



Track Gauges in
Railway Systems Engineering
Dontae Spain

Revised Edition: 2014

ISBN 978-81-323-2909-1

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Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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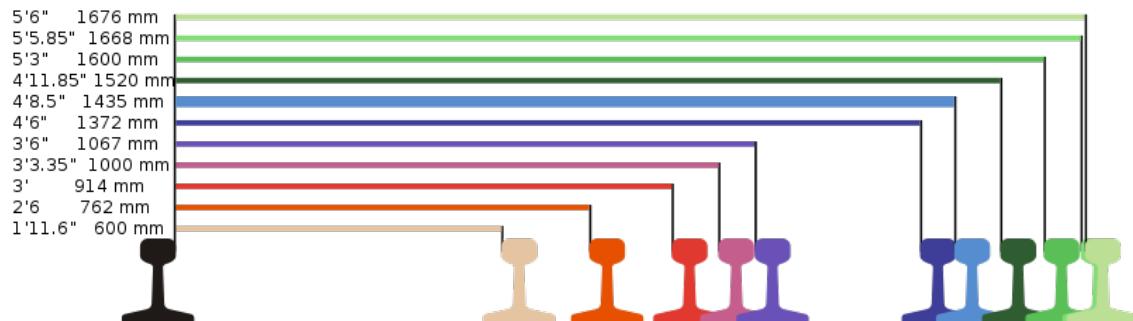
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Chapter- 1

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 8½ 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 9½ 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

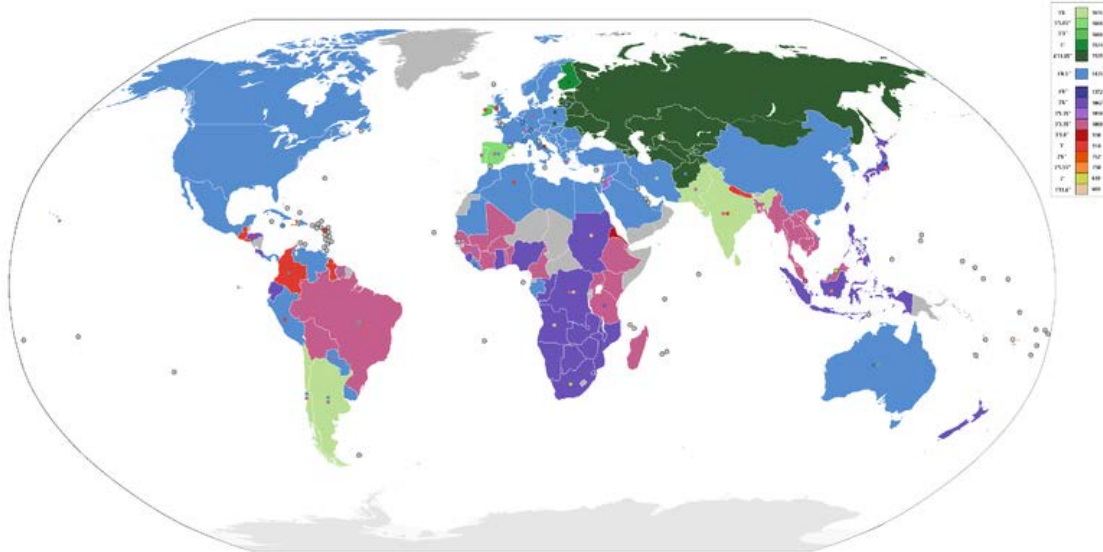
New railways, especially recent high speed rail (AVE and Shinkansen), are usually built to standard gauge. Advantages are:

- 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 ³/₈ 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' 5 ² / ₃ "	1668
5' 3"	1600
5'	1524
4' 11 ⁷ / ₈ "	1520
4' 8¹/₂"	1435
4' 6"	1372
3' 6"	1067
3' 5 ¹ / ₃ "	1050
3' 3 ³ / ₈ "	1000
3' 1 ³ / ₈ "	950
3'	914
2' 6"	762
2' 5 ¹ / ₂ "	750
2'	610
1' 11 ⁵ / ₈ "	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 <i>(approx. 6.55% of the world's railways)</i>
1,668 mm (5 ft 5 2/3 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 5/6 in)	Russian gauge	220,000	CIS states (including Russia), Estonia, Latvia, Lithuania, Mongolia <i>(approx. 17% of the world's railways)</i>
1,435 mm (4 ft 8 1/2 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. <i>(approx. 60% of the world's railways)</i>
1,067 mm (3 ft 6 in)	Cape	112,000	Southern and Central Africa, Indonesia,

	gauge		Japan, Taiwan, Philippines, New Zealand, Queensland Australia Queensland Rail <i>(approx. 9% of the world's railways)</i>
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 <i>(approx. 7% of the world's railways)</i>

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 1/2 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 5/6 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 5/6 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 5/6 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 5⁵/₆ in) and five Portuguese feet (1,664 mm/5 ft 5¹/₂ 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 5²/₃ 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.

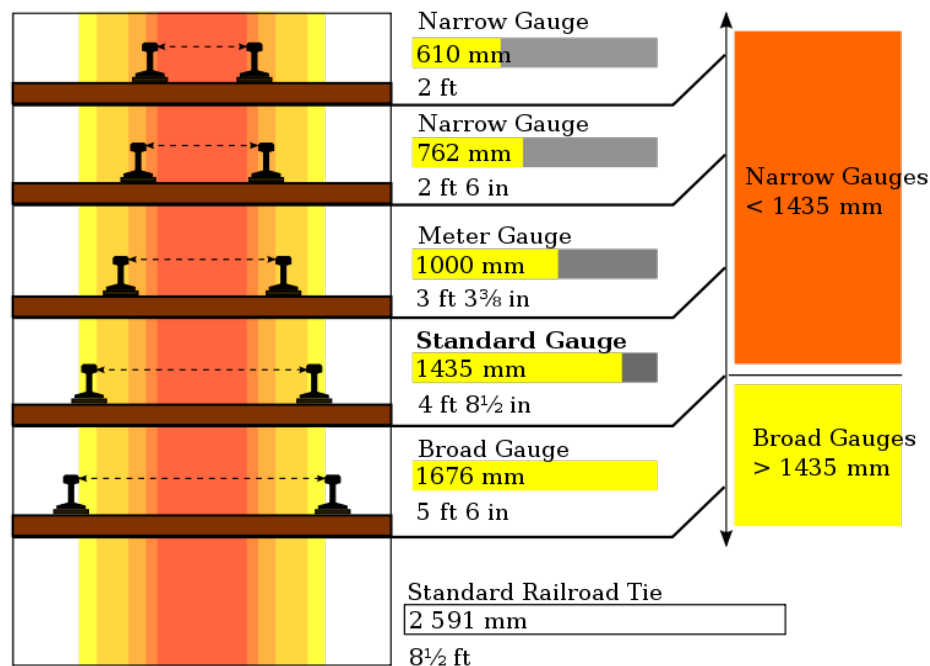
Since the beginning of the 1990s new high-speed passenger lines in Spain have been built to standard gauge of 1,435 mm (4 ft 8¹/₂ in), to allow these lines to eventually link to the European high-speed network. Although the 21 km from Tardienta to Huesca (part of a branch from the Madrid to Barcelona 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 8½ 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 3³/₈ 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 8¹/₂ 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 3³/₈ 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 3³/₈ 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 8¹/₂ 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 3³/₈ 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.