

Tram Transport & Technology

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WORLD TECHNOLOGIES

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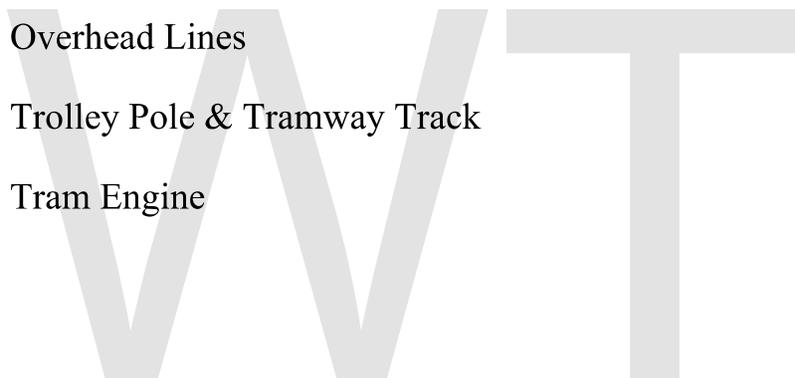
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Chapter 1

Tram



Czech Tatra T3 - 14,113 units sold worldwide make it the most successful type of tram.

A **tram** or **tramcar** in most forms of English, referred to as **streetcar** or **trolley car** in North American English, is a rail vehicle which—at least in parts of its route—runs on tracks in streets. It may also run between cities and/or towns (interurbans, tram-train), and/or partially grade separated even in the cities (light rail or light rapid transit). Trams are designed for the transport of passengers and (very occasionally) freight.

Trams are usually lighter and shorter than conventional trains and rapid transit trains. However, the differences between these modes of public transportation are confusing.

Some trams (for instance Tram-Trains) may also run on ordinary railway tracks, a tramway may be upgraded to a light rail or a rapid transit line, two urban tramways may be united to an interurban, etc.

Most trams today use electrical power, usually fed by a pantograph; in some cases by a third rail or trolley pole. If necessary, they may have several power systems. Certain types of cable car are also known as trams. Another power source is diesel; a few trams use electricity in the streets and diesel in more rural environments. Also steam and petrol (gasoline) have been used. Horse and mule driven trams do still occur.

Tramways are now included in the wider term "light rail", which also includes segregated systems. Some systems have both segregated and street-running sections, but are usually then referred to as trams, because it is the equipment for street-running which tends to be the decisive factor. Vehicles on wholly segregated light rail systems are generally called trains, although cases have been known of "trains" built for a segregated system being sold to new owners and becoming "trams".



A tram used on Tramlink Route 3 of the Croydon Tramlink owned by TfL in London



A tram in Helsinki, Finland

Etymology and terminology



Old tram stop on-demand notifier

The terms *tram* and *tramway* were originally (ca. 1500) Scottish words for the type of truck used in coal mines and the tracks on which they ran, probably derived from Middle Flemish tram "beam, handle of a barrow, bar, rung", a North Sea Germanic word of unknown origin meaning the beam or shaft of a barrow or sledge, also the barrow itself. *Tram-car* is attested from 1873.

Although *tram* and *tramway* have been adopted by many languages, they are not used universally in English, North Americans preferring *trolley*, *trolleycar* or *streetcar*. The term *streetcar* is first recorded in 1840. When electrification came, Americans began to speak of trolleycars or later, trolleys, believed to derive from the *troller*, a four-wheeled

device that was dragged along dual overhead wires by a cable that connected the troller to the top of the car and collected electrical power from the overhead wires, sometimes simply strung, sometimes on a catenary. The trolley pole, which supplanted the troller early on, is fitted to the top of the car and is spring-loaded in order to keep the trolley wheel or skate, at the top of the pole, firmly in contact with the overhead wire. The terms *trolley pole* and *trolley wheel* both derive from the troller. Trams using trolley-pole current collection are normally powered through a single pole, grounded through the wheels and rails. The motor circuit is designed to allow electrical current to flow through the underframe.

Although this use of "trolley" for tram was not adopted in Europe, the term did appear with "trolleybus": a rubber-tyred vehicle without tracks which draws its power from overhead wires.

Modern trolley cars often use a metal shoe with a carbon insert instead of a trolley wheel, or have a pantograph. In North America, trams are sometimes called trolleys, even though strictly this may be incorrect: for example, cable cars, or conduit cars that draw power from an underground supply.

Tourist buses made to look like streetcars are sometimes called trolleys in the U.S. (tourist trolley). Open, low-speed segmented vehicles on rubber tires, generally used to ferry tourists short distances, can be called trams, for example on the Universal Studios backlot tour.

Electric buses, which use twin trolley poles (one for live current, one for return) but have wheels with tyres rolling on a hard surface rather than tracks, are called **trolleybuses**, *trackless trolleys* (particularly in the Northeastern U.S.), or sometimes (in the UK, as well as in Seattle and Vancouver) simply *trolleys*.

