occurs if the driver should fail to acknowledge a warning. Some systems act intermittently (at each signal), but the most sophisticated systems provide continuous supervision.

In-cab safety systems are of great benefit during fog, when poor visibility would otherwise require that restrictive measures be put in place.

Cab signalling

Example of cab signal

Cab signalling is a system that communicates track status information to the train cab (driving position), where the engine driver can see the information. The simplest systems display the trackside signal aspect, while more sophisticated systems also display allowable speed and dynamic information about the track ahead. In modern systems, a train protection system is usually overlaid on top of the cab signalling system to warn the driver of dangerous conditions, and to automatically apply the brakes and bring the train to a stop if the driver ignores the dangerous condition. Cab signalling systems range from simple coded track circuits, to transponders that communicate with the cab, and communication-based train control systems.

Interlocking

In the early days of the railways, signalmen were responsible for ensuring any points (US: switches) were set correctly before allowing a train to proceed. Mistakes were made which led to accidents, sometimes with fatalities. The concept of the interlocking of points, signals and other appliances was introduced to improve safety. This prevents a signalman from operating appliances in an unsafe sequence, such as setting a signal to 'clear' while one or more sets of points in the route ahead of the signal are improperly set.

Early interlocking systems used mechanical devices both to operate the signalling appliances and to ensure their safe operation. Beginning around the 1930s, electrical relay interlockings were used. Since the late 1980s, new interlocking systems have tended to be of the electronic variety.

Operating rules

Operating rules, policies and procedures are used by railroads to enhance safety. Specific operating rules may differ from country to country and even from railroad to railroad within the same country.

Australian operating rules

In Australia, operating rules are called Safeworking.

North American operating rules

In North America and especially the US, operating rules are called *method of operation*. There are five main sets of operating rules in North America:

- Canadian Rail Operating Rules (CROR), used by most Canadian railroads
- General Code of Operating Rules (GCOR), used by many Class I railroads, Class II railroads, and many Short-line railroads
- Northeast Operating Rules Advisory Committee (NORAC), used by many railroads in the Northeast US
- Class I Norfolk Southern uses a unique set of operating rules.
- Class I CSX Transportation uses a unique set of operating rules.

UK operating rules

In the UK, operating rules are called *method of working*. It is commonly known as the "Rule-book" by railway employees. It is controlled by the Rail Safety and Standards Board (RSSB), which is independent from Network Rail or any other Train/Freight Operating Company. Most heritage railways operate to a simplified variant of a British Railways rule book.

Italian operating rules

In Italy, railway signalling is described in a particular instruction called *Regolamento Segnali* (*Signal Regulation*).

Chapter- 5

Railroad Tie

While wooden ties dominate North American railways, concrete is widely used in other parts of the world.

A **railway sleeper**, **railroad tie** (US usage), or **railway tie** (Canadian usage) is a rectangular object used as a base for railroad tracks. Ties are members generally laid transverse to the rails, on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade, and to hold the rails to the correct gauge.

Traditionally, ties have been made of wood, but concrete is now widely used. Steel ties and plastic composite ties are currently used as well, although far less than wood or concrete ties. As of January 2008, the approximate market share, in North America, for traditional and wood ties was 91.5%, whereas the approximate combined market share for (all) concrete, steel, azobe (exotic hardwood) and plastic composite ties was 8.5%.

Ties are normally laid on top of track ballast, which supports and holds them in place, and provides drainage and flexibility. Heavy crushed stone is the normal material for the ballast, but on lines with lower speeds and weight, sand, gravel, and even ash from the fires of coal-fired steam locomotives have been used.

Approximately 3000 ties are used per mile of railroad track. Ties/sleepers are set much closer together in the USA, where rails are traditionally fastened to the ties by a railroad spike rather than the substantial iron/steel chairs used in Europe.

Types

Stone block

The type of sleeper used on the predecessors of the first true railway (Liverpool and Manchester Railway) consisted of a pair of stone blocks laid into the ground, with the chairs holding the rails fixed to those blocks. One advantage of this method of construction was that it allowed horses to tread the middle path without the risk of tripping. In railway use with ever heavier locomotives, it was found that it was hard to maintain the correct gauge. The stone blocks were in any case unsuitable on soft ground, where something like timber sleepers had to be used. Two centuries later, stone sleepers would reappear in the form of slab track.

Wooden

A variant fastening of rails to wooden ties

Timber ties are usually of a variety of hardwoods, oak being a popular material. Some lines use softwoods, sometimes due to material necessity; while they have the advantage of accepting treatment more readily, they are more susceptible to wear. They are often heavily creosoted. Creosote treating can reduce insect infestation and rot. For more information on creosote and the environment the Creosote Council maintains a comprehensive. Less often, ties are treated with other preservatives. New boron based wood preserving technology is being employed by major US railroads in a dual treatment process in order to extend the life of wood ties in wet areas. Some timbers (such as sal) are durable enough that they can be used untreated.

Problems with wood ties include rot, splitting, insect infestation, plate-cutting (abrasive damage to the tie caused by lateral motion of the tie plate) and spike-pull (where the spike is gradually worked out and loosened from the tie). For more information on wood ties the Railway.

Concrete

Interest in concrete railroad ties was revived due to material shortages after World War II.

Concrete ties have become more common mainly due to greater economy and better support of the rails under high speed and heavy traffic than wooden ties. In early railway history, wood was the only material used for making ties in Europe. Even in those days, occasional shortages and increasing cost of wood posed problems. This induced engineers to seek alternatives to wooden ties. As concrete technology developed in the 19th century, concrete established its place as a versatile building material and could be adapted to meet the requirements of railway industry.

In 1877, M. Monnier, a French gardener, suggested that concrete could be used for making ties for railway track. Monnier designed a tie and obtained a patent for it, but it was not successful. Designs were further developed and the railways of Austria and Italy used the first concrete ties around the turn of the 20th century. This was closely followed by other European railways.

Major progress could not be achieved until World War II, when the timbers used for ties were extremely scarce due to material shortages. Due to research carried out on French and other European railways, the modern concrete tie was developed. Heavier rail sections and long welded rails were also being produced, requiring higher-quality ties.

These conditions spurred the development of concrete ties in France, Germany and Britain, where the technology was perfected.

Steel

Steel Sleepers

In past times steel ties (sleepers) have suffered from poor design and increased traffic loads over their normal long service life. These aged and often obsolete designs limited load and speed capacity but can still, to this day, be found in many locations globally and performing adequately despite decades of service. There are great numbers of steel ties with over 50 years of service and in some cases they can and have been rehabilitated and continue to perform well.

Modern day steel ties, particularly in North America where track loads are greater than in other continents, are not the steel ties of old. Newer steel ties handle heavy loads, have proven performance in signalized track, and handle adverse track conditions. Of high importance to railroad companies is the fact that steel ties are more economical to install in new construction than creosote treated wood ties and concrete ties. Steel ties are 100% recyclable and require up to 60% less ballast than concrete ties and up to 45% less than wood ties.

Steel ties are utilized in nearly all sectors of the worldwide railroad systems including Heavy-Haul, Class 1's, Regional, Shortlines, Mining, Electrified Passenger Lines (OHLE) and all manner of industries.

Notably, steel ties (bearers) have proven themselves over the last few decades to be advantageous in turnouts (switches) and provide the solution to the ever growing problem of long timber ties for such use.

The steel ties' cost benefits together with the ability to hold rail gauge, lower long-term maintenance costs, increase the life of other track components, reduce derailments and meet ever growing and stricter environment standards provide railroad companies with savings and capital to redirect to other areas of maintenance-of-way and business projects.

Plastic/Rubber Composite

In more recent times, a number of companies are selling composite railroad ties manufactured from recycled plastic resins, and recycled rubber. These ties are said to outlast the classic wooden tie, and are impervious to rot and insect attack, and can be modified to provide additional lateral stability while otherwise exhibiting properties similar to their wooden counterparts in terms of damping impact loads and sound absorption.

Aside from the environmental benefits of using recycled material, plastic ties usually replace hardwood ties soaked in creosote, the latter being a toxic chemical, and are themselves recyclable. Plastic/Rubber composite ties are used in other rail applications such as underground mining operations.

Non conventional sleeper forms

Y shaped sleepers

Y sleeper track next to conventional track

An unusual form of sleeper is the Y shaped sleeper. First developed in 1983, Y steel sleepers have advantages and disadvantages compared to conventional steel sleepers. Compared to conventional sleepers the volume of ballast required is reduced due to the load spreading characteristics of the Y-sleeper. Noise levels are high but the resistance to track movement is very good. For curves the three point contact of a Y steel sleeper means that an exact geometric fit cannot be observed with a fixed attachment point.

The cross section of the sleepers is an I-beam.

As of 2006 less than 1000 km of Y-sleeper track had been built of which approximately ninety percent is in Germany.

Twin sleepers

The ZSX Twin sleeper is manufacturer by Leonhard Moll Betonwerke GmbH & Co KG and is a pair of two pre-stressed concrete sleepers longitudinally connected by four steel rods. The design is said to be suitable for regions with sharp curves, track subject to temperature stress such as that operated by trains with eddy brakes, bridges and as transition track between traditional track and slab track or bridges.

Wide sleepers

Concrete monoblock sleepers have also been produced in a wider form (e.g. 57 cm (22 in)) such that there is no ballast between the sleepers; this wide sleeper increase lateral resistance and reduces ballast pressure. The system has been used in Germany where wide sleepers have also been used in conjunction with the GETRAC A3 ballastless track systems.

Bi-block sleepers

Bi-block (or twinblock) sleepers consist of two concrete rail supports joined by steel. Advantages include increase lateral resistance and lower weight than monobloc concrete sleepers, as well as elimination of damage from torsional forces on the sleeper centre due the more flexible steel connections. This sleeper type is in common use in France, and are used on the high-speed TGV lines. Bi-block sleepers are also used in ballastless track systems.

Frame sleepers

Frame sleepers (German: *Rahmenschwelle*) comprise both lateral and longitudinal members in a single monolithic concrete casting. This system is in use in Austria; in the Austrian system the track is fastened at the four corners of the frame, and is also supported midway along the frame. Adjacent frame sleepers are butted close to each other. Advantages of this system over conventional cross tie sleepers are reduced ballast pressure (up to half), increased lateral resistance, and increased support of track. In addition, construction methods used for this type of track are similar to those used for conventional track.

Ladder track

In ladder track the "sleepers" are laid parallel to the rails and are several meters in length. The structure is similar to Brunel's baulk track; these longitudinal sleepers can be used with ballast, or with elastomer supports on a solid non-ballasted support.

Fastening rails to railroad ties

Various methods exist for fixing the rail to the sleeper (railroad tie). Historically spikes gave way to cast iron chairs fixed to the sleeper, more recently springs (such as Pandrol clips) are used to fix the rail to the sleeper chair.

Other uses

Wooden sleepers recycled as sculptures at Northfield station

In recent years, wooden railroad ties have also become popular for gardening and landscaping, both in creating retaining walls and raised-bed gardens, and sometimes for building steps as well. Traditionally, the ties sold for this purpose are decommissioned ties taken from rail lines when replaced with new ties, and their lifespan is often limited due to rot. Some entrepreneurs sell new ties. However, due to the presence of wood preservatives such as coal tar, creosote or salts of heavy metals, railroad ties introduce an extra element of soil pollution into gardens and are avoided by many property owners. In the UK, new oak beams of the same size as standard railroad ties, but not treated with dangerous chemicals, are now available specifically for garden construction. They are about twice the price of the recycled product. In some places, railroad ties have been used in the construction of homes, particularly among those with lower incomes, especially those residing near railroad tracks, including railroad employees. They are also used as cribbing for docks and boathouses.

The Spanish artist Agustín Ibarrola has used recycled ties from RENFE in several projects.

In Germany, use of wooden railroad ties as building material (namely in gardens, houses and in all places where regular contact to human skin would be likely, in all areas frequented by children and in all areas associated with the production or handling of food in any way) has been prohibited by law since 1991 because they pose a significant risk to health and environment. From 1991 to 2002, this was regulated by the *Teerölverordnung* (Carbolineum By-law), and since 2002 has been regulated by the *Chemikalien-Verbotsverordnung* (Chemicals Prohibition By-law), §1 and Annex, Parts 10 and 17.

Ballastless track

Slab track, System "Rheda 2000", prior to concrete pouring.

Slab track, System "FF Bögl" on Nuremberg-Munich high-speed rail line

slab track at St Pancras station

First such tracks were mountain railways (like Pilatus railway, built in 1889) with rails attached directly to the mountain rock. From the late 1960s onwards, German, British, Swiss and Japanese railroads experimented with alternatives to the traditional railway tie in search of solutions with higher accuracy and longevity, and lowered maintenance costs.

This gave rise to the ballastless railway track, especially in tunnels, high-speed rail lines and on lines with high train frequency, which have high stress imposed on trackage. Paved concrete track has the rail fastened directly to a concrete slab, about half a meter thick, without ties. A similar but less expensive alternative is to accurately position concrete ties and then pour a concrete slab between and around them; this method is called "cast-in precast sleeper track".

These systems offer the advantage of superior stability and almost complete absence of deformation. Ballastless track systems incur significantly lower maintenance costs compared to ballasted track. Due to the absence of any ballast, damage by flying ballast is eliminated, something that occurs at speeds in excess of 250 km/h (150 mph). It is also useful for existing railroad tunnels; as slab track is of shallower construction than ballasted track, it may provide the extra overhead clearances necessary for converting a line to overhead electrification, or for the passage of larger trains.

Building a slab track is more expensive than building traditional ballasted track, which has slowed its introduction outside of high-speed rail lines. These layouts are not easy to modify after they are installed, and the curing time of the concrete makes it difficult to convert an existing, busy railway line to a ballastless setup.

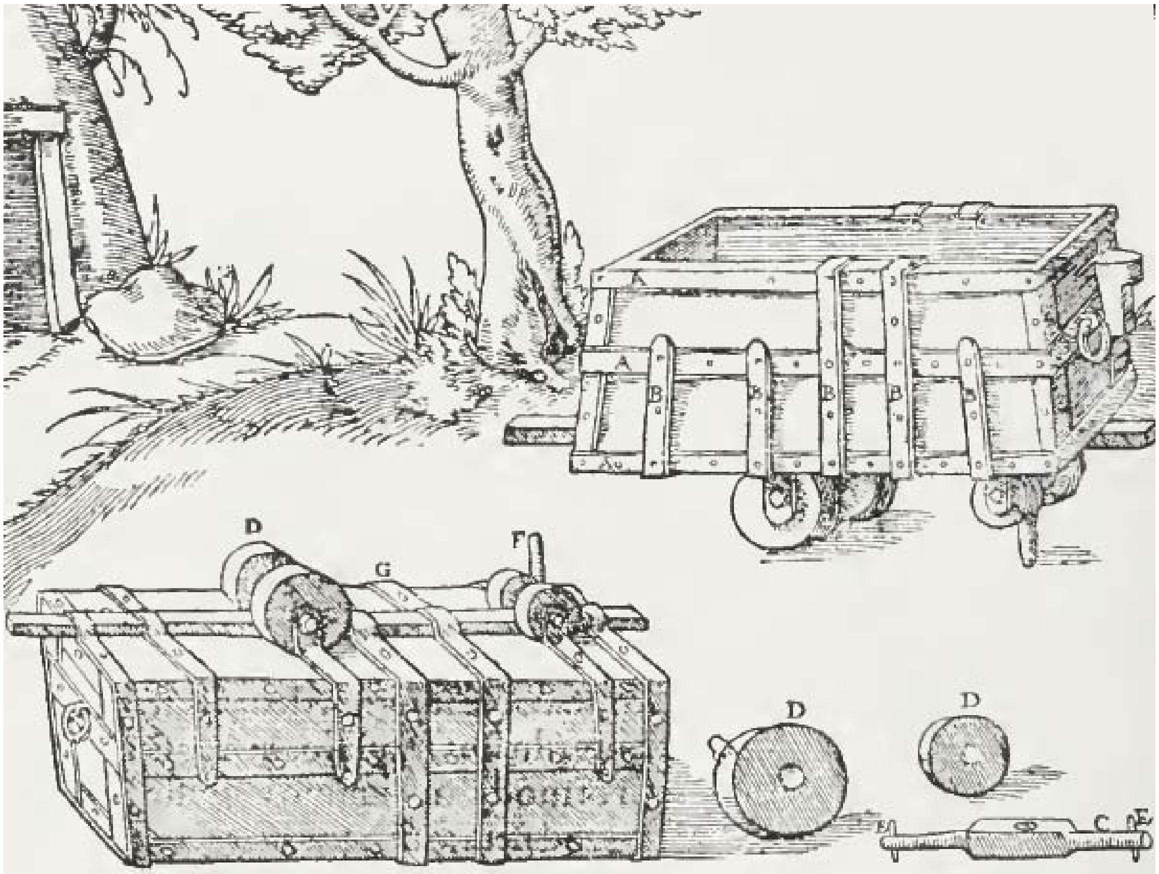
Slab track can also be significantly louder and cause more vibration than traditional ballasted track. While this is in some part attributable to slab track's decreased sound absorption qualities, a more significant factor is that slab track typically uses softer rail fasteners to provide vertical compliance similar to ballasted track; these can lead to more noise, as they permit the rail to vibrate over a greater length.

Where it is critical to reduce noise and vibration, the concrete slab can be supported upon soft resilient bearings. This configuration, called "floating slab track", is expensive and requires more depth or height, but can reduce noise and vibration by around 80%. Alternatively, the rail can be supported along its length by an elastic material; when combined with a smaller rail section, this can provide a significant noise reduction over traditional ballasted track.

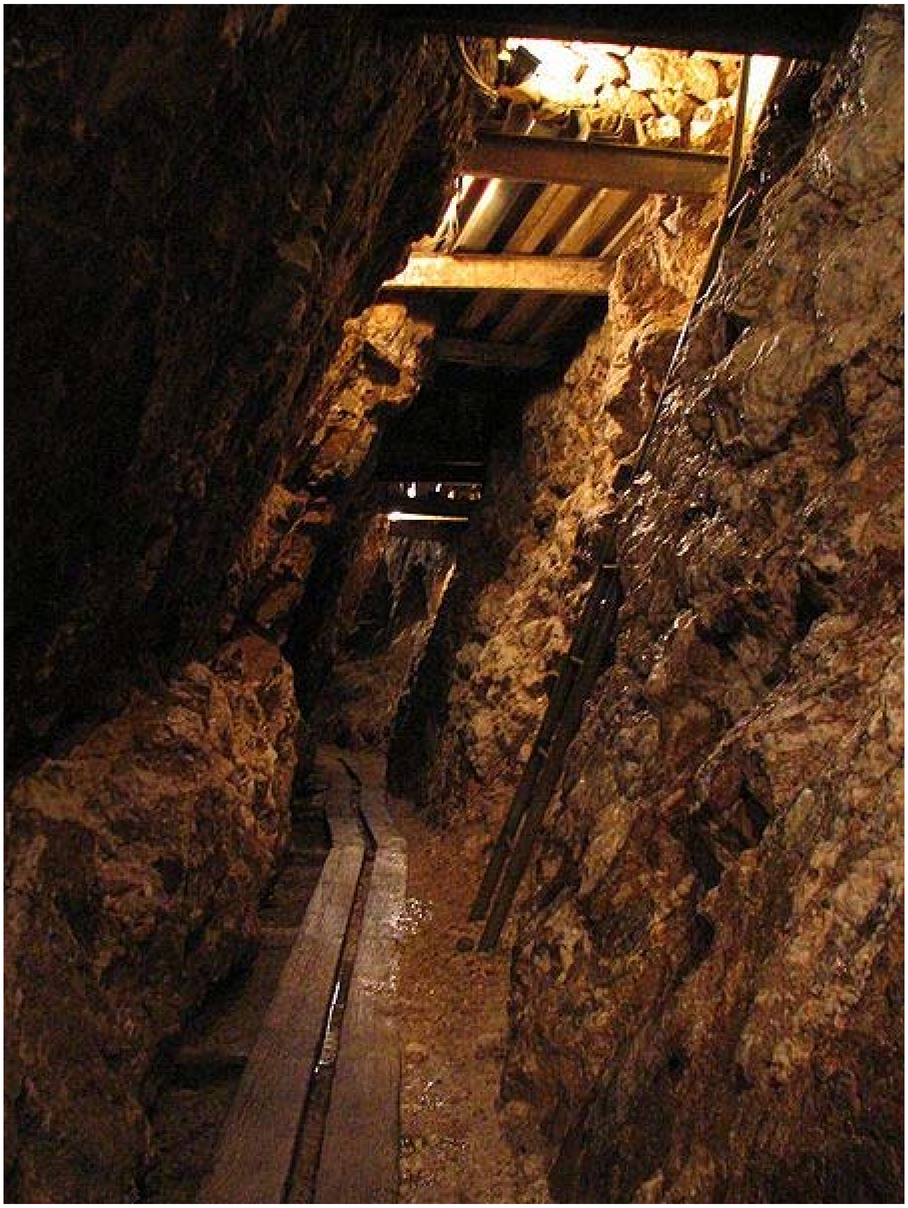
Chapter- 6

Permanent Way

Section of timber track from a 16th-century gold mine in Siebenbürgen. The wagons were guided by the pronounced flange on the wooden wheels, and the narrow gauge of 48 cm allowed the points to be altered by swinging the single switch rail.



Contemporary illustration of guided truck used in 16th-century mines in Germany



Reconstruction of flat wooden track for transporting silver ore; guidance was by a vertical pin running between the timbers

The **permanent way** is the elements of railway lines: generally the pairs of rails typically laid on the sleepers ("ties" in American parlance) embedded in ballast, intended to carry the ordinary trains of a railway. It is described as permanent way because in the earlier days of railway construction, contractors often laid a temporary track to transport spoil and materials about the site; when this work was substantially completed, the temporary track was taken up and the permanent way installed.

Wooden tracked systems

Plank ways

The earliest use of a railway track seems to have been in connection with mining in Germany in the 12th century. Mine passageways were usually wet and muddy, and moving barrows of ore along them was extremely difficult. Improvements were made by laying timber planks so that wheeled containers could be dragged along by manpower. By the 16th century the difficulty of keeping the wagon running straight had been solved by having a pin going into a gap between the planks. Georg Agricola describes box-shaped carts, called "dogs", about half as large again as a wheelbarrow, fitted with a blunt vertical pin and wooden rollers running on iron axles. An Elizabethan era example of this has been discovered at Silvergill in Cumbria, England, and they were probably also in use in the nearby Mines Royal of Grasmere, Newlands and Caldbeck. Where space permitted round-section wooden tracks to take trucks with flanged wheels were installed: a painting from 1544 by the Flemish artist Lucas Gassel shows a coppermine with rails of this type emerging from an adit.

Edged rails

A different system was developed in England, probably in the late 16th century near Broseley for conveying coal from mines, sometimes drift mines down the side of the Severn Gorge to the river Severn. This, probably a rope-hauled incline plane, had existed 'long before' 1605. This probably preceded the Wollaton Wagonway of 1604, which has hitherto been regarded as the first.

In Shropshire, the gauge was usually narrow, to enable the wagons to be taken underground in drift mines. However by far the greatest number of wagonways were near Newcastle upon Tyne, where a single wagon was hauled by a horse on a wagonway of about the modern standard gauge. These took coal from the pithead down to a staithe where the coal was what was loaded into river boats called keels.

Wear of the timber rails was a problem. They could be renewed by turning them over, but had to be regularly replaced. Sometimes, the rail was made in two parts, so that the top portion could easily be replaced when worn out. The rails were held together by sleepers, covered with ballast to provide a surface for the horse to walk on.

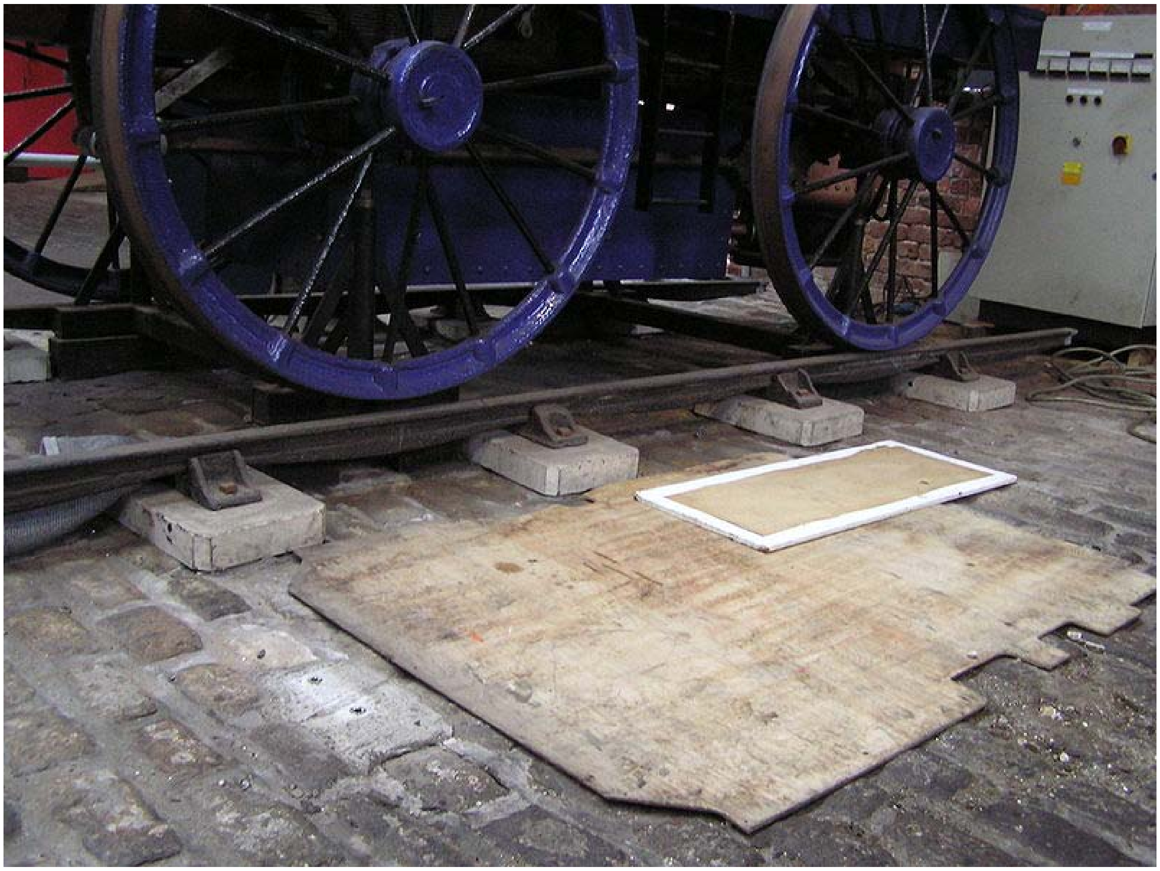
Early iron rails

In 1767, Ketley ironworks began producing cast iron plates, which were fixed to the top of wooden rails with nails, to provide a more durable running surface. This construct was known as **strap rail** (or **strap-iron rail**) and was widely used on pre-steam railways in the United States. Although relatively cheap and quick to build, they were unsuited to heavy loads and required 'excessive maintenance'. Train wheels rolling over the spikes loosened them, allowing the rail to break free and curve upwards sufficiently that a car wheel could get beneath it and force the end of the rail up through the floor of the car, writhing and twisting, endangering passengers. These broken rails became known as "snake heads".

When wrought iron became available, wrought iron plates provided an even more durable surface. The rails had projecting lugs (or ears) with a hole to enable them to be fixed to the underlying wooden rail.

Iron plateways

Section of L-shaped plate rails



A long fish bellied rail supported over several chairs

An alternative, developed by John Curr of Sheffield, the manager of the Duke of Norfolk's colliery there. This had a L-shaped rail, so that the flange was on the rail rather than on the wheel. This was also used by Benjamin Outram of Butterley Ironworks and William Jessop (who became a partner in them in 1790). These were used to transport goods for relatively short distances down to canals, though Curr's ran between the manor colliery and Sheffield town. These rails are referred to as plates, and the railway is sometimes called a plateway. The term "platelayer" also derives from this origin. In theory, the unflanged wheels could have been used on ordinary highways, but in practice this was probably rarely done, because the wagon wheels were so narrow that they would have dug into the road surface.

The system found wide adoption in Britain. Often, they plates were mounted on stone blocks, and sometimes without sleepers, but that was liable to cause the rails to spread apart, increasing the gauge. Railways of this kind were widely used in south Wales. In particular to transport limestone down to ironworks, and then iron from the ironworks to a canal, sometimes several miles away, to take the products to market. The rails were at first made of cast iron in lengths of typically three feet, spanning between stone blocks.

The stone blocks had been assumed to be permanent, but experience quickly showed that they settled and gradually moved under traffic, creating chaotic track geometry and causing derailments. Another problem was that the running surface was liable to become obstructed by stones, displaced from the ballast. An alternative was to use an iron tie bar to keep the rails to the proper gauge, incoprating a shoe in which the rail was fixed.

An example of this was the Penydarren or Merthyr tramway. This was used by Richard Trevithick to demonstrate a pioneer locomotive in 1804, using one of his high pressure steam engines, but the engine was so heavy that it broke many of the rails.

Early edge rails

Cast iron edge rails were used by Thomas Dadford junior when building the Beaufort and Blaenavon lines to the Monmouthshire canal in 1793. These were rectangular, 2½ inches in width with a depth of 3 inches and 4 feet in length, and required flanges on the wagon wheels. The same year Benjamin Outram used edge rails on the Cromford Canal. T-shaped beams were used by William Jessop on the Loughborough-Nanpanton line in 1794, and his sons used I-shaped beams in 1813–15 on a railway from Grantham to Belvoir Castle. Samples of these rails are held in the Science Museum, London.

A short-lived alternative was the *fish-bellied* profile, first used by Thomas Barnes at Walker Colliery, near Newcastle in 1798, which enabled rails to have a longer span between blocks. These were edge rails, perhaps up to six feet long. These were still made of cast iron.

Modern edge rails

The breakthrough came when John Birkinshaw of Bedlington Ironworks in Northumberland developed rolled wrought iron rails in 1820 in 15 feet (4.6 m) lengths, as used for the Stockton and Darlington Railway. This was strong enough to bear the weight of a locomotive and of a train of wagons (or carriages) pulled by it. This marks the beginning of the modern rail era.

This system was instantly successful, although some false starts took place. Some early rails were made in a T cross section, but the lack of metal at the foot limited the bending strength of the rail, which has to act as a beam between supports.

As metal technologies improved, these wrought iron rails were made progressively somewhat longer, and with a heavier, and therefore stronger, cross-section. By providing more metal in the foot of the rail, a stronger beam was created, achieving much better strength and stiffness, and a section was created similar to the bullhead rail section still visible today. This was expensive, however, and the promoters of early railways struggled with decisions about the appropriate weight (and therefore strength, and cost) of their rails.

At first the rail section was almost symmetrical top-to-bottom, and was described as a double-headed rail. The intention was to invert the rail after the top surface had become worn, but rails tend to develop chair gall, an attrition of the rail where it is supported in the chairs, and this would have made running on the former bottom surface impossibly noisy and irregular. It was obviously better to provide the extra metal on the top surface and gain extra wear there without the need to invert the rail at half life.

Many railways preferred a flat bottom rail section, where the rails could be laid directly on the ties (sleepers), representing a marked cost saving. Indenting of the sleeper was the problem, and where the traffic was heavy, it became necessary to provide a sole plate under the rails to spread the load on the tie, partly vitiating the cost saving. However in main line situations, this form found almost universal adoption in North America and Australia, and in much of continental Europe. The UK persisted with bullhead rail in main line use, with widespread introduction of flat-bottom rail only starting in about 1947.

Steel rails

The first rails made from steel were made by Robert Forester Mushet in 1857, and were laid experimentally at Derby railway station on the Midland Railway in England. The rails proved far more durable than the iron rails they replaced and remained in use until 1873. Steel being a much stronger material, gradually replaced iron over the following years,

Associated features

Ties (sleepers)

Timber sleepers, that is transverse beams supporting the two rails that form the track, replaced the individual stone blocks formerly used. This system has the major advantage that maintenance adjustments to the track geometry did not disrupt the all-important track gauge. The alignment of the track could be adjusted by sluing it bodily, without loss of gauge. Softwood was widely used, but its life was limited if it was not treated with preservative, and some railways set up creosoting plants for the purpose. Creosote-treated hardwood is now widely used in North America and elsewhere.

By now we had relatively long (perhaps 20 ft) wrought iron rails supported in chairs on timber cross-sleepers – a track form recognisable today in older track.

Steel sleepers were tried as an alternative to timber; Acworth writing in 1889 describes the production of steel sleepers on the London & North Western Railway, and there is an illustration showing rolled channel section (shallow upturned "U" shapes) with no shaped ends, and with three-part forged chairs riveted direct. However steel sleepers seem not to have enjoyed widespread adoption until about 1995. Their dominant usage now is for life extension of existing track on secondary routes. They have a significant advantage on weak formations and poor ballast conditions, as the bearing area is at a high level, immediately under the rail seat.

Rail fastenings

The early cast iron rails of the 18th century and before used integral fixings for nailing or bolting to the railroad ties. Strap rails introduced in the late 18th century, of cast and later rolled iron were nailed to wooden supports via countersunk holes in the metal. The introduction of rolled rail profiles in the 1820s such as the *single flanged T parallel rail* and later *double flanged T parallel rail* required the use of chairs, keys to hold the rail, and bolts or spikes to fix the chair. The *flat bottomed rail* invented by Robert L. Stevens in 1830 was initially spiked directly to wooden sleepers, later tie plates were used to spread the load and also keep the rail in gauge with inbuilt shoulders in the plate. Outside North America a wide variety of spring based fastening systems were later introduced in combination with baseplates and flat bottomed rail, these are now ubiquitous on main line high speed railways.

Ballast

The track was originally laid direct on the ground, but this quickly proved unsatisfactory and some form of ballast was essential, to spread the load and to retain the track in its proper position. The natural ground is rarely strong enough to accept the loading from locomotives without excessive settlement, and a layer of ballast under the sleeper reduces the bearing pressure on the ground. The ballast surrounding the sleepers also tends to keep them in place and resists displacement.

The ballast was usually some locally available mineral product, such as gravel or reject material from coal and iron mining activities. The Great North of Scotland Railway used river gravel – round pebbles – which must have made track maintenance a challenge. In later years the ash from steam engines was used (as it would otherwise have incurred a cost to dispose of it) and slag (a by-product of steel making).

Gauges

Early track gauges

The early railways were almost exclusively local concerns involved with conveying minerals to some waterway; for them the gauge of the track was adopted to suit the wagons intended to be used, and it was typically in the range 4 ft to 4 ft 8½ in, and at first there was no idea of the need for any conformity with the gauge of other lines. When the first public railways developed, George Stephenson's skilful innovation meant that his railways were dominant and the 4 ft 8 ½ in (1,435 mm) gauge he used was therefore the most widespread. As early notions of linking up different railway systems evolved, this gauge secured general adoption. It is more or less an accident of history that this gauge – which suited the wagons already in use at the colliery where George Stephenson had been an engine man – became the British standard gauge: it was exported to most of Europe and North America.

Reference is sometimes made to the "gauge" of ruts in stone roadways at ancient sites such as Pompeii, and these are often asserted to be about the same as Stephenson's gauge. Of course the ruts were made by the wheels of carts, and the carts were of a sensible size for horse drawn carts prior to the industrial era, pretty much the same as the size of the pre-railway carts at the colliery where Stephenson worked: that is the only connection.

Broad gauge track

When Isambard Kingdom Brunel conceived the Great Western Railway (GWR), he sought an improved design for his railway track and accepted none of the previous received wisdom without challenge. The 4 ft 8½in gauge had been fine for small mineral trucks on a horse-drawn tramway, but he wanted something more stable for his high speed railway. The large diameter wheels used in stage coaches gave better ride quality over rough ground, and Brunel originally intended to have his passenger carriages carried in the same way – on large diameter wheels placed outside the bodies of the carriages. To achieve this he needed a wider track gauge and he settled on the famous 7 ft broad gauge. (It was later eased to 7 ft 0¼in). When the time came to build the passenger carriages, they were designed conventionally with smaller wheels under the bodies after all, but with a seven-foot track gauge the bodies could be much wider than on the standard gauge. His original intention to have the wheels outside the width of the bodies was abandoned.

Brunel also looked at novel track forms, and decided to use a continuously supported rail. Using longitudinal timbers under each rail, he achieved a smoother profile while not requiring such a strong rail section, and he used a shallow bridge rail for the purpose. The wider, flat foot also meant that the chair needed by the bullhead section could be dispensed with. The longitudinal timbers needed to be kept at the proper spacing to retain the gauge correctly, and Brunel achieved this by using timber transoms – transverse spacers – and iron tie-bars. The whole assembly was referred to as the baulk road – railwaymen usually call their track a road. Initially Brunel had the track tied down to timber piles to prevent lateral movement and bounce, but he had overlooked the fact that the made ground on which his track was supported between piles would settle. The piles remained stable and the ground between them settled so that his track soon had an unpleasant undulation, and he had to have the piles severed, so that the track could settle more or less uniformly. A variant of the baulk road can still be seen today on many older under-bridges where no ballast was provided. The design varies considerably, but in many cases longitudinal timbers are supported directly on the cross-girders, with transoms and tiebars to retain the gauge, but of course with modern rails and base-plates or chairs. The longitudinal sleepers are somewhat similar to modern-day Ladder track.

The group of railways that had Brunel as their engineer were successful and the broad gauge track spread throughout the west of England, South Wales, and the West Midlands. But as the British railway network spread, the incompatibility of the two systems became a serious blockage, as a wagon could not be sent from one system to the other without transshipping the goods by hand. A Gauge Commission was appointed to determine national policy. The Broad Gauge was technically superior but conversion of the standard gauge routes to broad would have meant reconstructing every tunnel, bridge and station platform, whereas universal adoption of the standard gauge only required the progressive conversion of the track itself. The broad gauge was doomed, and no further independent broad gauge lines could be built.

The existing broad gauge routes could continue, but as they had no development potential it was only a matter of time before they were eventually converted to standard. In the meantime an extensive mileage of mixed gauge track was installed, where each line had three rails to accommodate trains of either gauge. There were some instances of *mixed gauge trains* being run, where wagons of each gauge were run in a single train. The legacy of the broad gauge can still be seen where there seems to be an unnecessarily wide space between station platforms.

Twentieth century and beyond

1900 to 1945

At the beginning of the twentieth century, the form of British track had converged on the use of wrought iron bullhead rails supported in cast iron chairs on timber sleepers, laid in some form of ballast. In North America, the standard was T-rails and tie plates fastened to timber crossties with cut spikes. Many railways were using very light rails and as locomotive weights and speeds increased these were inadequate, so that on main lines the rails in use were made progressively heavier (and stronger). Metallurgical processes improved and better rails including some steel rails came into use. From a maintenance point of view the rail joints were the source of most of the work, and as steel-making techniques improved it became possible to roll steel rails of increased length – reducing the number of joints per mile. The standard length became 30 ft (9 144mm), then 45 ft ((13 716mm) and finally 60 ft (18 288mm) rails became the norm. For main line use the standard rail section became the 95BH section, weighing 95 lb per yard (47.13 kg per metre). For secondary routes a lighter 85BH (42.16 kg per metre) section was used.

Flat bottom rails were still seen as undesirable for British main line railway use, despite their successful use in North America, although some lightly operated British railways used them, generally spiked direct to the sleepers. Under heavy usage they indent the sleepers severely and the incremental cost of a base-plate appeared at this early date, to rule the flat bottom section out.

Timber sleepers were expensive and not durable, and the railways' engineers had strong – and conflicting – views about the best wood species and the best preservative treatments. The railways moved towards standardisation on a softwood sleeper preserved by pressure injection of creosote, measuring 8 ft 6in (2 591 mm) long by 10in (254mm) by 5in (127mm). Chairs were secured to the sleepers by trenails (steel spikes driven through a timber sleeve) or three chair-screws on first class routes. The GWR alone among the main line railways kept to its own standard, the 00 rail at 97½ lb/yd (48.365 kg per metre), and with two fangbolts securing each chair to the sleeper, with the head of the bolt under the sleeper and a nut above the chair—more secure but much more difficult to adjust.

Some experiments were made before 1945 with reinforced concrete sleepers, in most cases with bullhead chairs mounted on them. This was in response to the very high price of the best (most durable) timber, but reinforced concrete sleepers were never successful in main line use. Concrete pots were also used in sidings; they are sometimes called twin-block sleepers, and consisted of two concrete blocks each mounted with a chair, and an angle iron connecting them and retaining the gauge.

Post-war developments

At the end of the war in 1945, the British railways were worn out, having been patched up following war damage without the availability of much new material. The country was economically in a weak situation also, and for nearly a decade after the war, materials – especially steel and timber – were in very short supply. Labour too was seriously restricted in availability.

The railway companies became persuaded that the traditional bullhead forms of track needed revision, and after some experimentation a new flat bottom rail format was adopted. The British Standard sections were unsuitable and a new profile, a 109 lb/yard rail, was made the new standard. In 60 ft lengths, laid on steel baseplates on softwood sleepers, it was to be the universal standard. The fastenings were to be of a resilient steel type, and for secondary routes a 98 lb/yd rail was adopted. Regional variations still persisted, and hardwood sleepers and Mills clip fastenings were favoured on the Eastern Region, for example.

The new designs were successful, but they introduced many challenges, especially as the availability of experienced track maintenance staff became acutely difficult, and poorly maintained flat bottom track seemed more difficult to keep in good order than poorly maintained bullhead track. The greater stiffness of flat-bottom was an advantage but it tended to straighten out between the joints on curves; and flat bottom's rigidity led to high vertical impact forces at badly maintained joints and this resulted in high volumes of fatigue fractures at the joints. Moreover the elastic rail fastenings had little resistance to rail creep – the propensity of the rails to move gradually in the direction of traffic, and the workload of pulling back the rails to regulate the joints was surprisingly high.

Long welded rails

Much of the work of maintaining the track was at the joints, especially as the stiff rails became dipped, and the joint sleepers took a hammering. Pre-war experiments with long welded rail lengths were built upon, and in the years from 1960 long rail lengths were installed, at first on hardwood sleepers but soon on concrete sleepers. In this pioneering stage some catastrophic mistakes in detailed design were made, but from about 1968 continuous welded rail became a reliable standard for universal installation on main and secondary routes. The form adopted used pre-stressed concrete sleepers and a 110A rail section – a slight improvement on the 109 rails previously used – the A was to distinguish it from the British Standard 110 lb/yd rail section, which was unsuitable. Rail fastenings eventually converged onto a proprietary spring clip made by the Pandrol company which was the exclusive form of fastening in Britain for about 30 years.

The welded track was to be laid on six to twelve inches of crushed stone ballast, although this was not always achieved, and the bearing capacity of the formation was not always taken into account, leading to some spectacular formation failures.

A further enhancement to the rail profile produced the 113A section which was the universal standard until about 1998; detail improvements to the sleepers and ballast profile completed the picture and the general form of the track had stabilised. This format is now in place over 99% of the first-class main lines in Britain.

Track gauge

As stated, the general track gauge in Britain was 4 ft 8 ½ in (1,435 mm). In the later 1950s general track maintenance standards deteriorated rapidly due to manning difficulties, and freight train speeds increased on some routes. Freight trains consisted almost entirely of short wheelbase (10 ft) four-wheeled wagons carried on a very stiff elliptical leaf spring suspension, and these wagons showed an alarmingly rapid rate of increase of derailment events. Anyone standing at the lineside could watch a freight train pass at speed and observe several of the wagons weaving and swaying alarmingly even on good track, and derailment occurred when any poor track was encountered.

The dynamic behaviour of the wagons was the problem, but the solution adopted was to reduce the permitted speed of the wagons to 45 mph, and to reduce the track gauge by one-eighth of an inch, to 4 ft 8⅜in (1432mm) for new installations of continuously welded track on concrete sleepers. Of course the long life cycle of the track meant that this conversion process would take 30 years or more to complete. However the basis of the gauge narrowing was mistaken. The idea seems to have been to reduce the free space for lateral movement of the wagons, so that they would be "contained" to run in a straight line. In fact railway vehicles are not contained by the flanges of the wheels except in *very* sharp curves, and in normal running the steering effect due to the conicity of the wheels is dominant. In reducing the track gauge the effective conicity is increased – worsened – and the tendency of the wagons to yaw and roll was increased. Many derailments took place on relatively new continuously welded rail track, and often such a derailment destroyed about a mile of the new track, as the freight train might take that distance to stop; the concrete sleepers were not robust under a derailed wagon's wheels.

The effect reduced as the wagon fleet was modernised (and other effects took first place) and the track gauge for new track was quietly restored to 4 ft 8 ½ in (1,435 mm) in 1998. Of course the vast majority of the track on main lines is still, as installed, at the tighter gauge, and it will be several decades before the gauge change is complete.

Switches and crossings

Railway turnouts

Terminology is difficult for "switches and crossings" (S&C) previously "points and crossings", or "fittings".

Early S&C allowed only a very slow speed on the subsidiary route (the "turnout"), so geometrical design was not too important. Many older s&c units had a loose joint at the heel so that the switch rail could turn to close to the stock rail or open from it. When the switch rail was closed a reasonable alignment was secured; when it was open, no wheel could run on it so it did not matter.

As speeds rose this was no longer feasible and the switch rails were fixed at the heel end, and their flexibility enabled the toe end to open and close. Manufacture of the switch rails was a complex process, and that of the crossings even more so. Speeds on the subsidiary route were rarely higher than 20 mph except in very special designs, and great ingenuity was employed to give a good ride to vehicles passing through at speed on the main line. A difficulty was the common crossing where continuous support to wheels passing was difficult, and the point rail was planed down to protect it from direct impact in the facing direction, so that a designed irregularity in support was introduced.

As faster speeds were required, more configurations of s&c were designed, and a very large number of components, each specific to only one type of s&c, was required. At faster speeds on the turnout road, the divergence from the main route is much more gradual, and therefore a very considerable length of planning of the switch rail is required.

About 1971 this trend was reversed with the so-called vertical s&c, in which the rails were held vertical, rather than at the customary 1 in 20 inclination. With other simplifications, this considerably reduced the stockholding required for a wide range of s&c speeds, although the vertical rail imposes a loss of the steering effect and the ride through new vertical s&c is often irregular.

Continuous welded track

Continuous welded track with conductor rail installed in the 1970s

Continuous welded track was developed in response to the observation that the bulk of track maintenance work takes place at the joints. As steel production and manufacturing processes improved, the rail lengths installed were progressively increased, and the logical extension of this would be to eliminate the joints altogether.

A major obstacle to doing so is thermal expansion: the rails expand in higher temperatures. Without joints, there is no room for the rails to expand; as the rails get warmer they will develop an enormous force in *trying* to expand. If prevented from expanding, they develop a force of 1.7 tonnes (17 kN) for every 1 degree Celsius of temperature change in a practical rail section.

If a small cube of metal is compressed between the jaws of a press, it will contract—that is it will be squashed somewhat—and a very large force can be resisted by it without ultimate failure. However if a long piece of metal of the same cross section is compressed, it will deform sideways into a bow shape; the process is called buckling, and the compressive force it can withstand is very much less.

If the long thin piece of metal could be constrained to prevent it from buckling (e.g. by being contained inside a tube) then it can resist a much higher compressive force. If the rails can be constrained in a similar way, they can be prevented from buckling. The weight of the track resists buckling upwards, so buckling is most likely to take place laterally. This is prevented by:

- providing heavy sleepers, that generate friction on the ballast bed
- ensuring that the sleepers are well supported on consolidated ballast to enable the generation of the friction
- providing consolidated ballast around the sides of the sleepers to provide additional friction
- heating the rails when they are installed and fastened in cool or cold weather, so that the expansion on the hottest days is less than otherwise
- making sure that any rail added if rail breaks during cold weather is removed before warm weather returns.
- making sure that curves do not line themselves inward during cold weather sufficiently to make buckling more likely when warm weather returns
- taking precautions when track maintenance work is performed in hot weather, and making sure ballast is sufficiently consolidated before full-speed operation is resumed.

If the rail is held so that it cannot expand at all, then there is no limit on the length of rail that can be handled. The expansive force in a one-foot length of rail at a certain temperature is the same as in a 100-mile length of rail. Early continuous welded rail was installed in limited lengths only because of technological limitations. However at the end of the cwr section where it abutted older, ordinary jointed track, that track would be unable to resist the expansive force and the jointed track might be forced to buckle. To prevent that, special expansion switches, sometimes called breathers, were installed. The expansion switches could accommodate a considerable expansive movement—typically four inches (100mm) or so—in the end section of the cwr without passing the movement on to the jointed track.

The cwr is installed and fastened down at an optimum temperature, to ensure that the highest possible expansive force is limited. This temperature is called the stress-free temperature, and in the UK it is 27 °C (81 °F). It is in the upper range of ordinary outdoor temperatures, and the actual installation work tends to be done at cooler temperatures. Originally the rails were physically heated to the stress-free temperature with propane gas heaters; they were then rattled with hand bars to eliminate any binding, preventing even expansion, and then clipped down. Since about 1963 however hydraulic jacks are used to physically stretch the rails while they are supported on temporary rollers. By stretching the rails to the length they would be if they were at the stress-free temperature, then there is no need to heat them; they can just be clipped down before the jacks are released.

The cwr rails are made by welding ordinary rails together. For many years rails could only be made in lengths of up to 60 ft (18 288mm) in Britain, and the factory welding process made them into 600, 900 or 1200 ft lengths, depending on the factory. The process used was a flash-butt process in which high electrical currents are used to soften the rail end, and the ends are then forced together by rams. The flash-butt process is very reliable, providing that the factory ensured good geometry of the rail ends.

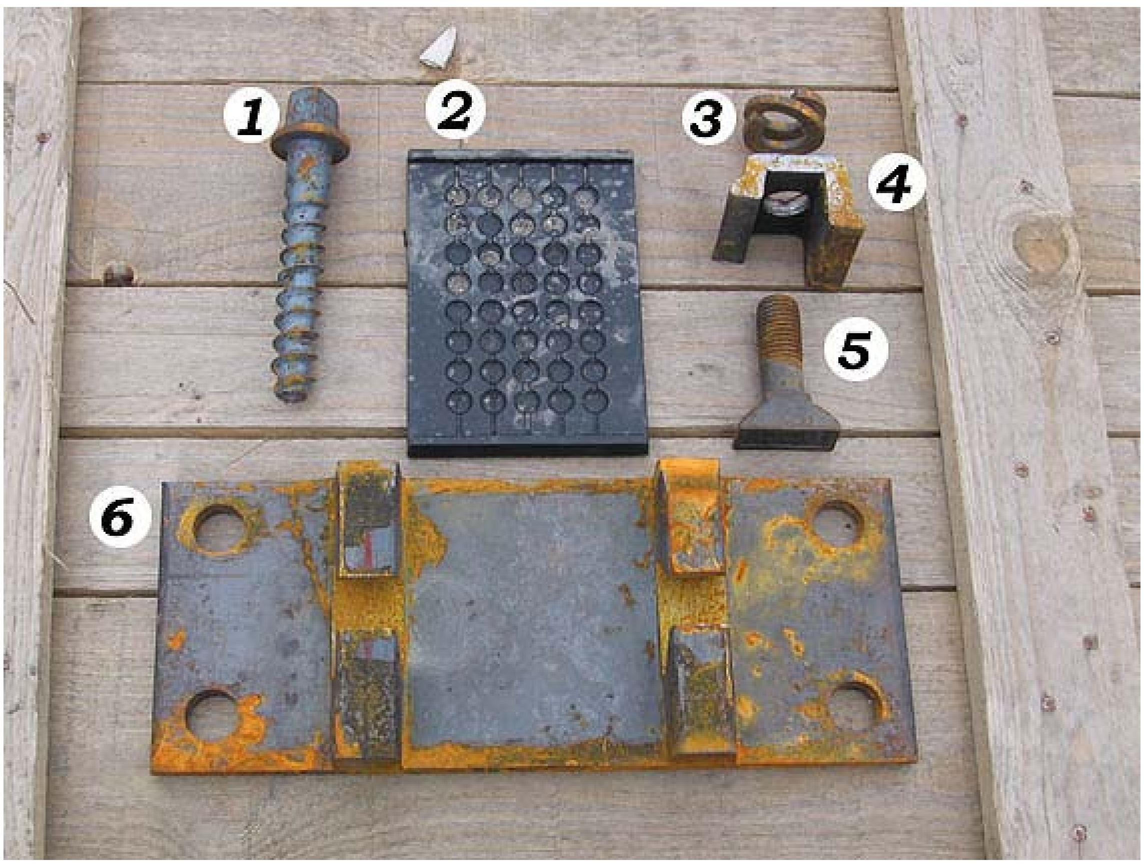
The long rails could be conveyed to site by special train, and unloaded on to the ground (by chaining the end in position and pulling the train out from underneath the rails). The long rails had to be welded together (or to adjacent track) using a site welding process, and after initial experimentation the proprietary Thermit welding process was used. This was an alumino-thermic process in which a powder 'portion' was ignited; the aluminium was the fuel and a metallurgically appropriate composition of molten steel descended into the gap between the rail ends, contained in refractory moulds.

The original SmW process was very sensitive to operator skill, and as the welding was usually the final process before returning the track to traffic, time pressure was sometimes applied resulting in unwanted improper welds. The improved SkV process was less sensitive and over the years weld quality improved.

It is worth mentioning that jointed track has suffered buckles in the past; the fish-plates need to be removed and greased annually (the requirement was relaxed to bi-annually in 1993) and where this was forgotten or where ballast conditions were especially weak, buckling took place in hot weather. In addition, if rails were allowed to creep, it was always possible that several successive joints closed up, so that the expansion gap was lost, with inevitable results at the onset of hot weather.

Chapter- 7

Rail Fastening System



Elements of a baseplate based rail fastening system
1. Screw for fixing plate to sleeper
2. Elastomeric pad supporting rail
3. Tension washer
4. Rail clamp
5. Tensioning bolt (nut not shown)
6. Baseplate

Assembled example

A **rail fastening system** is a means of fixing rails to railroad ties (United States) or sleepers (international). The terms *rail anchors*, *tie plates*, *chairs* and *track fasteners* are used to refer to parts or all of a rail fastening system. Various types of fastening have been used over the years.

History and overview

The earliest wooden rails were fixed to wooden sleepers by pegs through holes in the rail, or by nails. By the 17th century cast iron rails had come into use, and also had holes in the rail itself to allow them to be fixed to a support. 18th century developments such as the flanged rail and fish bellied rail also had holes in the rail itself; when stone block sleepers were used the nails were driven into a wooden block which had been inserted into a recess in the block. The first chair for a rail is thought to have been introduced in 1797 which attached to the rail on the vertical web via bolts.

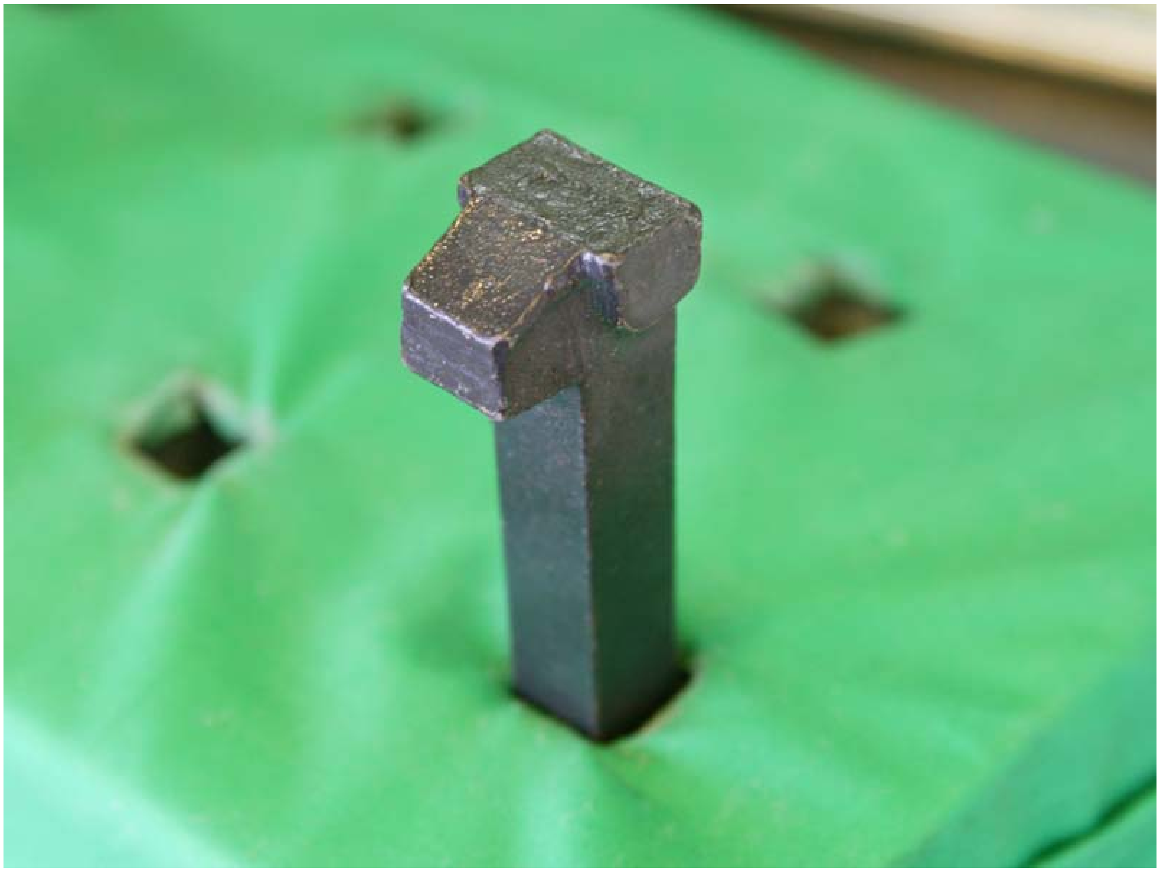
By the 1820s the first shaped rolled rails had begun to be produced initially of a T shape which required a chair to hold them; the rails were held in position by iron wedges (which sometimes caused the rail to break when forced in) and later by wooden wedges, which became the standard. In the 1830s Robert L. Stevens invented the flanged 'tee' rail (actually a distorted I beam), which had a flat bottom and required no chair, a similar design was the contemporary bridge rail (an inverted 'U' shaped with bottom flange and used on longitudinal sleepers); these rails were initially nailed directly to the sleeper.

In North American practice the flanged T rail became the standard, later being used with tie-plates. Elsewhere T rails were replaced by bull head rails of a rounded 'I' or 'figure-8' appearance which still required a supporting chair. Eventually the flanged T rail became commonplace on all the worlds railways, though differences in the fixing system still exist.

Spikes and screws

Rail spikes

Rusted cut spikes (scale in inches)



Dog spike

A **rail spike** (also known as a **cut spike** or **crampon**) is a large nail with an offset head that is used to secure rails and base plates to railroad ties in the track. Robert Livingston Stevens is credited with the invention of the railroad spike, being first used in at least 1832. The railroad spike was an invention which resulted from the state of industrialisation in the United States in the early 19th century: English mainline railways of that period used heavy and expensive cast iron chairs to secure T shaped rails; instead, Stevens added a supporting base to the T rail which could be fixed with a simple spike. The spike is still (as of 1982) the most common rail fastening in North America. Common sizes are from 9 to 10/16 inch square and ~5.5 to 6 inch long.

A rail spike is roughly chisel shaped and with a flat edged point; the spike is driven with the edge against the grain, which gives greater resistance to loosening. The main function is to keep the rail in gauge. When attaching tie plates the attachment is made as strong as possible, whereas when attaching a rail to tie or tie plate the spike is not normally required to provide a strong vertical force, allowing the rail some freedom of movement.

Originally spikes were driven into wooden sleepers by hammering them with a heavy hammer by hand. This manual work has been replaced by machines, commonly called "spike drivers" (A machine that removes spikes is called a "spike puller"). Splitting of the wood can be limited by pre-boring spike holes or adding steel bands around the wood.

For use in the United States three basic standards are described in the ASTM A65 standard, for different carbon steel contents.

The rail spike has entered American popular consciousness; the driving of the Golden spike was a key point in North American development of the western seaboard. Also characters such John Henry (folklore) have been celebrated in song and verse, as have railroad workers in general.

A ***dog spike*** is functionally equivalent to a cut spike and is also square in horizontal section and of similar dimensions but has a pointed penetrating head, and the rail or plate holding head has two lugs on either side (which aid spike removal) giving the impression of a dogs head.

Screw spikes

Rusted screw spike

A ***screw spike***, *rail screw* (or Lag bolt) is a large (~6" length, slightly under 1" diameter) metal screw used to fix a tie plate or fasten rail. Screw spikes are fixed into a hole bored in the sleeper. The screw spike has a higher cost to manufacture that the rail spike but has the advantage of greater fixing power; approximately twice that of a rail spike, and can be used in combination with spring washers.

The screw spike was first introduced in 1860 in France (French *tire-fond*), and became common in continental Europe.

Fang bolts

Fang bolts have also been used for fixing rails or chairs to sleepers; the fang bolt is a bolt inserted through a hole in the sleeper with a fanged nut that bites into the lower surface of the sleeper. For fastening flat bottomed rails an upper lipped washer can be used to grip the edge of the rail. They are more resistant to loosening by vibrations and movement of the rail. They are thought more effective than spikes and screws and so are used in positions such as switch (point) tieplates, and on sharp curves.

Spring spikes

Spring spike fastener (unknown type)

Spring spikes, (or *elastic rail spikes*) are used with flat bottomed rail, baseplates and wooden sleepers; the spring spike holds the rail down and prevents tipping, and also secures the baseplate to the sleeper. The *Macbeth spike* (tradename) is a two pronged U shaped staple like spike bent at the bend so that it appears M shaped when viewed side on. Inverted J shaped single pointed spikes have also been used.

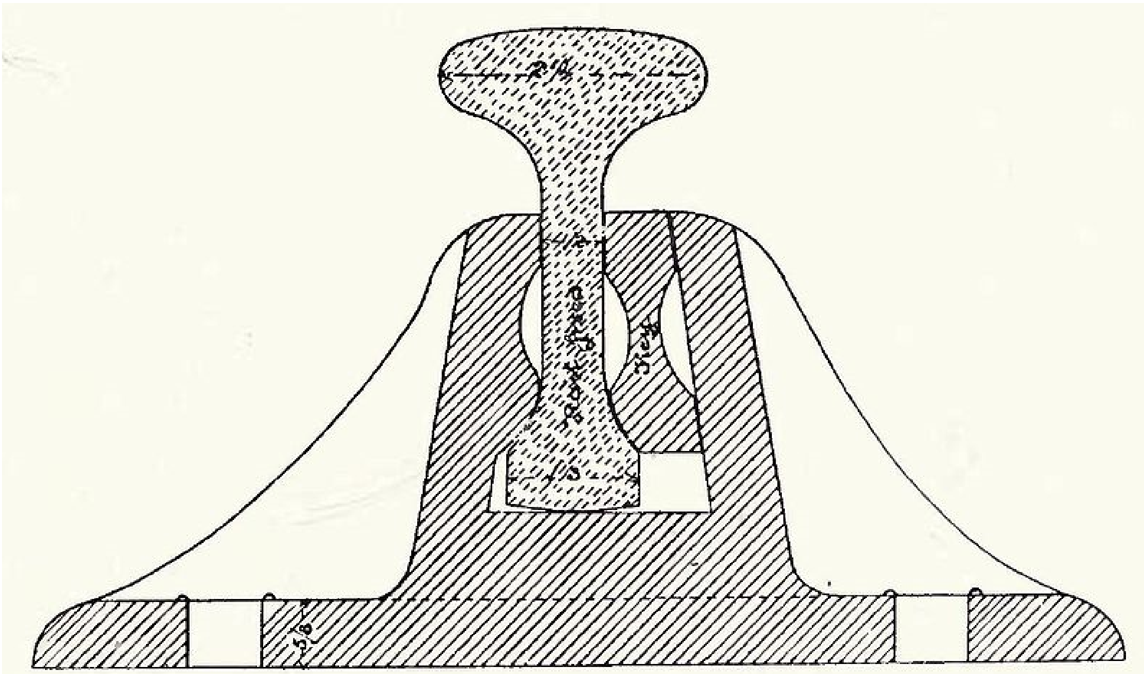
Fixing equipment

The spike maul also known as a *spiking hammer*, a type of sledgehammer with a long thinnish head was originally used to drive spikes.

Manual hole drilling and spike or screw insertion and removal have been replaced by semi-automated or automated machines, both pneumatic and hydraulic. Machines that remove spikes are called *spike pullers*.

Rail supports

Chairs



SECTION OF LEEDS AND SELBY CHAIR, SHOWING THE RAIL AND KEY.

Cross section of early T rail, chair and key

The earliest ***railway chairs***, made of cast iron, were introduced around 1800 used to fix and support cast iron rails at the ends, they were also used to join the adjacent rails.

In the 1830s T shaped (or *single flanged T parallel rail*) and I shaped rails (*double flanged T parallel* or *bullhead rail*) rolled rails were introduced; both required cast iron chairs to support them. Originally iron keys were used to wedge the rail into the vertical parallel jaws of the chair, these were superseded by entirely wooden keys. The wooden keys were formed from oak, steam softened and then compressed with hydraulic presses and stored in a drying house; when inserted into the chair exposure to the wet atmosphere would cause the key to expand resulting the rail being firmly held. The wedge may be on the inside or outside of the rail, usually the wedge is applied on the outside edge.

Chairs have been fixed to the sleeper using wooden spikes (trenails), screws, fang-bolts or spikes.

In most of the world flat bottomed rail and baseplates became the standard, however in Britain bullhead rail and chairs remained in use until the middle of the twentieth century. It is now largely obsolete but can still be found on sidings.

Tie plates

A ***tie plate***, *baseplate* or *sole plate* is a steel plate used on rail tracks between flanged T rail and the crossties. The tie plate increases bearing area and holds the rail to correct gauge. They are fastened to wooden ties by means of spikes or bolts through holes in the plate.

The part of the plate under the rail base is tapered, setting the cant of the rail, an inward rotation from the vertical. The usual slope is one in forty (1.4 degrees). The top surface of the plate has one or two shoulders that fit against the edges of the base of the rail. The double-shoulder type is currently used. Older single-shoulder types were adaptable for various rail widths, with the single shoulder positioned on the outside (field side) of the rails. Most plates are slightly wider on the field side, without which the plates tend to cut more into the outsides of the tie, reducing cant angle.

Many railways use large wood screws, also called *lag screws*, to fasten the tie plates (or baseplates) to the railroad ties.

Tie plates came into use around the year 1900, before which time flanged T rail was spiked directly to the ties.

Clips

A variety of different types of heavy-duty clips are used to fasten the rails to the underlying baseplate, one common one being the *Pandrol* fastener (Pandrol clip), named after its maker, which is shaped like a stubby paperclip. Another one is the Vossloh Tension Clamp.

The newer Pandrol fastclip is applied at right angles to the rail. Because the clip is captive, it has to be installed at the time of manufacture of the concrete sleeper.

Rail fastening types

Rail spike with baseplate above the tie

Track joint and chairs

Pandrol 'e-Clip' fastening

Pandrol 'fastclip' fastening

Tension clamp fastening

Steel spring keyed rail in chair

Chapter- 8

Track Ballast

Good quality track ballast is made of crushed stone. The sharp edges help the particles interlock with each other.

Track ballast forms the trackbed upon which railway sleepers (UK) or railroad ties (US) are laid. It is packed between, below, and around the ties. It is used to facilitate drainage of water, to distribute the load from the railroad ties, and also to keep down vegetation that might interfere with the track structure. This also serves to hold the track in place as the trains roll by. It is typically made of crushed stone, although ballast has sometimes consisted of other, less suitable materials. The term "ballast" comes from a nautical term for the stones used to stabilize a ship.

Material properties

A good ballast should be strong, hard-wearing, stable, drainable, easy to clean, workable, resistant to deformation, easily available, and reasonably cheap to purchase. Early railway engineers did not understand the importance of quality track ballast; they would use cheap and easily-available materials such as ashes, chalk, clay, earth, and even cinders from locomotive fireboxes. It was soon clear that good-quality ballast made of rock was necessary if there was to be a good foundation and adequate drainage.

Good quality track ballast is made of crushed natural rock with particles between 28 mm and 50 mm in diameter; a high proportion of particles finer than this will reduce its drainage properties, and a high proportion of larger particles result in the load on the ties being distributed improperly. Angular stones are preferable to naturally rounded ones, as angular stones interlock with each other, inhibiting track movement. Soft materials such as limestone are not particularly suitable, as they tend to degrade under load when wet, causing deterioration of the line; granite, although expensive, is one of the best materials in this regard.

In the early days of railroads in the United States, much material for ballast came from rock found in the local area. In the Midwest, for example, much use was made of quartzite, while states in the southeast, such as Florida, made use of limestone. One specific type of quartzite used in the Midwest earned the name "Pink Lady" due to its color; in other areas, the ballast can be a mix of light and dark colors called "Salt and Pepper".

Construction

The thickness of a layer of track ballast depends on the size and spacing of the ties, the amount of traffic expected on the line, and various other factors. Track ballast should never be laid down less than 150 mm (6 inches) thick; high-speed railway lines may require ballast up to half a metre (20 inches) thick. An insufficient depth of ballast overloads the underlying soil; in the worst cases, this can cause the track to sink. If the ballast is less than 300 mm (12 inches) thick, this can lead to vibrations, which can damage nearby structures (though increasing the depth beyond this has no measurable effect).

Track ballast typically sits on a layer of sub-ballast; the latter is typically made of small crushed stones. It gives a solid support for the top ballast, and seals out water from the underlying ground. Sometimes, an elastic mat is placed under the ballast layer as well; this can allow for significant reductions in vibration.

It is essential for ballast to be piled as high as the ties, and for a substantial "shoulder" to be placed at their ends; the latter being especially important, since this ballast shoulder is, for the most part, the only thing restraining lateral movement of the track. The ballast shoulder should be at least 150 mm (6 inches) wide under any circumstances, and may be as large as 450 mm (18 inches).

Maintenance

New track ballast is placed at the Boxmeer railway station, The Netherlands.

A ballast regulator shaping newly placed ballast

Ballast tamping machine as used in railroad track maintenance -- Dade City, Florida

If ballast is badly fouled, the clogging will reduce its ability to drain properly; this, in turn, causes more debris to be sucked up from the sub-ballast, causing more fouling. Therefore, keeping the ballast clean is essential. Bioremediation can be used to clean ballast.

It is not always necessary to replace the ballast if it is fouled, nor must all the ballast be removed if it is to be cleaned. Removing and cleaning the ballast from the shoulder is often sufficient, if shoulder ballast is removed to the correct depth. While this job was historically done by manual labour, this process is now, like many other railway maintenance tasks, a mechanised one, with a chain of specially-designed railroad cars handling the task. One wagon cuts the ballast and passes it via a conveyor belt to a cleaning machine, then the cleaning wagon washes the ballast, and deposits the dirt and ballast into other wagons for disposal and re-use, respectively. Such machines can clean up to two kilometres of ballast in an hour.

Cleaning, however, can only be done a certain number of times before the ballast is damaged to the point that it cannot be re-used; furthermore, track ballast that is completely fouled can not be corrected by shoulder cleaning. In such cases, it is necessary to replace the ballast altogether. One method of "replacing" ballast, if necessity demands, is to simply dump fresh ballast on the track, jack the whole track on top of it, and then tamp it down; alternatively, the ballast underneath the track can be removed with an undercutter, which does not require removing or lifting the track.

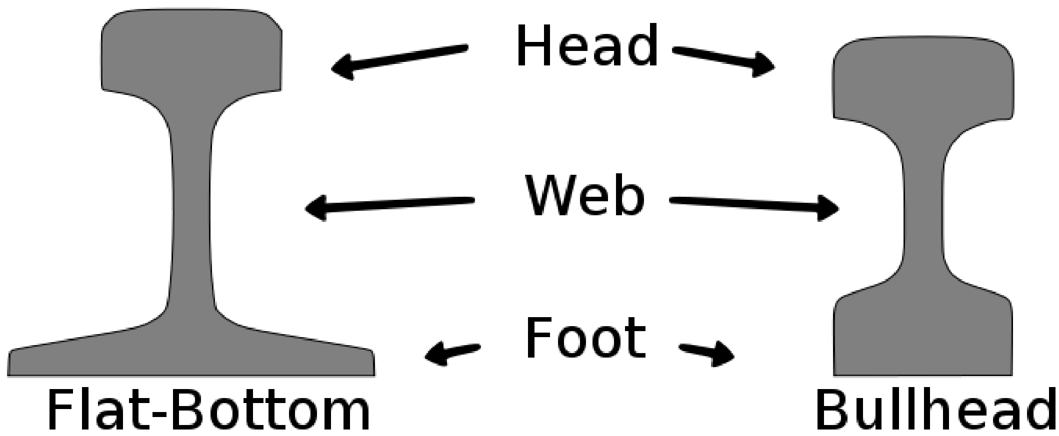
Regular inspection of the ballast shoulder is important; as noted earlier, the lateral stability of the track depends upon the shoulder. The shoulder acquires some amount of stability over time, being compacted by traffic; maintenance tasks such as replacing ties, tamping, and ballast cleaning can upset this stability. After performing these tasks, it is necessary for either trains to run at reduced speed on the repaired routes, or to employ machinery to compact the shoulder again.

If the trackbed becomes uneven, it is necessary to pack ballast underneath sunk ties to level the track out again. This is, in the mechanized age, usually done by a ballast tamping machine. A more recent, and probably better, technique is to lift the rails and ties, and to force stones, smaller than the track ballast particles and all of the same size, into the void. This has the advantage of not disturbing the well-compacted ballast on the trackbed, as tamping is likely to do. This technique is called pneumatic ballast injection (PBI; or, less formally, "stoneblowing"). However, this technique is not as effective with fresh ballast, as the smaller stones tend to move down between the larger pieces of ballast.

Chapter- 9

Rail Profile

Rail from 1896



Cross-sections of flat-bottomed which can rest directly on the sleepers, and bullhead rails which sit in chairs.

The **rail profile** is the cross sectional shape of a railway rail, perpendicular to the length of the rail.

In all but very early cast iron rails, a rail is hot rolled steel (once wrought iron) of a specific cross sectional profile (an asymmetrical I-beam) designed for use as the fundamental component of railway track.

Unlike some other uses of iron and steel, railway rails are subject to very high stresses and have to be made of very high quality steel. It took many decades to improve the quality of the materials, including the change from iron to steel. Minor flaws in the steel that pose no problems in reinforcing rods for buildings, can, however, lead to broken rails and dangerous derailments when used on railway tracks.

By and large, the heavier the rails and the rest of the trackwork, the heavier and faster the trains these tracks can carry.

The rails represent a substantial fraction of the cost of a railway line. Only a small number of rail sizes are made by steelworks at one time, so a railway must choose the nearest suitable size. Worn, heavy rail from a mainline is often reclaimed and downgraded for re-use on a branchline, siding or yard.

Rail weights and sizes

Two commonly used rail profiles: a heavily used 50 kg-profile and a new 60 kg-profile

The weight of a rail per length is an important factor in determining rails strength and hence axleloads and speeds.

Weights are measured in pounds per yard or kilograms per metre; the pounds-per-yard figure is almost exactly double the kilograms-per-metre figure. Rails in Canada, the United Kingdom and United States are still described using imperial units. In Australia, metric units are now used as in mainland Europe.

In rail terminology *Pound* is used synonymously with pounds per yard, e.g. a 132 pound rail means a rail of 132 lb/yd.

Europe

Rails are made in a large number of different sizes. Some common European rail sizes include:

- 40 kg/m (80.6 lb/yd)
- 50 kg/m (100.8 lb/yd)
- 54 kg/m (108.9 lb/yd)
- 56 kg/m (112.9 lb/yd)
- 60 kg/m (121 lb/yd)

In the countries of former USSR 65 kg/m (131 lb/yd) rails and 75 kg/m (151.2 lb/yd) rails (not thermally hardened) are common. Thermally hardened 75 kg/m (151.2 lb/yd) rails also have been used on heavy-duty railroads like Baikal-Amur Mainline, but have proven themselves deficient in operation and were mainly rejected in favor of 65 kg/m (131 lb/yd) rails.

North America

Weight mark on a jointed segment of 155 lb/yd (76.9 kg/m) "Pennsylvania Special" rail. The heaviest grade of rail ever mass produced.

The American Society of Civil Engineers (or ASCE) specified rail profiles in 1893 for 5-pound-per-yard (2.5 kg/m) increments from 40 to 100 pounds per yard (20 to 50 kg/m). Height of rail equaled width of foot for each ASCE tee-rail weight; and the profiles specified fixed proportion of weight in head, web and foot of 42%, 21% and 37%, respectively. ASCE 90 lb/yd (45 kg/m) profile was adequate; but heavier weights were less satisfactory. In 1909 the American Railway Association (or ARA) specified standard profiles for 10 lb/yd (5.0 kg/m) increments from 60 to 100 lb/yd (30 to 50 kg/m). The American Railway Engineering Association (or AREA) specified standard profiles for 100 lb/yd (50 kg/m), 110 lb/yd (55 kg/m) and 120 lb/yd (60 kg/m) rails in 1919, for 130 lb/yd (64 kg/m) and 140 lb/yd (69 kg/m) rails in 1920, and for 150 lb/yd (74 kg/m) rails in 1924. The trend was to increase rail height/foot-width ratio and strengthen the web. Disadvantages of the narrower foot were overcome through use of tie-plates. AREA recommendations reduced the relative weight of rail head down to 36%, while alternative profiles reduced head weight to 33% in heavier weight rails. Attention was also focused on improved fillet radii to reduce stress concentration at the web junction with the head.

AREA recommended the ARA 90 lb/yd (45 kg/m) profile. Old ASCE rails of lighter weight remained in use, and satisfied the limited demand for light rail for a few decades. AREA merged into the American Railway Engineering and Maintenance-of-Way Association in 1997. By the mid-20th century, most rail production was *medium heavy* (112 to 119 lb/yd/55.6 to 59.0 kg/m) and *heavy* (127 to 140 lb/yd/63.0 to 69.4 kg/m) Sizes under 100 lb/yd (50 kg/m) rail are usually for lighter duty freight, low use trackage, or light rail. Track using (100 to 120 lb/yd (50 to 60 kg/m)) rail is for lower speed freight branch lines or rapid transit (for example, most of the New York City Subway system track is constructed with 100 lb/yd (50 kg/m) rail). Main line track is usually built with 130 lb/yd (64 kg/m) rail or heavier. Some common North American rail sizes include:

- 75 lb/yd (37 kg/m) (ASCE)
- 85 lb/yd (42 kg/m) (ASCE)
- 90 lb/yd (45 kg/m) (ARA)
- 100 lb/yd (50 kg/m) (AREA)
- 105 lb/yd (52.1 kg/m) New York Central Railroad
- 115 lb/yd (57.0 kg/m) (AREA)
- 119 lb/yd (59.0 kg/m) Colorado Fuel and Iron
- 127 lb/yd (63.0 kg/m) New York Central Railroad
- 132 lb/yd (65.5 kg/m) (AREA)
- 133 lb/yd (66.0 kg/m) (AREA)
- 136 lb/yd (67.5 kg/m) Colorado Fuel and Iron
- 140 lb/yd (69.4 kg/m) (AREA)
- 141 lb/yd (69.9 kg/m) (produced by Nippon (Japan))
- 155 lb/yd (76.9 kg/m) (no longer production) Pennsylvania Railroad

Some common North American crane rail sizes include:

- 12 lb/yd (5.95 kg/m)
- 20 lb/yd (9.9 kg/m)
- 25 lb/yd (12.4 kg/m)
- 30 lb/yd (14.9 kg/m)
- 40 lb/yd (19.8 kg/m)
- 60 lb/yd (29.8 kg/m)
- 80 lb/yd (39.7 kg/m)
- 85 lb/yd (42.2 kg/m)
- 104 lb/yd (51.6 kg/m)
- 105 lb/yd (52.1 kg/m)
- 135 lb/yd (67 kg/m)
- 171 lb/yd (84.8 kg/m)
- 175 lb/yd (86.8 kg/m)

Australia

Some common Australian rail sizes include:

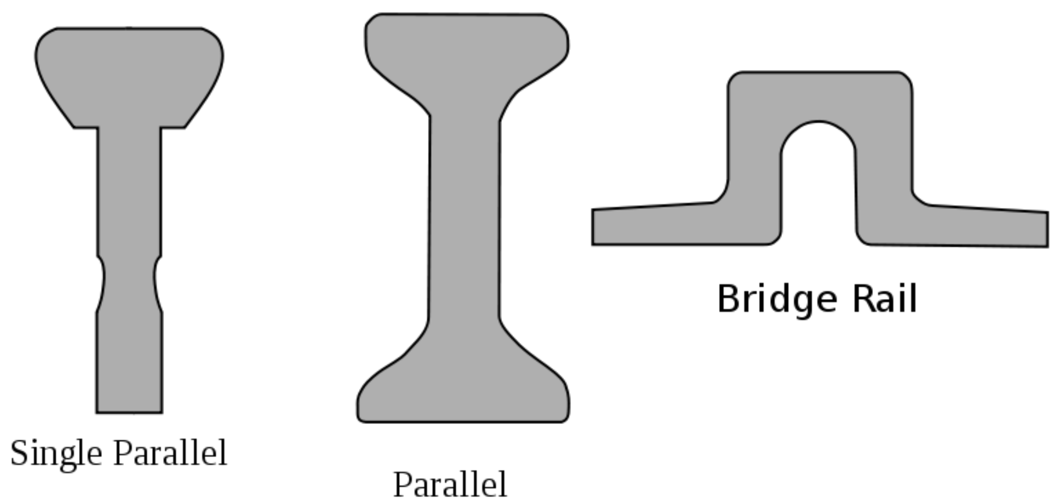
- 30 kg/m (60.5 lb/yd)
- 36 kg/m (72.6 lb/yd)
- 40 kg/m (80.6 lb/yd)
- 47 kg/m (94.7 lb/yd)
- 50 kg/m (100.8 lb/yd)
- 53 kg/m (106.8 lb/yd)
- 60 kg/m (121 lb/yd)
- 68 kg/m (137.1 lb/yd) (no longer production)

- 50 kg and 60 kg are the current standard, although some other sizes are still manufactured.

- Some American sizes are used on northwest Western Australian iron ore railways.

History

Fishbelly edge rails laid on stone blocks



Cross sections of early rails

Early rails were used on horse drawn wagonways, originally with wooden rails, but from the 1760s using **strap-iron rails**, which consisted of thin strips of cast iron fixed onto wooden rails. These rails were too fragile to carry heavy loads, but because the initial construction cost was less, this method was sometimes used to quickly build an inexpensive rail line. Strap rails sometimes separated from the wooden base and speared into the floor of the carriages above, creating what was referred to as a "snake head." However, the long-term expense involved in frequent maintenance outweighed any savings.

These were superseded by cast iron rails which were flanged (i.e. 'L' shaped) with the wagon wheels being flat, an early exponent being Benjamin Outram. His partner William Jessop had pioneered the use of "edge rails" in 1789 where the wheels were flanged and, over time it was realised that these worked better.

The earliest of these in general use were the so-called cast iron **fishbelly** rails from their shape. Rails made from cast iron were brittle and broke easily. They could only be made in short lengths which would soon become uneven. John Birkinshaw's 1820 patent, as rolling techniques improved, introduced wrought iron in longer lengths, replaced cast iron and contributed significantly to the explosive growth of railroads in the period 1825-40. The cross-section varied widely from one line to another, but were of three basic types as shown in the diagram. The parallel cross-section which developed in later years was referred to as **Bullhead**.

Meanwhile, in May 1831, the first flanged T rail (also called T-section) arrived in America from Britain and was laid into the Pennsylvania Railroad by Camden and Amboy Railroad. They were also used by Charles Vignoles in Britain.

The first steel rails were made in 1857 by Robert Forester Mushet, who laid them at Derby station in England. Steel is a much stronger material, which steadily replaced iron for use on railway rail and allowed much longer lengths of rails to be rolled.

The American Railway Engineering Association (AREA) and the American Society for Testing Materials (ASTM) specified carbon, manganese, silicon and phosphorus content for steel rails. Tensile strength increases with carbon content, while ductility decreases. AREA and ASTM specified 0.55 to 0.77 percent carbon in 70-to-90-pound-per-yard (35 to 45 kg/m) rail, 0.67 to 0.80 percent in rail weights from 90 to 120 pounds per yard (45 to 60 kg/m), and 0.69 to 0.82 percent for heavier rails. Manganese increases strength and resistance to abrasion. AREA and ASTM specified 0.6 to 0.9 percent manganese in 70 to 90 pound rail and 0.7 to 1 percent in heavier rails. Silicon is preferentially oxidised by oxygen and is added to reduce the formation of weakening metal oxides in the rail rolling and casting procedures. AREA and ASTM specified 0.1 to 0.23 percent silicon. Phosphorus and sulfur are impurities causing brittle rail with reduced impact-resistance. AREA and ASTM specified maximum phosphorus concentration of 0.04 percent.

The use of welded rather than jointed track began in around the 1940s and had become widespread by the 1960s.

Types

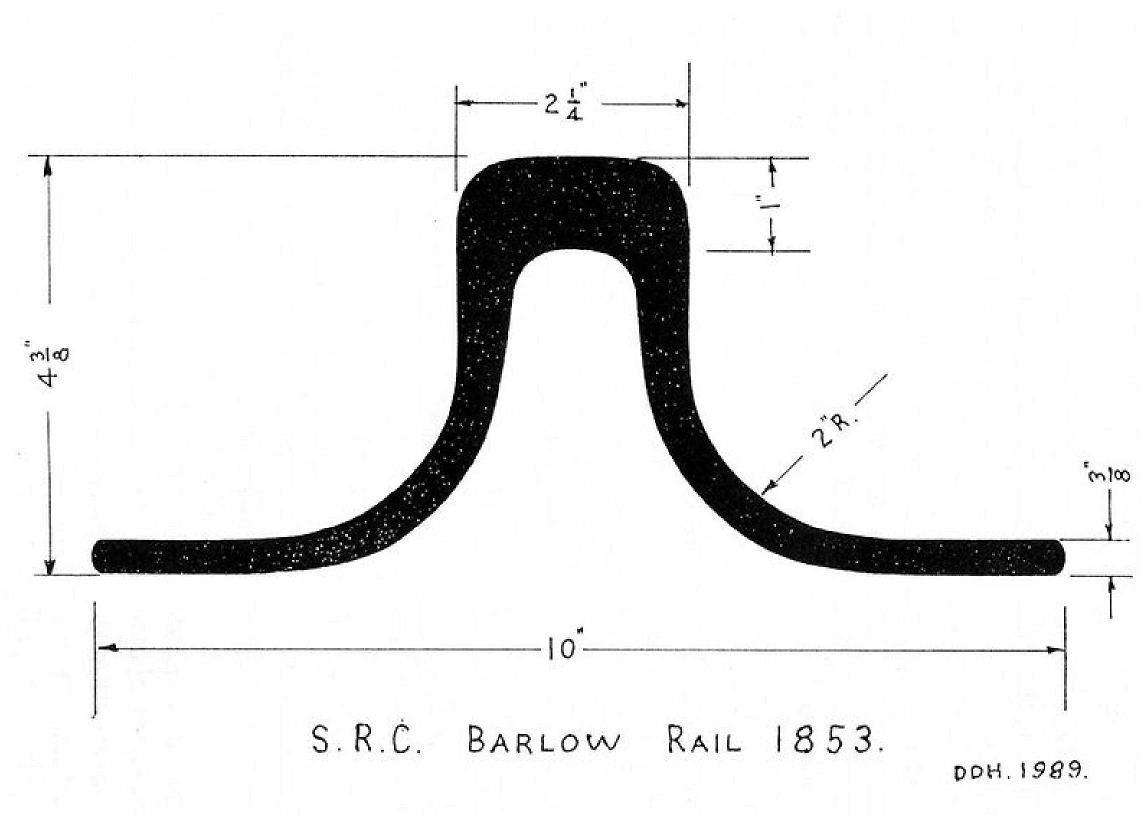
Flanged rail

Flanged rail was an early type of rail and had an 'L' cross section in which the flange kept an unflanged wheel on the track.

Baulk rail

Baulk road was an early type of longitudinally supported rail, pioneered by Isambard Kingdom Brunel.

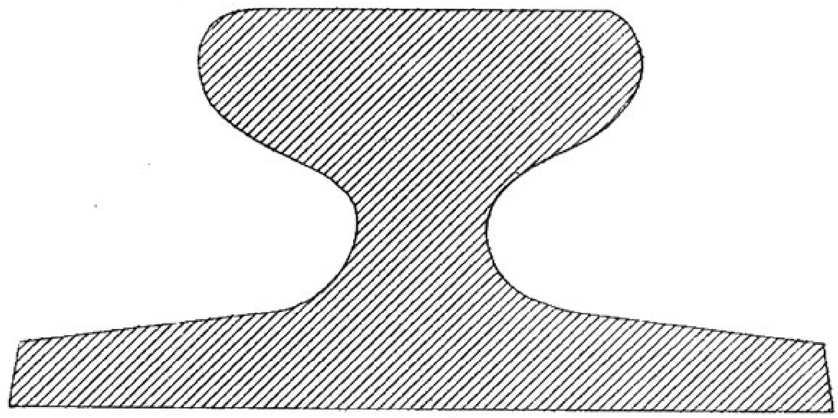
Barlow rail



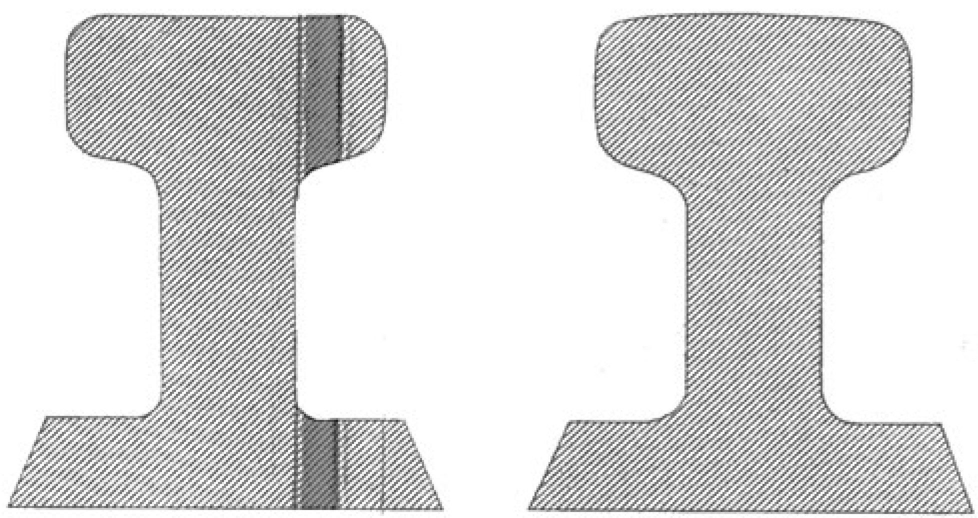
Cross section of Barlow rail as used by Sydney Railway Company

Barlow rail was invented by William Henry Barlow in 1849. It was designed to be laid straight onto the ballast, but the lack of sleepers meant that it was difficult to keep it in gauge.

Vignoles rail



Vignoles Rail as used for the London and Croydon Railway in 1839



Vignoles rail as used for the Birmingham and Gloucester Railway in 1840

Vignoles rail is the popular name of the flat-bottomed rail used internationally for railway track, recognising engineer Charles Vignoles who introduced it to Britain.

Flat bottomed rail was first introduced in America by R.L.Stevens in 1830. There were no steel mills in America capable of rolling long lengths, so it was manufactured in Britain. Charles Vignoles observed that wear was occurring with steel rails and steel chairs upon stone blocks, the normal system at that time. In 1836 he recommended flat-bottomed rail to the London and Croydon Railway for which he was consulting engineer.

His original rail had a smaller cross-section to the Stevens rail, with a wider base than modern rail, fastened with screws through the base. Other lines which adopted it were the Hull and Selby, the Newcastle and North Shields, and the Manchester, Bolton and Bury Canal Navigation and Railway Company.

When it became possible to preserve wooden sleepers with mercuric chloride (a process called Kyanising) and creosote, they gave a much quieter ride than stone blocks and it was possible to fasten the rails directly using clips or rail spikes. Their use spread worldwide and acquired Vignoles' name.

Flanged T rail

Cross section of new flanged T rail.

Iron-strapped wooden rails were used on all American railways until 1831. Col. Robert L. Stevens, the President of the Camden and Amboy Railroad, conceived the idea that an all-iron rail would be better suited for building a railroad. He sailed to England which was the only place where his flanged T rail (also called T-section) could be rolled. Railways in England had been using rolled rail of other cross-sections which the ironmasters had produced.

In May, 1831, the first 500 rails, each 15 feet (4.57 m) long and weighing 36 pounds per yard (17.9 kg/m), reached Philadelphia and were placed in the track, marking the first use of the flanged T rail. Afterwards, the flanged T rail became employed by all railroads in the United States. Col. Stevens also invented the hooked spike for attaching the rail to the crosstie (or sleeper). At the present time, the screw spike is being used widely in place of the hooked spike.

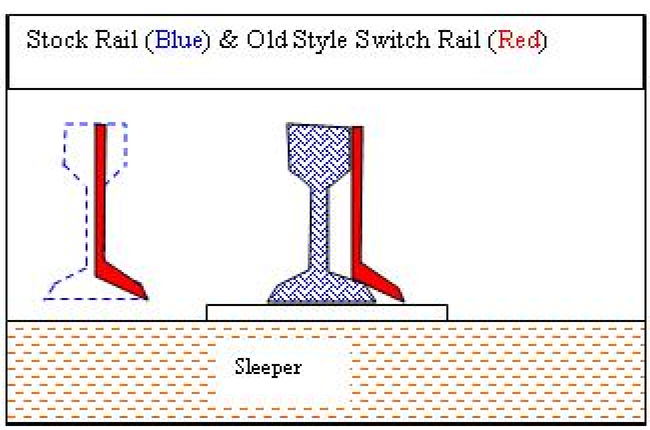
At the present time, crossties or sleepers constructed of concrete are in use in some places. The use of creosote as a treatment for wooden crossties has been declared to be detrimental to the health of people and plants. The use of creosote as a preservative treatment for wooden crossties has been approved in the U.S., and is widely used in other countries. The crossties or sleepers are embedded in ballast in order to provide stability and drainage.

The joint where two rails are connected is the weakest part of a rail line. The earliest iron rails were joined by a simple fishplate or bar of metal bolted through the web of the rail. Stronger methods of joining two rails together have been developed. When sufficient metal is put into the rail joint, the joint is almost as strong as the rest of the rail length. The noise generated by trains passing over the rail joints, described as "the clickity clack of the railroad track", can be eliminated by welding the rail sections together forming a continuous rail. One kind of welding is the Thermite welding process.

Double-headed rail

In late 1830s England, railway lines had a vast range of different patterns. One of the earliest lines to use double-headed rail was the London and Birmingham Railway, which had offered a prize for the best design. This rail was supported by chairs and the head and foot of the rail had the same profile. The supposed advantage was that, when the head became worn, the rail could be turned over and re-used. In practice, this form of recycling was not very successful as the chair caused dents in the lower surface, and double-headed rail evolved into bullhead rail in which the head was more substantial than the foot.

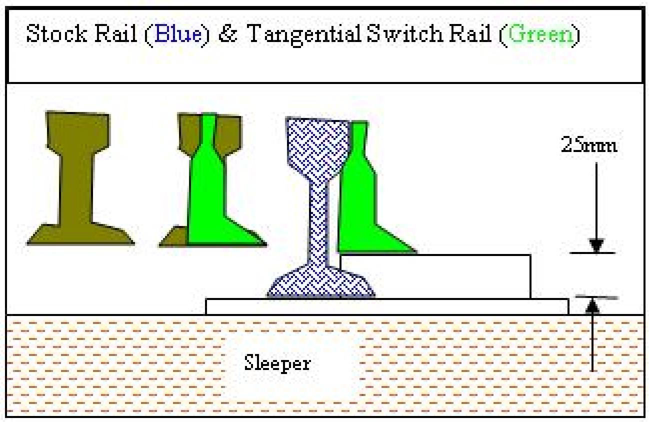
Bullhead rail



A lot of steel shaved away; tips are weak and straight leading to slow speeds on turnout.

Bullhead rail is similar to double-headed rail but with a heavier profile to the top edge. It became the standard for the British railway system until the mid-20th century but has now been largely replaced by flat-bottom rail. Bullhead rail is still used on the London Underground and survives on the national rail system in some sidings. One of the first British Standards, BS 9, was for bullhead rail - it was originally published in 1905, and revised in 1924. Rails manufactured to the 1905 standard were referred to as "O.B.S." (Original), and those manufactured to the 1924 standard as "R.B.S." (Revised).

Tangential turnouts



Not so much steel shaved away; tips are strong allowing curved turnouts and higher speeds.

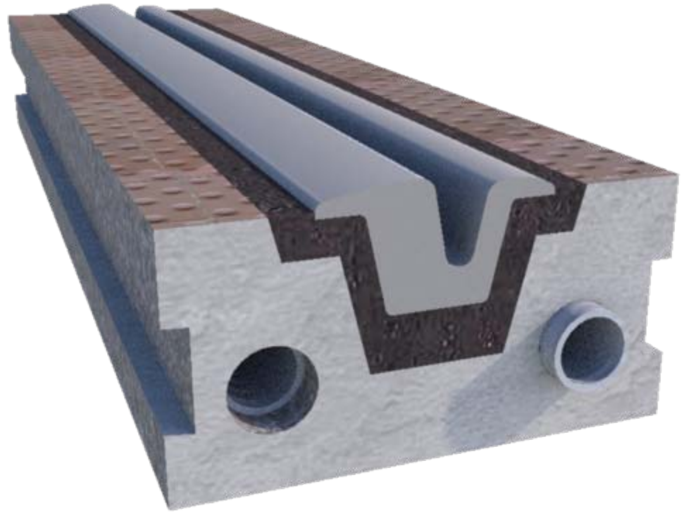
Old style turnouts use the same section rail for both stock rail and switch rail. A lot of steel has to be "filed" away, and the point tends to be thin and weak. To minimise the weak part, the switches are straight and form a coarse angle, which gives trains a jolt.

Tangential turnouts are made using two different rail profiles, the normal flat bottom rail for the stock rails, and a lower height and stockier profile for the switches. The difference in height of these two profiles is about 25mm, but as the switch rail rests on a base plate 25mm taller, both rails present themselves at the same height to the wheels.

The tangential switch rail has less steel filed away, and the mid part of the switch "scallops" into the web of the stock rail for greater strength. The higher baseplate also supports the switch rail better. The stronger switch allows that switch to be curved, reducing any jolt to the train and allowing higher speeds.

The weight of the two types of rail is about the same.

LR55 rail



LR55 cross section

LR55 rail is a special rail section, designed for use in embedded tramway track installations. It is a top-suspended rail: the load is transmitted by the rail head, rather than the base. The rail is laid in concrete troughs in slots cut in the roadway; a polyurethane mastic provides a resilient cushion between the rail section and the concrete, minimising transmitted noise, and providing insulation against leakage currents. Since the load is spread across a wider base, it requires less depth for a sub-base than conventional tramway track avoiding the need to disturb existing underground utility services. The installation and maintenance time, and hence cost, is thus greatly reduced. Gauge is maintained by the pavement in which it is installed; there is no need for separate gauging bars between the rails. LR55 has been tested in parts of the Sheffield Supertram network.

The same rail has been tested to 80 t (79 LT; 88 ST) axle loadings for mainline use, and can be used in tunnels and other locations where the loading gauge is restricted. Replacing flat bottom girder rails on sleepers and ballast with LR55 in tunnels can increase the head room by a minimum of 300 mm (11.8 in), without the need to excavate the tunnel invert. A method statement to undertake this transformation allows contractors to proceed on an incremental basis without closing the tunnel to rail traffic. Temporary transition rails link flat bottom and LR55 rails, until the conversion is completed. The extra loading gauge can then be used to install OHL electrification, or to move larger rail vehicles. These can include double deck passenger trains and freight trains with high cube (9 ft 6 in/2,900 mm) maritime containers.

Conical or Cylindrical Wheels

It has long been recognised that conical wheels and rails that are sloped by the same amount follow curves better than cylindrical wheels and vertical rails. A few railways such as Queensland Railways have always had cylindrical wheels until much heavier traffic required a change.

Manufacturers

Rails are made from high quality steel and not in huge quantities compared to other forms of steel, and so the number of manufacturers in any one country tends to be limited.

- Corus (UK)
- Krupp (Germany)
- OneSteel, Whyalla, South Australia (Australia)
- ArcelorMittal Steelton, USA
- Nippon (Japan)

Defunct manufacturers

- Bethlehem Steel (US)
- Sydney Steel Corporation (Canada)
- Dowlais Ironworks (Wales)

Chapter- 10

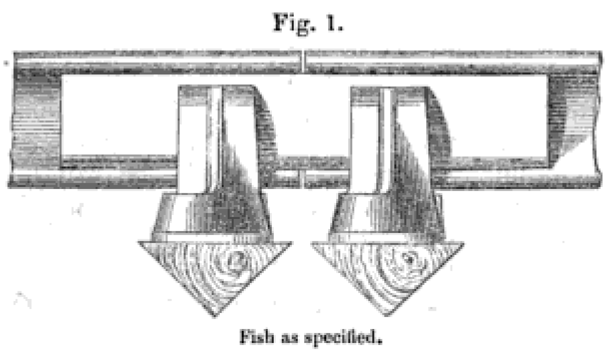
Fishplate

Fishplate on the Bluebell Railway

Short rail, sometimes known as a "Dutchman"

In rail terminology, a **fishplate**, **splice bar** or **joint bar** is a metal bar that is bolted to the ends of two rails to join them together in a track. The name is derived from *fish*, a wooden bar with a curved profile used to strengthen a ship's mast. The top and bottom edges are tapered inwards so the device wedges itself between the top and bottom of the rail when it is bolted into place. In rail transport modelling, a fishplate is often a small copper or nickel silver plate that slips onto both rails to provide the functions of maintaining alignment and electrical continuity.

History



The first railway fishplate, patented by William Adams and Robert Richardson in 1847

The device was invented by William Bridges Adams in May 1842, because of his dissatisfaction with the scarf joints and other systems of joining rails then in use. He noted that to form the scarf joint the rail was halved in thickness at its ends, where the stress was greatest. It was first deployed on the Eastern Counties Railway in 1844, but only as a wedge between the adjoining rails. Adams and Robert Richardson patented the invention in 1847, but in 1849 James Samuel, the engineer of the ECR developed fishplates that could be bolted to the rails.

Electrical connection

Electrically bonded main line 6-bolt rail joint on a segment of 155 lb/yd rail

Old fishplate

When railway lines are equipped with track circuits, or where the line is electrified for electric traction, the electrical connection provided by fishplates is poor and unreliable and has to be supplemented by bonding wire fixed to the two rails either side of the joint by spot welding or other means.

Welded rail

Even though fishplates strengthen the weak points represented by rail joints, improvements can still be made. For example, the joints can be welded together using the thermite welding process.

Shorter Pennsylvania RR standard joint

Rusty line across end of the left-hand rail, indicates right-hand rail is higher (mismatch)

Turnouts

The moving blades of a set of points can be connected to the stock rails by looser than normal fishplates. This is called a heeled switch. Alternatively, the blade and stock rail can be a one piece heel-less switch, with a flexible thinned section to create the moving heel.

Examples of fishplates

A connector that matches rails of different heights

Fishplate and electrical connecting wire

Pennsylvania RR standard joint

Portec insulated fishplate

Chapter- 11

Baulk Road

A baulk road crossing showing the baulks (under the rails) and transoms (to maintain the gauge)

Baulk road is the name given to a type of railway track or 'rail road' that is formed using rails carried on continuous timber bearings, as opposed to the more familiar 'cross-sleeper' track that uses closely spaced sleepers or ties to give intermittent support to taller rails. Baulk road was popularised by Isambard Kingdom Brunel for his 7 ft 0 $\frac{1}{4}$ in (2,140 mm) broad gauge railways in the United Kingdom, but has also been used for other railways and can still be found in modified form in special locations on present day railways.

Development

A section through a baulk and bridge rail

Brunel sought an improved design for the railway track needed for the Great Western Railway, authorised by Act of Parliament in 1835 to link London and Bristol.

He refused to accept received wisdom without challenge. The 4 ft 8 $^1\!/_2$ in (1,435 mm) gauge that had been adopted by most railways at that time had been fine for small mineral trucks on a horse-drawn tramway, but he wanted something more stable for his high-speed railway. The large diameter wheels used in stage coaches gave better ride quality over rough ground, and Brunel originally intended to have his carriages carried in the same way – on large diameter wheels placed outside their bodies. To achieve this he needed a wider track gauge and he settled on a 7 ft (2,134 mm) broad gauge but it was soon eased slightly to 7 ft 0 $^1\!/_4$ in (2,140 mm). When the time came to build the passenger carriages they were designed conventionally with smaller wheels under the bodies after all, but with the broad track gauge the bodies could be much wider than on the standard gauge. His original intention to have the wheels outside the width of the bodies was abandoned.

Early locomotive-powered railways had used short cast iron rails carried on stone blocks; a few were trying timber sleepers to give the rails their necessary support and to maintain the gauge between them. These rails were brittle and broke easily, and they gave a very rough ride due to the difficulty of maintaining a smooth line between the blocks or sleepers. Wrought iron rails were being manufactured but they were of poor quality due to the difficulty of cooling them evenly during manufacture. Brunel decided to use a continuously supported wrought iron rail, a bridge rail with a smaller rail section that cooled more evenly. This was an inverted-U section with wide flanges that could be bolted to the timber bearer, which was known as a 'longitudinal' baulk. The rail was usually kept off this by small wooden packing pieces that could be replaced when they were worn out by the passage of the trains and therefore avoid the expense of replacing the heavier longitudinals. The rails were bolted to the longitudinals by long fang bolts or coach screws, and the rail joints were later supported by a base plate formed with a plug in the void of the inverted U shape rails so as to keep the rails in line with each other.

The longitudinal baulks, and therefore the rails, were kept to gauge by 'transoms' – transverse timber spacers – and iron tie-bars. The transom kept the longitudinals from getting too close together; the tie rods stopped them spreading too far apart. In later years the tie rods were replaced by strap bolts. These were bolted to the transoms and passed through a hole drilled through the longitudinal to a nut on the outside.

On the first section of line, from London Paddington station to a temporary station at Taplow known as 'Maidenhead Bridge', Brunel had the track tied down to timber piles so that the gravel ballast (which was necessary on all railways for drainage) could be packed very firmly. It was packed so firmly, in fact, that the track was forced upwards between the piles and thus gave an undulating ride, just the thing that Brunel had tried to address by using continuous bearings and firm packing! He cut the piles away from the transoms and this solved the problem. The bridge rail for this line weighed 43 lb/yd (21.3 kg/m) but this was soon increased, generally to 62 lb/yd (30.8 kg/m). A large quantity of the now redundant 43lb bridge rail removed from Brunel's "Bath Road" was sold to the Netherlands in 1832, but a small batch was recently found having been used as reinforcement during the demolition of a stable block in Berkshire. The longitudinal baulks were around 12 in (305 mm). wide and 5 in (127 mm). deep or 10 by 7 in (254 by 178 mm), but the sizes varied depending on the timber available and the weight of traffic to be carried. Transoms were around 6 by 9 in (152 by 229 mm) and initially spaced at 15 feet (4.57 m) intervals but this was reduced over time to around 11 feet (3.35 m).

Broad gauge was superseded by standard gauge in 1892 but baulk road continued to be used for some time afterwards, although new work was already being constructed with conventional cross-sleepered track. Converting broad gauge baulk road to standard gauge involved cutting the transoms and slewing the longitudinal and its rail to its new position. Between 1852 and 1892 an ever-increasing length of the Great Western Railway was laid as mixed gauge that could be used by trains of either gauge. For baulk road this meant laying an additional longitudinal between the existing two (one rail was common to both gauges), but this significantly increased the cost and complexity of the track.

Alternative systems

MacDonnell plate track

Vignoles rail was a light section that today would be classed as flat-bottomed rail. In its original form it was only about 4 inches (102 mm) deep and was used on baulk road interchangeably with bridge rail.

William Henry Barlow's Barlow rail was patented in 1849 as a purely metal road. Deep rails with an inverted, curved V section were designed to be laid directly into the ballast; gauge was maintained by iron tie bars between the rails. The rails weighed 93 lb/yd (46.1 kg/m) but this was later increased to 99 lb/yd (49.1 kg/m). They were used on lines such as the West Cornwall Railway, Wycombe Railway and South Wales Railway. They soon fell out of favour as it proved difficult to pack the ballast properly. A large number were sold to the engineers building Clevedon Pier who bolted them together to use as girders.

The Bristol and Exeter Railway and the Bridport Railway used Brunel's bridge rail section but laid it on iron MacDonnell plates. These had three ridges to keep the rail in line and were laid directly into the ballast without any timber supports. It proved difficult to keep in alignment.

Seaton rail was similar to Vignoles rail but with the flanged foot angled down to give an inverted V section that was then used on triangular longitudinal.

Other applications

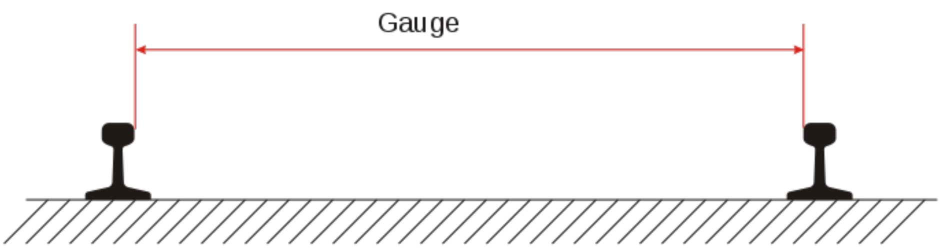
Modern baulk road at London Paddington station

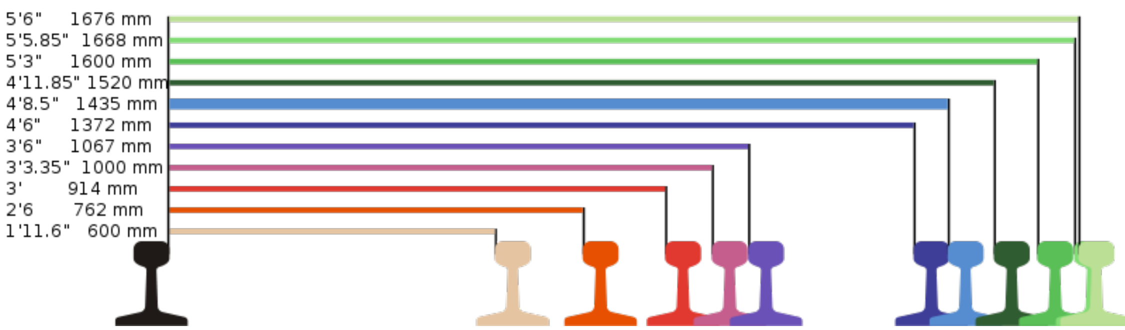
Baulk road was used by John Coode for a number of 7 ft 0 ¼ in (2,140 mm) railways that he built as part of large construction schemes for harbour breakwaters at places such as Portland and Table Bay. The great widths between the rails and between the transoms allowed him to support the tracks on piles and discharge rocks from wagons directly between the rails to form the foundations of the breakwaters.

A variant of baulk road can still be seen today on some older under-line bridges where no ballast is provided. The design varies considerably, but in many cases longitudinal timbers are supported directly on the cross-girders, with transoms and tiebars to retain the gauge, and modern rails and base-plates or chairs laid on top. It can also be found in places where easy drainage is required.

Chapter- 12

Track Gauge





Track gauge or **rail gauge** is the distance between the inner sides of the heads of the two load bearing rails that make up a single railway line. Sixty percent of the world's railways use a standard gauge of 1,435 mm (4 ft 8 ½ in). Wider gauges are called broad gauge; smaller gauges, narrow gauge. Break-of-gauge refers to the meeting of different gauges. Some stretches of track are dual gauge, with three or four rails, allowing trains of different gauges to share them. Gauge conversion can resolve break-of-gauge problems. An exception of a railway with no gauge is monorail where there is only one supporting rail. Some electrified railways use non load bearing third rail and occasionally a '4th' rail.

These additional rails are positioned between or outside the 'running rails' to feed and return electrical current, they do not define the rail gauge.

Gauge tolerances specify how much the actual gauge may vary from the nominal gauge. For example, the U.S. FRA specifies that the actual gauge of track that is rated for a maximum of 60 mph (96.6 km/h) must be between 4 ft 8 in (1,422 mm) and 4 ft 9 ½ in (1,460 mm).

A **track gauge** is also the name of the measuring device used to test whether rails are within the correct gauge.

Overview

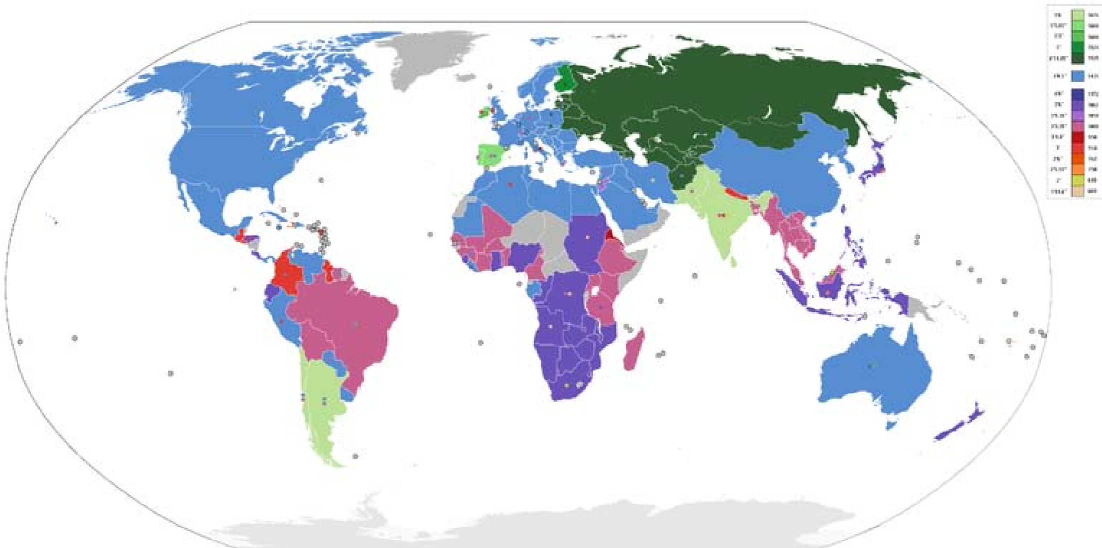
New railways, especially recent high speed rail (AVE and Shinkansen), are usually built to standard gauge. Advantages are:

- It facilitates inter-running with neighbouring railways
- Locomotives and rolling stock can be ordered from manufacturers' standard designs and do not need to be custom built, though some adaptation to local conditions may be necessary, for example, regarding loading gauge.

Generally speaking, of the gauges between 1,000 mm (3 ft 3 ⅜ in) and 1,700 mm (5 ft 6.93 in), standard gauge works well enough. The supposed advantages of broader or narrower gauges in this range are not enough to overcome the disadvantages of any break of gauge in a railway system.

Dominant gauges

ft′ in″	mm
5′ 6″	1676
5′ 5⅔″	1668
5′ 3″	1600
5′	1524
4′ 11⅞″	1520
4′ 8½″	**1435**
4′ 6″	1372
3′ 6″	1067
3′ 5⅓″	1050
3′ 3⅜″	1000
3′ 1⅜″	950
3′	914
2′ 6″	762
2′ 5½″	750
2′	610
1′ 11⅝″	600



The dominant rail gauge in each country shown

Gauge	Name	Installation, km	Usage
1,676 mm (5 ft 6 in)	Indian gauge	77,000	India (42,000 km; increasing with Project Unigauge), Pakistan, Argentina (24,000 km), Chile *(approx. 6.55% of the world's railways)*
1,668 mm (5 ft 5 ⅔ in)	Iberian gauge	15,394	Portugal, Spain. In Spain as of the Iberian gauge 21 km are of three-rail dual Iberian and standard gauges, more to come in the future
1,600 mm (5 ft 3 in)	Irish gauge	9,800	Ireland, and in Australia mainly Victoria and some South Australia Victorian gauge (4,017 km), Brazil (4,057 km)
1,524 mm (5 ft)	Russian gauge	5,865	Finland
1,520 mm (4 ft 11 ⅚ in)	Russian gauge	220,000	CIS states (including Russia), Estonia, Latvia, Lithuania, Mongolia *(approx. 17% of the world's railways)*
1,435 mm (4 ft 8 ½ in)	Standard gauge	720,000	Europe, Argentina, United States, Canada, China, Korea, Australia, Middle East, North Africa, Mexico, Cuba, Panama, Venezuela, Peru, Uruguay and Philippines. Also high-speed lines in Japan and Spain. *(approx. 60% of the world's railways)*

1,067 mm (3 ft 6 in)	Cape gauge	112,000	Southern and Central Africa, Indonesia, Japan, Taiwan, Philippines, New Zealand, Queensland Australia Queensland Rail *(approx. 9% of the world's railways)*
1,000 mm (3 ft 3 3⁄8 in)	Metre gauge	95,000	SE Asia, India (17,000 km, decreasing with Project Unigauge), Argentina (11,000 km), Brazil (23,489 km), Bolivia, northern Chile, Switzerland(RhB, MOB, BOB, MGB), Kenya, Uganda *(approx. 7% of the world's railways)*

Note: Russian gauge can be 1524 mm or 1520 mm.

History

Historically, the choice of gauge was partly arbitrary and partly a response to local conditions. Narrow-gauge railways are cheaper to build and can negotiate sharper curves but broad-gauge railways give greater stability and permit higher speeds. Standard gauge is a compromise between the narrow and broad gauges.

Sometimes railway companies chose their own gauge, such as the Great Western Railway choosing 2,140 mm (7 ft 0 1⁄4 in).

Other times, statutes required railways to use a particular gauge, such as the Thomasville, Tallahassee and Gulf Railroad having to use standard gauge.

Early origins of the standard gauge

There is an urban legend that Julius Caesar specified a legal width for chariots at the width of standard gauge, causing road ruts at that width, so all later wagons had to have the same width or else risk having one set of wheels suddenly fall into one deep rut but not the other.

In fact, the origins of the standard gauge considerably pre-date the Roman Empire, and may even pre-date the invention of the wheel. The width of prehistoric vehicles was determined by a number of interacting factors which gave rise to a fairly standard vehicle width of a little under 2 m (6.6 ft). These factors have changed little over the millennia, and are still reflected in today's motor vehicles. Road rutting was common in early roads, even with stone pavements. The initial impetus for the ruts probably came from the grooves made by sleds and slide cars dragged over the surfaces of ancient trackways. Since early carts had no steering and no brakes, negotiating hills and curves was dangerous, and cutting ruts into the stone helped them negotiate the hazardous parts of the roads.

Neolithic wheeled carts found in Europe had gauges varying from 130 to 175 cm (4 ft 3 in to 5 ft 9 in). By the Bronze age, wheel gauges appeared to have stabilized between 140 to 145 cm (4 ft 7 in to 4 ft 9 in) which was attributed to a tradition in ancient technology which was perpetuated throughout European history. The ancient Assyrians, Babylonians, Persians and Greeks constructed roads with artificial wheelruts cut in rock spaced the wheelspan of an ordinary carriage. Such ancient stone rutways connected major cities with sacred sites, such as Athens to Eleusis, Sparta to Ayklia, or Elis to Olympia. The gauge of these stone grooves was 138 to 144 cm (4 ft 6 in to 4 ft 9 in). The largest number of preserved stone trackways, over 150, are found on Malta.

Some of these ancient stone rutways were very ambitious. Around 600 BC the citizens of ancient Corinth constructed the Diolkos, which some consider the world's first railway, a granite road with grooved tracks along which large wooden flatbed cars carrying ships and their cargo were pulled by slaves or draft animals. The space between the grooved tracks in the granite was a consistent 1.5 m (4 ft 11 in).

The Roman Empire actually made less use of stone trackways than the prior Greek civilization because the Roman roads were much better than those of previous civilizations. However, there is evidence that the Romans used a more or less consistent wheel gauge adopted from the Greeks throughout Europe, and brought it to England with the Roman conquest of Britain in AD 43. After the Roman departure from Britain, this more-or-less standard gauge continued in use, so the wheel gauge of animal drawn vehicles in 19th century Britain was 1.4 to 1.5 m (4 ft 7 in to 4 ft 10 in). In 1814 George Stephenson copied the gauge of British coal wagons in his area (about 1.42 m (4 ft 8 in)) for his new locomotive, and for technical reasons widened it slightly to achieve the modern railway standard gauge of 1.435 m (4 ft 8.5 in).

Standard gauge

What became the standard gauge of 4 ft 8 ½ in (1,435 mm) was chosen for the first main-line railway, the Liverpool and Manchester Railway (L&MR), by the British engineer George Stephenson; the de facto standard for the colliery railways where Stephenson had worked was 4 ft 8 in (1,422 mm). Whatever the origin of the gauge, it seemed to be a satisfactory choice: not too narrow and not too wide.

Isambard Kingdom Brunel, engineer of the Great Western Railway, chose the broader gauge of 7 ft 0 ¼ in (2,140 mm) because it offered greater stability and capacity at high speed. Brunel's first locomotives were exactly 7 foot gauge and had no slack, hence the extra quarter inch. The Eastern Counties Railway chose 5 ft (1,524 mm) gauge, but soon realised that lack of compatibility was a mistake and changed to Stephenson's gauge. The conflict between Brunel and Stephenson is often referred to as the Gauge War. Several non-interconnecting lines in Scotland were 5 ft 6 in (1,676 mm) but were changed to standard gauge for compatibility reasons.

In 1845 a United Kingdom of Great Britain and Ireland Royal Commission recommended adoption of 4 ft 8 ½ in (1,435 mm) as standard gauge in Great Britain, 5 ft 3 in (1,600 mm) in Ireland. The following year the Parliament of the United Kingdom passed the Gauge Act, which required that new railways use the standard gauge. Except for the Great Western Railway's broad gauge, few main-line railways in Great Britain used a different gauge. The last Great Western line was converted to standard gauge in 1892.

Broad gauge

Broad gauge refers to any gauge wider than standard gauge or 1,435 mm (4 ft 8 ½ in). Russian, Indian, Irish, and Iberian gauges are all broad gauges. Broad gauge railways are also common for cranes in docks for short distances. Broad gauge is used to provide better stability or to prevent the easy transfer of rolling stock from railroads of other countries for political or military reasons. Compare with narrow gauge.

Russian gauge

Russian gauge is 1,520 mm (4 ft 11 ⅚ in) and is the second most widely used gauge in the world.

Engineer Pavel Melnikov hired George Washington Whistler, a prominent American railroad engineer (and father of the artist James McNeill Whistler), to be a consultant on the building of Russia's first major railroad, the Moscow–Saint Petersburg Railway line. The selection of 1,500 mm (4 ft 11 1⁄16 in) gauge was recommended by German and Austrian engineers but not adopted: it was not the same as the 1,524 mm (5 ft) gauge in common use in the southern United States at the time. Russian gauge was defined as 1,524 mm (5 ft) on September 12, 1842 and standardised to the present 1,520 mm (4 ft 11 ⅚ in) in the late 1960s.

The interconnected and compatible system covers Russia and most of the former Soviet Union, including the Baltic states, Ukraine, Belarus, the Caucasian and Central Asian republics and Mongolia.

Curiosities

Finland, which was a Grand Duchy under Russia in the 19th century, uses 1,524 mm (5 ft) gauge. Upon gaining independence in 1917 much thought was given to converting to standard gauge, but nothing came of it. Most of Finland's rail-freight trade is still with Russia, and this trade continues because the Russian 1,520 mm (4 ft 11 ⅚ in) gauge is close enough to allow through-running.

This 1,067 mm (3 ft 6 in) Japanese D51 steam locomotive stands outside the Yuzhno-Sakhalinsk Railway Station on Sakhalin Island, Russia.

The unconnected system on Sakhalin Island, in the far east of Russia, has retained the previous Japanese 1,067 mm (3 ft 6 in) gauge, as built. In 2004 a project was presented to convert this system to Russian gauge, in conjunction with a bridge/tunnel connection to the mainland.

Iberian gauge

The main railway networks of Spain and Portugal were constructed to gauges of six Castilian feet (1,672 mm/5 ft $5\frac{5}{6}$ in) and five Portuguese feet (1,664 mm/5 ft $5\frac{1}{2}$ in). The two gauges were sufficiently close to allow inter-operation of trains, and in recent years they have both been adjusted to a common "Iberian gauge" (*ancho ibérico* or *trocha ibérica* in Spanish, *bitola ibérica* in Portuguese) of 1,668 mm/5 ft $5\frac{2}{3}$ in. Although it has been said that the main reason for the adoption of this non-standard gauge was to obstruct any French invasion attempts, it was a technical decision to allow for the running of larger, more powerful locomotives in a mountainous country.

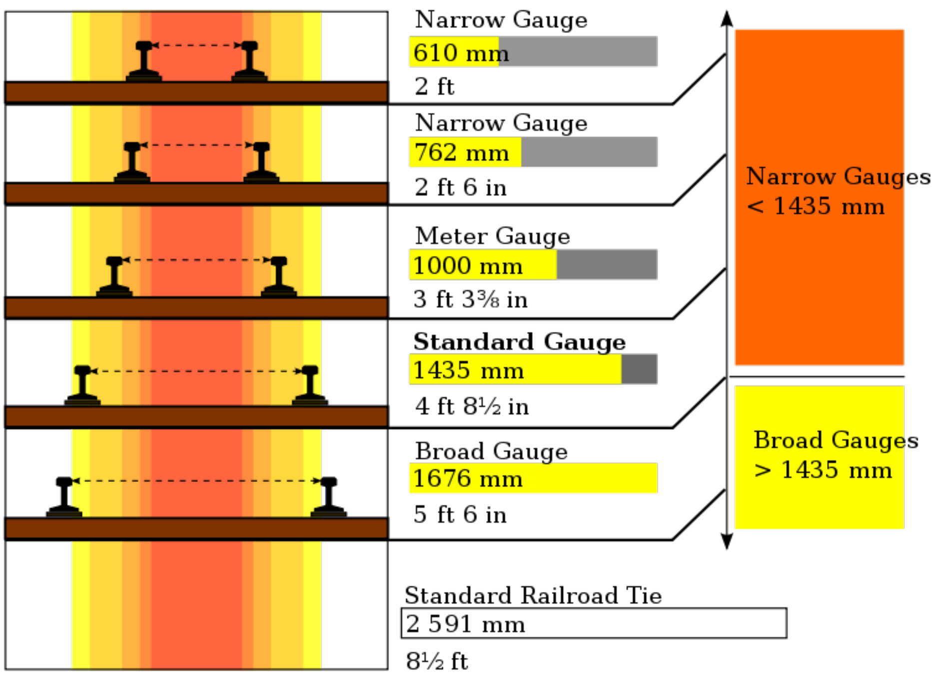
Since the beginning of the 1990s new high-speed passenger lines in Spain have been built to standard gauge of 1,435 mm (4 ft $8\frac{1}{2}$ in), to allow these lines to eventually link to the European high-speed network. Although the 21 km from Tardienta to Huesca (part of a branch from the Madrid to Barcelona high-speed line) has been reconstructed as dual Iberian and standard gauges, so are now being adapted lines between Barcelona and

Figueres that will be put into service at the end of 2010. In general the interface between the two gauges in Spain is dealt with by gauge-changing installations, which can adjust the gauge of appropriately designed wheelsets on the move.

There are plans to convert the whole broad gauge network to standard gauge, but so far the only visible indication is the use of dual-gauge concrete sleepers with two positions of bolt holes on renewed stretches of broad-gauge track.

Indian gauge

Bangladesh, India, Pakistan and Sri Lanka inherited a diversity of rail gauges, of which 1,676 mm (5 ft 6 in) was first and predominant. Indian Railways has adopted Project Unigauge, which seeks to systematically convert most of its narrower gauge railways to 1,676 mm.



Comparison of standard gauge with various gauges common in India.

Irish gauge

The gauge of main-line railways in Ireland is 5 ft 3 in (1,600 mm), found also in the Australian states of Victoria, southern New South Wales (as part of the Victorian rail network) and South Australia (where it was introduced by the Irish railway engineer F. W. Sheilds), and Brazil.

The first three railways all had different gauges: the Dublin and Kingstown Railway, 4 ft 8 in (1,422 mm); the Ulster Railway, 6 ft 2 in (1,880 mm); and the Dublin and Drogheda Railway, 5 ft 2 in (1,575 mm). The Board of Trade, recognising the chaos that would ensue, investigated the matter, and in 1843 recommended the use of 5 ft 3 in (1,600 mm).

This was given legal status by the Railway Regulation (Gauge) Act of 1846 which specified 4 feet 8½ inches (1,435 mm) for Great Britain and 5 feet 3 inches (1,600 mm) for Ireland.

Australian gauge

Despite early attempts at coordination, Australia has three different rail gauges in one country.

The then three mainland colonies adopted 1,435 mm (4 ft 8 ½ in) in 1848, with some states passing legislation to that effect.

Then there was a change to 1,600 mm (5 ft 3 in) at the instigation of New South Wales, which was agreed to by those then three states.

Then New South Wales reverted to standard gauge while Victoria and South Australia stayed with broad gauge, having ordered rolling stock to that gauge.

Queensland was built with 1,067 mm (3 ft 6 in) to save costs. Narrow gauge worked well enough for light traffic to persuade Tasmania, Western Australia and parts of South Australia to follow suit.

Dual and standard gauge lines have been introduced to the main interstate routes. Pilbara iron ore railways have always been standard gauge.

Italian gauge

Italy defined its gauges from the centres of each rail, rather than the inside edges of the rails, giving some unusual measurements (for example, 950 mm instead of 1000 mm). According to the law of 28 July 1879, the only legal gauges in Italy were 1500, 1000 and 750 mm measured to the middle of the rail, corresponding to 1445, 950, and 700 mm inside the rail.

A disadvantage of measuring from the centre of the rail is that the width of the rail varies, affecting the gauge. It is easier and more reliable to measure from the inner edges of the rails.

Narrow gauge

In many areas narrow gauge railways have been built. As the gauge of a railway is reduced the costs of construction can also be reduced since narrow gauges allow a smaller radius curves allowing obstacles to be avoided rather than having to be built over or through (valleys and hills); the reduced cost is particularly noticeable in mountainous regions. For example, many narrow gauge railways were built in Wales and the Rocky Mountains of North America. The disadvantage of tight turns and steep gradients is a reduced line speed and smaller trains leading to higher operating costs. Many narrow gauge railways have been abandoned or converted to standard gauge. Industrial railways are often constructed using narrow gauge. Sugar cane and banana plantations are often served by narrow gauges such as 2 ft (610 mm), as there is little through-traffic to other systems.

The most widely used narrow gauges are

- 1,067 mm (3 ft 6 in) Cape gauge (e.g. Southern and Central Africa, Indonesia, Japan, Taiwan, Philippines, parts of Australia, New Zealand)
- 1,000 mm (3 ft 3 ⅜ in) metre gauge (e.g. SE Asia, 17,000 km (11,000 mi) in India, but gauge conversion with Project Unigauge, East Africa, South America)

There are also minimum gauge railways.

Break of gauge

When a railway line of one gauge meets a line of another gauge there is a **break of gauge**. A break of gauge adds cost and inconvenience to traffic that passes from one system to another.

An example of this is on the Transmongolian Railway, where Russia and Mongolia use broad gauge while China uses standard gauge. At the border, each carriage has to be lifted in turn to have its bogies changed. The whole operation, combined with passport and customs control, can take several hours.

Other examples include crossings into or out of the former Soviet Union: Ukraine/Slovakia border on the Bratislava-L'viv train, and from the Romania/Moldova border on the Chisinau-Bucharest train.

This can be avoided however by implementing a system similar to that used in Australia, where some lines between states using different gauges were converted to dual gauge with three rails, one set of two forming a standard gauge line, with the third rail either inside or outside the standard set forming rails at either narrow or broad gauge. As a result, trains built to either gauge can use the line.

Dual gauge

Dual gauge allows trains of different gauges to share the same track. This can save considerable expense compared to using separate tracks for each gauge, but introduces complexities in track maintenance and signalling, as well as requiring speed restrictions for some trains. If the difference between the two gauges is large enough, for example between 1,435 mm (4 ft 8 ½ in) and 3 ft 6 in (1,067 mm), three-rail dual-gauge is possible, but if the difference is not large enough, for example between 3 ft 6 in (1,067 mm) and 1,000 mm (3 ft 3 ⅜ in), four-rail dual-gauge is used. Dual-gauge rail lines are used in the railway networks of Switzerland, Australia, Argentina, Brazil, North Korea, Spain, Tunisia and Vietnam.

Variable gauge axles

Variable gauge axles (VGA), developed by the Talgo company and Construcciones y Auxiliar de Ferrocarriles (CAF) of Spain, amongst others, enable trains to change gauge with only a few minutes spent in the gauge conversion process. The same system is also used between China and Central Asia, and Poland and Ukraine (SUW 2000 and INTERGAUGE variable axles system). China and Poland are standard gauge, while Central Asia and Russia are 1520 mm gauge.

Designed for Conversion

Equipment can be designed for easy conversion, such as the Garratt locomotives on the Kenya and Uganda Railway designed for conversion from 1,000 mm (3 ft 3 ⅜ in) to 1,067 mm (3 ft 6 in). Several classes of steam locomotives of the Victorian Railways were designed for easy conversion from 1,600 mm (5 ft 3 in) to 1,435 mm (4 ft 8 ½ in). Only one, R766, a preserved historic locomotive, has actually been converted.

Future

Further standardisation of rail gauges seems likely, as individual countries seek to build inter-operable national networks, and international organisations seek to build macro-regional and continental networks. National projects include the Australian and Indian efforts mentioned above to create a uniform gauge in their national networks. The European Union has set out to develop inter-operable freight and passenger rail networks across the EU area, and is seeking to standardise track gauge, signalling and electrical power systems. EU funds have been dedicated to convert key railway lines in the Baltic states of Lithuania, Latvia, and Estonia from 1520 mm gauge to standard gauge, and to assist Spain and Portugal in the construction of high-speed rail lines to connect Iberian cities to one another and to the French high-speed lines. The EU has developed plans for improved freight rail links between Spain, Portugal, and the rest of Europe.

High speed

Except in Russia and neighbouring states, all high-speed rail systems use standard gauge, even in countries like Japan, Taiwan, Spain and Portugal where most of the existing rail lines use a different gauge. Once standard gauge high-speed networks exist, they may provide the impetus for gauge conversion of existing passenger lines to allow for interoperability. All high speed lines have adopted 25 kV 50 Hz AC overhead line as the standard electrification system except in Germany, Sweden, Norway and Switzerland (15 kV AC and 3000 V DC), the first high speed lines in Italy (3000 V DC), the Tōkaidō, Sanyō and Kyūshū Shinkansen lines in Japan (25 kV 60 Hz) and the United States, which uses 25 kV 60 Hz in new construction and has older 12 kV segments.

Mining

Heavy duty mining railways which have little interconnection with other lines, such as in the Pilbara region of Western Australia, also tend to choose standard gauge to allow them to use off-the-shelf equipment, especially heavy-duty rolling stock.

New lines

The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) is planning a Trans-Asian Railway that will link Europe and the Pacific, with a Northern Corridor from Europe to the Korean Peninsula, a Southern Corridor from Europe to Southeast Asia, and a North-South corridor from Northern Europe to the Persian Gulf. All the proposed corridors would encounter one or more breaks of gauge as they cross Asia. Current plans have mechanized facilities at the breaks of gauge to move shipping containers from train to train rather than widespread gauge conversion.

- Rail lines for iron ore to Oakajee port in Western Australia are proposed to form a combined dual gauge network.
- Rail lines for iron ore to Kribi in Cameroon are likely to be 1435 mm with a likely connection to the same port from the 1000 mm gauge Cameroon system.

Kenya-Uganda-Sudan proposal

A proposal was aired in October 2004 to build a high-speed electrified line to connect Kenya with southern Sudan. Kenya and Uganda use 1,000 mm (3 ft $3\frac{3}{8}$ in) gauge, while Sudan uses 3 ft 6 in (1,067 mm) gauge. Standard gauge was proposed for the project.

Latin America

- 2008 proposed VCE link between Venezuela, Colombia and Ecuador
- 2008 - VBA - Venezuela via Brazil to Argentina - standard gauge
- 2008 A proposed metre gauge line across Southern Paraguay to link the Argentine rail at Resistencia to the Brazilian line at Cascavel; both those lines are metre gauge, and the new line would allow uninterrupted "bioceanic" running from one

coast to the other, from the Atlantic port of Paranagua in Brazil to that of Antofagasta in Chile on the Pacific.

Chapter- 13

Signalling Control

Bardon Hill box in England is a Midland Railway box dating from 1899, although the original mechanical lever frame has been replaced by electrical switches. Seen here in 2009.

On a rail transport system, **signalling control** is the process by which control is exercised over train movements by way of railway signals and block systems to ensure that trains operate safely, over the correct route and to the proper timetable. Signalling control was originally exercised via a decentralised network of control points that were known by a variety of names including **signal box** (British), **interlocking tower** (North America), **signal poste** (France) and **signal cabin**. Currently these decentralised systems are being consolidated into wide scale **signalling centres** or **dispatch offices**. Whatever the form, signalling control provides an interface between the human signal operator and the lineside signalling equipment.

History

Signal box and tracks at Deval interlocking, Des Plaines, Illinois, in 1993

Originally, all signalling was done by mechanical means. Points and signals were operated locally from individual levers or handles, requiring the signalman to walk between the various pieces of equipment to set them in the required position for each train that passed. Before long, it was realised that control should be concentrated into one building, which came to be known as a signal box. The signal box provided a dry, climate controlled space for the complex interlocking mechanics and also the signalman. The raised design of most signal boxes (which gave rise to the term "tower" in North America) also provided the signalman with a good view of the railway under his control. The first use of a signal box was by the London and Croydon Railway in 1844 to control the branch line to Bricklayers' Arms.

With the practical development of electric power, the complexity of a signal box was no longer limited by the distance a mechanical lever could work a set of points or a semaphore signal via a direct physical connection (or the space required by such connections). Power operated switch points and signalling decides greatly expanded the territory that a single control point could operate from several hundred yards to several miles. As the technology of electric relay logic was developed, it no longer became necessary for signalmen to operate control devices with any sort of mechanical logic at all. With the jump to all electronic logic, physical presence was no longer needed and the individual control points could be consolidated to increase system efficiency.

Another advancement made possible by the replacement of mechanical control by all electric systems was that the signalman's user interface could be enhanced to further improve productivity. The smaller size of electric toggles and push buttons put more functionality within reach of an individual signalman. Route-setting technology automated the setting of individual points and routes through busy junctions. Computerised video displays removed the physical interface all together, replacing it with a point-and-click or touchscreen interface. Finally, the use of Automatic Route Setting removed the need for any human input at all as common train movements could be fully automated according to a schedule or other scripted logic.

Signal boxes also served as important communications hubs, connecting the disparate parts of a rail line and linking them together to allow the safe passage of trains. The first signalling systems were made possible by technology like the telegraph and block instrument that allowed adjacent signal boxes to communicate the status of a section of track. Later, the telephone put centralised dispatchers in contact with distant signal boxes and radio even allowed direct communication with the trains themselves. The ultimate ability for data to be transmitted over long distances has proven the demise of most local control signal boxes. Signalmen next to the track are no longer needed to serve as the eyes and ears of the signalling system. Track circuits transmit train locations to distant control centres and data links allow direct manipulation of the points and signals.

While some rail systems have more signal boxes than others, most future signalling projects will result in increasing amounts of centralised control relegating the lineside signal box to niche or heritage applications.

Naming

In any node-based control system, proper identification is critical to ensuring that messages are properly received by their intended recipients. As such, signalling control points are provided with names or identifiers that minimise the likelihood of confusion during communications.

In the United Kingdom and other Commonwealth countries, each signal box is assigned a unique name based on the geographical locality. Where multiple signal boxes existed at one locality, suffixes such as "West" and "East" were added to the geographical name, or they would be individually numbered, e.g. "Stockport No. 1", etc. In very remote areas, the name may be derived from the lineside mileage, e.g. "73rd Mile".

In Central Europe, it is common to issue signalling control points with a regionally unique location code based roughly on the point's location and function. The signalling locations may have longer, full names associated with them, but the identification codes can be employed more efficiently.

In North America, signalling locations were most often provided with one or two digit telegraph call letters that were locally unique to the rail line or division. These letters could stand for the control point's location or function as a form of mnemonic aid, but sometimes they were simply randomly or problematically chosen. The purpose of the short IDs were to reduce overhead when transmitting messages in Morse code. As time went on and voice communications replaced the Morse code the codes began to be replaced with more human recognizable names, again often based on geographic location. As control passed from field operators to centralised dispatchers, the dispatching desks took on identifiers that could encompass geographic areas or entire routes as well as simple numbers or programmatic identification codes.

In most cases where the control locations are still in the field adjacent to railway tracks, the name or code of the control point is plainly labelled on the side of the signal box structure as an extra visual reminder to the train operators where they are. Moreover, wayside signals may also be equipped with identification plates that directly or indirectly indicate who controls that signal and that stretch of the line.

Control apparatus

Lever frame

A mechanical lever frame inside the signal box at Knockcroghery in Ireland

The earliest signal boxes housed mechanical lever frames. The frame was usually mounted on a beam beneath the operating floor. Interlocking was attached to the levers, which ensured that signals showed the correct indication with regard to the points and were operated in the right order. Wires or rods, connected at one end to the signals and points and at the other to levers in the signal box, ran alongside the railway.

In many countries, levers are painted according to their function, e.g. red for stop signals and black for points, and are usually numbered, from left to right, for identification. In most cases, a diagram of the track and signalling layout is mounted above the lever frame, showing the relevant lever numbers adjacent to the signals and points.

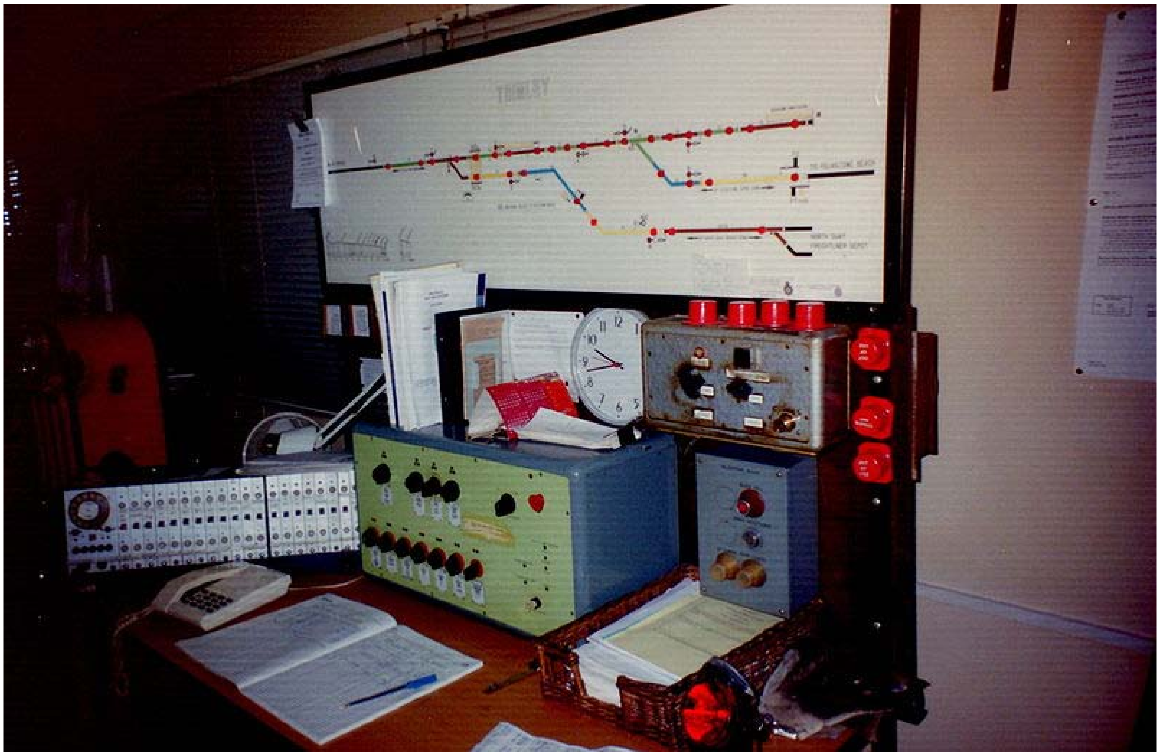
Handpowered interlockings were referred to as armstrongs and handthrows in the United States.

Power frames have miniature levers and control the signals and points electrically. In some cases, the interlocking was still done mechanically, but in others, electric lever locks were used.

In a few cases, signals and points were operated pneumatically upon operation of the appropriate lever or slide.

Control panel

In a signal box with a control panel, the levers are replaced by buttons or switches, usually appropriately positioned directly onto the track diagram. These buttons or switches are interfaced with an electrical or electronic interlocking. In the UK, control panels are of the following types:



Trimley Junction IFS panel in the 1988 replacement signal box; built by BREL York

Individual Function Switch (IFS)

A separate button/switch is provided for each signal and for each set of points. This type of panel is operated in a similar manner to a lever frame. The signalman must move each set of points to the desired position before operating the switch or button of the signal reading over them.

This type of panel needs the least complex circuitry but is not suited to controlling large or busy areas.

One Control Switch (OCS)

A separate switch/button is provided for every signalled route. There will be as many switches/buttons per signal as there are routes (i.e. signalled destinations) from that signal. To set the desired route, the relevant switch or button is operated. All points within the route are automatically set to the required position. Individual points switches are provided, but they are normally left in the central position, which allows the points to be automatically set by the action of setting a route.

Entrance-Exit (NX)

This type of panel has one switch/button provided for every signalled route (except that some panels have separate 'entrance' and 'exit' devices). To set a route, the signalman operates the device for the 'entrance' signal, followed by the device for the 'exit' (destination) signal. All points within the route are automatically set to the required position and, provided all the points are detected by the interlocking in the correct position the signal will clear.

Individual points switches are provided, but they are normally left in the central position, which allows the points to be automatically set to the normal or reverse position by the action of setting a route.

Similar principles of operation as described above are applicable throughout the world.

Visual Display Unit

Modern signal boxes nowadays tend to be provided with VDU based, or similar, control systems. These systems are less expensive to build and easier to alter than a traditional panel. In the UK, large modern signal boxes are typically of the Integrated Electronic Control Centre type. Variations of these control systems are used throughout the world.

Present day

Signal box in Krzeszowice, Poland in 2008

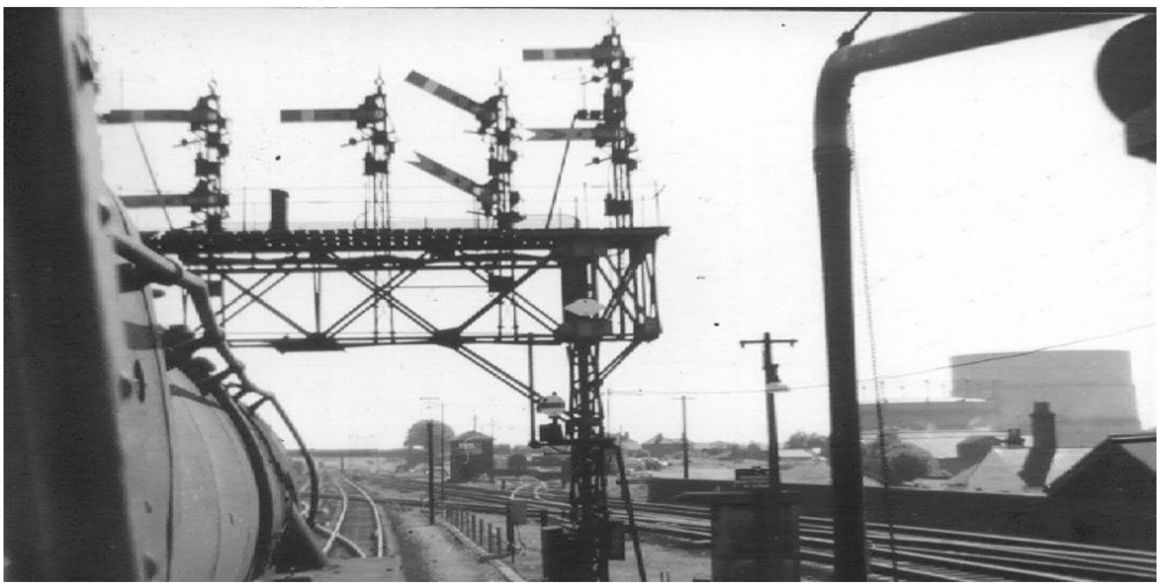
While rare, some traditional signal boxes can still be found. Some still control mechanical points and signals, although in many cases, the lever frame has been removed or is out of use, and a control panel or VDU has been installed. Most modern countries have little, if any, mechanical signalling remaining on the rail system. Both in the UK and

Ireland, however, mechanical signalling is still common away from the busiest lines. Traditional signal boxes can also be found on heritage railways.

The modern control centre has largely replaced widespread signal cabins. These centres, usually located near main railway stations, control the track network using electrical or electronic systems. One such system is CTC, Centralised Traffic Control.

Chapter- 14

Railway Signalling



A gantry of British semaphore signals seen from the cab of a steam locomotive

Railway signalling is a system used to control railway traffic safely, essentially to prevent trains from colliding. Being guided by fixed rails, trains are uniquely susceptible to collision; furthermore, trains cannot stop quickly, and frequently operate at speeds that do not enable them to stop within sighting distance of the driver. In the UK, the Regulation of Railways Act 1889 introduced a series of requirements on matters such as the implementation of interlocked block signalling and other safety measures as a direct result of the Armagh rail disaster in that year.

Most forms of train control involve movement authority being passed from those responsible for each section of a rail network (e.g., a signalman or stationmaster) to the train crew. The set of rules and the physical equipment used to accomplish this determine what is known as the *method of working* (UK), *method of operation* (US) or *safeworking* (Aus.). Not all these methods require the use of physical signals and some systems are specific to single track railways.

The earliest rail cars were first hauled by horses or mules. A mounted flagman on a horse preceded some early trains. Hand and arm signals were used to direct the “train drivers”. Foggy and poor-visibility conditions gave rise to flags and lanterns. Wayside signalling dates back as far as 1832, and used elevated flags or balls that could be seen from afar.

Timetable operation

The simplest form of operation, at least in terms of equipment, is to run the system according to a timetable. A fixed schedule is drawn up with which every train crew must be familiar. Trains may only run on each section of track at their scheduled time, during which they have 'possession' and no other train is permitted to use the same section.

When trains are running in opposite directions on a single-track railroad, meeting points ("meets") are scheduled, at which each train must wait for the other at a passing place. Neither train is permitted to move before the other has arrived. In the US the display of two green flags (green lights at night) is an indication that another train is following the first and the waiting train must wait for the next train to pass. In addition, the train carrying the flags gives eight blasts on the whistle as it approaches. The waiting train must return eight blasts before the flag carrying train may proceed.

The timetable system has several disadvantages. First, there is no positive confirmation that the track ahead is clear, only that it is scheduled to be clear. The system does not allow for engine failures and other such problems, but the timetable is set up so that there should be sufficient time between trains for the crew of a failed or delayed train to walk far enough to set up warning flags, flares, and *detonators* or *torpedoes* (UK and US terminology, respectively) to alert any other train crew.

A second problem is the system's inflexibility. Trains cannot be added, delayed, or rescheduled without advance notice.

A third problem is a corollary of the second: the system is inefficient. To provide flexibility, the timetable must give trains a broad allocation of time to allow for delays, so the line is in the possession of each train for longer than is otherwise necessary.

Nonetheless, this system permits operation on a vast scale, with no requirements for any kind of communication that travels faster than a train. Timetable operation was the normal mode of operation in North America in the early days of the railroad.

Timetable and train order

With the advent of the telegraph in 1851, a more sophisticated system became possible because this provided a means whereby messages could be transmitted ahead of the trains. The telegraph allows the dissemination of any timetable changes, known as *train orders*. These allow the cancellation, rescheduling and addition of train services.

Train crews generally receive their orders at the next station at which they stop, or they are sometimes handed up to a locomotive 'on the run' via a long staff. Train orders allowed dispatchers to set up meets at sidings, force a train to wait in a siding for a priority train to pass, and to maintain at least one block spacing between trains going the same direction.

Timetable and train order operation was commonly used on American railroads until the 1960s, including some quite large operations such as the Wabash Railroad and the Nickel Plate Road. Train order traffic control was used in Canada until the late 1980s on the Algoma Central Railway and some spurs of the Canadian Pacific Railway.

Timetable and train order was not used widely outside North America, and has been phased out in favor of radio dispatch on many light-traffic lines and electronic signals on high-traffic lines. More details of North American operating methods is given below.

Block signalling

British lower-quadrant semaphore stop signal (absolute) with subsidiary arm (permissive) below

Trains cannot collide with each other if they are not permitted to occupy the same section of track at the same time, so railway lines are divided into sections known as *blocks*. In normal circumstances, only one train is permitted in each block at a time. This principle forms the basis of most railway safety systems.

History of block signalling

On double-tracked railway lines, which enabled trains to travel in one direction on each track, it was necessary to space trains far enough apart to ensure that they could not collide. In the very early days of railways, men (originally called 'policemen') were employed to stand at intervals ("blocks") along the line with a stopwatch and use hand signals to inform train drivers that a train had passed more or less than a certain number of minutes previously. This was called "time interval working". If a train had passed very recently, the following train was expected to slow down to allow more space to develop.

The watchmen had no way of knowing whether a train had cleared the line ahead, so if a preceding train stopped for any reason, the crew of a following train would have no way of knowing unless it was clearly visible. As a result, accidents were common in the early days of railways. With the invention of the electrical telegraph, it became possible for staff at a station or signal box to send a message (usually a specific number of rings on a bell) to confirm that a train had passed and that a specific block was clear. This was called the "absolute block system".

Fixed mechanical signals began to replace hand signals from the 1830s. These were originally worked locally, but it later became normal practice to operate all the signals on a particular block with levers grouped together in a signal box. When a train passed into a block, a signalman would protect that block by setting its signal to 'danger'. When an 'all clear' message was received, the signalman would move the signal into the 'clear' position.

The block system came into use gradually during the 1850s and 1860s and became mandatory in the United Kingdom after Parliament passed legislation in 1889 following a number of accidents, most notably the Armagh rail disaster. This required block signalling for all passenger railways, together with interlocking, both of which form the basis of modern signalling practice today. Similar legislation was passed by the United States around the same time.

Not all blocks are controlled using fixed signals. On some single track railways in the UK, particularly those with low usage, it is common to use token systems that rely on the train driver's physical possession of a unique token as authority to occupy the line, normally in addition to fixed signals.

Entering and leaving a manually-controlled block

Before allowing a train to enter a block, a signalman must be certain that it is not already occupied. When a train leaves a block, he must inform the signalman controlling entry to the block. Even if the signalman receives advice that the previous train has left a block, he is usually required to seek permission from the next signal box to admit the next train. When a train arrives at the end of a block section, before the signalman sends the message that the train has arrived, he must be able to see the end-of-train marker on the back of the last vehicle. This ensures that no part of the train has become detached and remains within the section. The end of train marker might be a white disc by day or a steady or flashing red lamp. If a train has entered the next block before the signalman sees that the disc or lamp is missing, he will ask the next signal box to stop the train and investigate.

Permissive and absolute blocks

Under a permissive block system, trains are permitted to pass signals indicating the line ahead is occupied, but only at such a speed that they can stop safely driving by sight. This allows improved efficiency in some situations and is mostly used in the USA, and in most countries is restricted to freight trains only, and may be restricted depending on the level of visibility.

Permissive block working may also be used in an emergency, either when a driver is unable to contact a signalman after being held at a danger signal for a specific time, although this is only permitted when the signal does not protect any conflicting moves, and also when the signalman is unable to contact the next signal box to make sure the previous train has passed, for example if the telegraph wires are down. In these cases, trains must proceed at very low speed (typically 20 mph or less) so that they are able to stop short of any obstruction. In most cases this will not be allowed during times of poor visibility (e.g. fog or falling snow).

Even when an absolute block system is implemented, multiple trains may enter a block with authorisation. This may be necessary e.g. in order to split or join trains together, or to rescue failed trains. In giving authorisation, the signalman also ensures the driver knows precisely what to expect ahead, and the driver must operate the train in a safe manner taking this information into account. Generally, the signal will remain at danger, and the driver will be given verbal authority, usually accompanied by a yellow flag, to pass a signal at danger, and the presence of the train in front will be explained. At locations where trains regularly enter occupied blocks, such as stations where coupling takes place, a subsidiary signal, sometimes known as a "calling on" signal, will be provided for these movements, otherwise they are accomplished through train orders.

Automatic block

Under automatic block signalling, signals indicate whether or not a train may enter a block based on automatic train detection indicating whether a block is clear. The signals may also be controlled by a signalman, so that they only provide a *proceed* indication if the signalman sets the signal accordingly and the block is clear.

Fixed block

Most blocks are "fixed", i.e. they include the section of track between two fixed points. On timetable, train order, and token-based systems, blocks usually start and end at selected stations. On signalling-based systems, blocks start and end at signals.

The lengths of blocks are designed to allow trains to operate as frequently as necessary. A lightly-used line might have blocks many kilometres long, but a busy commuter line might have blocks a few hundred metres long.

A train is not permitted to enter a block until a signal indicates that the train may proceed, a dispatcher or signalman instructs the driver accordingly, or the driver takes possession of the appropriate token. In most cases, a train cannot enter the block until not only the block itself is clear of trains, but there is also an empty section beyond the end of the block for at least the distance required to stop the train. In signalling-based systems with closely-spaced signals, this overlap could be as far as the signal following the one at the end of the section, effectively enforcing a space between trains of two blocks.

When calculating the size of the blocks, and therefore the spacing between the signals, the following have to be taken into account:

- Line speed (the maximum permitted speed of each train)
- Gradient (to compensate for longer or shorter braking distances)
- The braking characteristics of trains on that line
- Sighting (how far ahead a driver can see a signal)
- Reaction time (of the driver)

Historically, some lines operated so that certain large or high speed trains were signalled under different rules and only given the right of way if two blocks in front of the train were clear.

Moving block

One disadvantage of having fixed blocks is that the faster trains are allowed to run, the longer the stopping distance, and therefore the longer the blocks need to be, thus decreasing the line's capacity.

Under a moving block system, computers calculate a 'safe zone' around each moving train that no other train is allowed to enter. The system depends on knowledge of the precise location and speed and direction of each train, which is determined by a combination of several sensors: active and passive markers along the track and trainborne tachometers and speedometers (GPS systems cannot be used because they do not work in tunnels.) With a moving block, lineside signals are unnecessary, and instructions are passed directly to the trains. This has the advantage of increasing track capacity by allowing trains to run closer together while maintaining the required safety margins.

Moving block is in use on Vancouver's Skytrain, London's Docklands Light Railway, New York City's BMT Canarsie Line, and London's Jubilee Line. It was supposed to be the enabling technology on the modernisation of Britain's West Coast Main Line which would allow trains to run at a higher maximum speed (140 mph), but the technology was deemed not mature enough, considering the large number of junctions on the line, and the plan was dropped. It forms part of the European Rail Traffic Management System's level-3 specification for future installation in the European Train Control System, which will (at level 3) feature moving blocks that allow trains to follow each other at exact braking distances.

Train detection

Track circuits

One of the most common ways to determine whether a section of line is occupied is by use of a track circuit. The rails at either end of each section are electrically isolated from the next section, and an electrical current is fed to both running rails at one end. A relay at the other end is connected to both rails. When the section is unoccupied, the relay coil completes an electrical circuit, and is energized. However, when a train enters the section, it short-circuits the current in the rails, and the relay is de-energized.

This method does not explicitly need to check that the entire train has left the section. If part of the train is left in the section, that part will continue to be detected by the track circuit.

This type of circuit is used to detect trains, both for the purpose of setting the signal indication and for providing various interlocking functions — for example, not permitting points to be moved when a train is standing over them. Electrical circuits are also used to *prove* that points are in the appropriate position before a signal over them may be cleared. Modern UK trains, and staff working in track circuit block areas, carry operating clips so that, in the event of a derailment fouling an adjacent track, the track circuit can be short-circuited. This places signals on that track to 'danger' and can be used to prevent a collision before the crew is able to contact a signalman.

Axle counters

An alternative method of determining the occupied status of a block is using devices located at its beginning and end that count the number of axles entering and leaving. If the same number leave the block as enter it, the block is assumed to be clear. Although axle counters can provide similar functionality to track circuits, they also exhibit a few other characteristics. In a damp environment an axle counted section can be far longer than a track circuited one. The low ballast resistance of very long track circuits reduces their sensitivity. Track circuits can automatically detect some types of track defect such as a broken rail. In the event of power restoration after a power failure, an axle counted section is left in an undetermined state until a train has passed through the affected section. When a block section has been left in an undetermined state, it may be worked under pilot working. The first train to pass through the section would typically do so at a speed no greater than 20 mph or walking pace in areas of high transition, reverse curvature and may have someone who has a good local knowledge of the area acting as the pilotman. A track circuited section will detect the presence of a train in section immediately.

Fixed signals

On most railways, physical signals are erected at the lineside to indicate to drivers whether the line ahead is occupied and to ensure that sufficient space exists between trains to allow them to stop.

Mechanical signals

Older forms of signal displayed their different aspects by their physical position. The earliest types comprised a board that was either turned face-on and fully visible to the driver, or rotated so as to be practically invisible. While this type of signal is still in use in some countries (e.g. France and Germany), by far the most common form of mechanical signal worldwide is the *semaphore signal*. This comprises a pivoted arm or blade that can be inclined at different angles. A horizontal arm is the most restrictive indication (for 'danger' or 'caution', depending on the type of signal).

To enable trains to run at night, one or more lights are usually provided at each signal. Typically this comprises a permanently-lit oil lamp with movable coloured spectacles in front that alter the colour of the light. The driver therefore had to learn one set of indications for day time viewing and another for night time viewing.

Whilst it is normal to associate the presentation of a green light with a safe condition, this was not historically the case. In the very early days of railway signalling, the first coloured lights (associated with the turned signals above) presented a white light for 'clear' and a red light for 'danger'. Green was originally used to indicate 'caution' but fell out of use when the time interval system was discontinued. A green light subsequently replaced white for 'clear', to address concerns that a broken red lens could be taken by a driver as a false 'clear' indication. It was not until scientists at Corning Glassworks perfected a shade of yellow without any tinges of green or red that yellow became the accepted colour for 'caution'.

Mechanical signals are usually remotely operated by wire from a lever in a signal box, but electrical or hydraulic operation is normally used for signals that are located too distant for manual operation.

Colour light signals

Vertical colour light signal on the Enshū Railway Line in Japan

On most modern railways, colour light signals have largely replaced mechanical ones. Colour light signals have the advantage of displaying the same aspects by night as by day, and require less maintenance than mechanical signals.

Although signals vary widely between countries, and even between railways within a given country, a typical system of aspects would be:

- Green: Proceed at line speed. Expect to find next signal displaying green or yellow.
- Yellow: Prepare to find next signal displaying red.

- Red: Stop.

On some railways, colour light signals display the same set of aspects as shown by the lights on mechanical signals during darkness.

Route signalling and speed signalling

Signalling of British origin generally conforms to the principle of *route signalling*. Most railway systems around the world, however, use what is known as *speed signalling*.

Under **route signalling**, a driver is informed which route the train will take beyond each signal (unless only one route is possible). This is achieved by a *route indicator* attached to the signal. The driver uses his route knowledge, reinforced by speed restriction signs fixed at the lineside, to drive the train at the correct speed for the route to be taken. This method has the disadvantage that the driver may be unfamiliar with a route onto which he has been diverted due to some emergency condition. Several accidents have been caused by this alone. For this reason, in the UK drivers are only allowed to drive on routes that they have been trained on and must regularly 'practice' on lesser used diversionary routes to keep their route knowledge up to date.

Under **speed signalling**, the driver is not informed which route the train will take, but the signal aspect informs him at what speed he may proceed. Speed signalling requires a far greater range of signal aspects than route signalling, but less dependence is placed on drivers' route knowledge.

Approach release

When the train is routed towards a diverging route that must be taken at a speed significantly less than the mainline speed, the driver must be given adequate prior warning.

Under 'route signalling', the aspects necessary to control speed do not exist, so a system known as *approach release* is employed. This involves holding the junction signal at a restrictive aspect (typically 'stop') in order that the signals on the approach show the correct sequence of caution aspects. The driver will brake in accordance with the caution aspect, without necessarily being aware that the diverging route has in fact been set. As the train approaches the junction signal, its aspect may clear to whatever aspect the current track occupancy ahead will permit. Where the turnout speed is the same, or nearly the same, as the mainline speed, approach release is unnecessary.

With speed signalling, the signals approaching the divergence will display aspects appropriate to control the trains speed, so no 'approach release' is required.

Safety systems

The consequence of a driver/engineer failing to respond to a signal's indication can be disastrous. As a result, various auxiliary safety systems have been devised. Any such system will necessitate the installation of trainborne equipment to some degree. Some systems only intervene in the event of a signal being passed at danger. Others include audible and/or visual indications inside the driver's cab to supplement the lineside signals. Automatic brake application occurs if the driver should fail to acknowledge a warning. Some systems act intermittently (at each signal), but the most sophisticated systems provide continuous supervision.

In-cab safety systems are of great benefit during fog, when poor visibility would otherwise require that restrictive measures be put in place.

Cab signalling

Example of cab signal

Cab signalling is a system that communicates track status information to the train cab (driving position), where the engine driver can see the information. The simplest systems display the trackside signal aspect, while more sophisticated systems also display allowable speed and dynamic information about the track ahead. In modern systems, a train protection system is usually overlaid on top of the cab signalling system to warn the driver of dangerous conditions, and to automatically apply the brakes and bring the train to a stop if the driver ignores the dangerous condition. Cab signalling systems range from simple coded track circuits, to transponders that communicate with the cab, and communication-based train control systems.

Interlocking

In the early days of the railways, signalmen were responsible for ensuring any points (US: switches) were set correctly before allowing a train to proceed. Mistakes were made which led to accidents, sometimes with fatalities. The concept of the interlocking of points, signals and other appliances was introduced to improve safety. This prevents a signalman from operating appliances in an unsafe sequence, such as setting a signal to 'clear' while one or more sets of points in the route ahead of the signal are improperly set.

Early interlocking systems used mechanical devices both to operate the signalling appliances and to ensure their safe operation. Beginning around the 1930s, electrical relay interlockings were used. Since the late 1980s, new interlocking systems have tended to be of the electronic variety.

Operating rules

Operating rules, policies and procedures are used by railroads to enhance safety. Specific operating rules may differ from country to country and even from railroad to railroad within the same country.

Australian operating rules

In Australia, operating rules are called Safeworking.

North American operating rules

In North America and especially the US, operating rules are called *method of operation*. There are five main sets of operating rules in North America:

- Canadian Rail Operating Rules (CROR), used by most Canadian railroads
- General Code of Operating Rules (GCOR), used by many Class I railroads, Class II railroads, and many Short-line railroads
- Northeast Operating Rules Advisory Committee (NORAC), used by many railroads in the Northeast US
- Class I Norfolk Southern uses a unique set of operating rules.
- Class I CSX Transportation uses a unique set of operating rules.

UK operating rules

In the UK, operating rules are called *method of working*. It is commonly known as the "Rule-book" by railway employees. It is controlled by the Rail Safety and Standards Board (RSSB), which is independent from Network Rail or any other Train/Freight Operating Company. Most heritage railways operate to a simplified variant of a British Railways rule book.