History



Renovated Tatra K2 in Sarajevo



Trams in Alexandria, Egypt (since 1860)



Tram in Timisoara, Romania



Škoda 15 T in Riga, Latvia

The very first tram was on the Swansea and Mumbles Railway in south Wales, UK; it was horse-drawn at first, and later moved by steam and electric power. The Mumbles Railway Act was passed by the British Parliament in 1804, and the first passenger railway (similar to streetcars in the US some 30 years later) started operating in 1807. The first streetcars, also known as horsecars in North America, were built in the United States and developed from city stagecoach lines and omnibus lines that picked up and dropped off passengers on a regular route without the need to be pre-hired. These trams were an animal railway, usually using teams of horses and sometimes mules to haul the cars, usually two as a team. Occasionally other animals were put to use, or humans in emergencies. The first streetcar line, developed by Irish-American John Stephenson, was the New York and Harlem Railroad's Fourth Avenue Line which ran along the Bowery and Fourth Avenue in New York City. Service began in 1832. It was followed in 1835 by New Orleans, Louisiana, which has the oldest continuously operating street railway system in the world, according to the American Society of Mechanical Engineers.

In 1883, Magnus Volk constructed his 2 feet (610 mm) gauge Volk's Electric Railway along the eastern seafront at Brighton, England. This two kilometer line, re-gauged to 2 feet 9 inches (840 mm) in 1884, remains in service to this day, and is the oldest operating electric tramway in the world. The first tram for permanent service with

overhead lines was the Mödling and Hinterbrühl Tram in Austria. It started operating in October 1883, but was closed down in 1932.

The first electric street tramway in Britain, the Blackpool Tramway, was opened on 29 September 1885 using conduit collection along Blackpool Promenade. Since the closure of the Glasgow Corporation Tramways in 1962, this has been the only first-generation operational tramway in the UK.

Electric trams have run in Budapest since 1887, and this first line has now grown to be the busiest tram line of Europe, with the tram cars following each other at an interval of 60 seconds at rush hour. Bucharest and Belgrade ran a regular service from 1894 and Sarajevo from 1885.

Types of propulsion

Horse-drawn



A horse tramway in Danzig (now Gdańsk) in the late 19th century



Horse-drawn trams in Calcutta (now Kolkata), India—Life size model at City Centre arcade

These early forms of public transport developed out of industrial haulage routes or from the omnibus that first ran on public streets in the 1820s, using the newly invented iron or steel rail or 'tramway'. These were local versions of the stagecoach lines and picked up and dropped off passengers on a regular route, without the need to be pre-hired. Horsecars on tramlines were an improvement over the omnibus as the low rolling resistance of metal wheels on iron or steel rails (usually grooved from 1852 on), allowed the animals to haul a greater load for a given effort than the omnibus and gave a smoother ride. The horse-drawn streetcar combined the low cost, flexibility, and safety of animal power with the efficiency, smoothness, and all-weather capability of a rail right-of-way.

Steam



Steam trams in Rockhampton, Queensland—note the small boiler at the front of the leading tram

The first mechanical trams were powered by steam. Generally, there were two types of steam tram. The first and most common had a small steam locomotive (called a tram engine in the UK) at the head of a line of one or more carriages, similar to a small train. Systems with such steam trams included Christchurch, New Zealand; Sydney, Australia; other city systems in New South Wales; Munich, Germany (from August 1883 on). Steam tramways also were used on the suburban tramway lines around Milan; the last *Gamba de Legn* tramway ("Peg-Leg" in Milanese) ran on the Milan-Magenta-Castano Primo route in late 1958.

The other style of steam tram had the steam engine in the body of the tram, referred to as a tram engine or steam dummy. The most notable system to adopt such trams was in Paris. French-designed steam trams also operated in Rockhampton, in the Australian state of Queensland between 1909 and 1939. Stockholm, Sweden, had a steam tram line at the island of Södermalm between 1887 and 1901. A major drawback of this style of tram was the limited space for the engine, so that these trams were usually underpowered.

Cable-pulled

The next type of tram was the cable car, which sought to reduce labour costs and the hardship on animals. Cable cars are pulled along the track by a continuously moving cable running at a constant speed that individual cars grip and release to stop and start. The power to move the cable is provided at a site away from the actual operation. The first cable car line in the United States was tested in San Francisco, California, in 1873. The second city to operate cable trams was Dunedin in New Zealand, from 1881 to 1957. In Dresden, Germany, in 1901 an elevated suspended cable car following the *Eugen Langen one-railed floating tram system* started operating.

Cable Cars operated on Highgate Hill in North London and Kennington to Brixton Hill In South London.

They also worked around "Upper Douglas" in the Isle of Man, Cable Car 72/73 being the sole survivor of the fleet.

Cable cars suffered from high infrastructure costs, since an expensive system of cables, pulleys, stationary engines and vault structures between the rails had to be provided. They also require strength and skill to operate, to avoid obstructions and other cable cars. The cable had to be dropped at particular locations and the cars coast, for example when crossing another cable line. Breaks and frays in the cable, which occurred frequently, required the complete cessation of services over a cable route, while the cable was repaired. After the development of electrically powered trams, the more costly cable car systems declined rapidly.

Cable cars were especially effective in hilly cities, because the cable laid in the tracks physically pulled the car up the hill at a strong, steady pace, as opposed to the low-powered steam dummies trying to chug up a hill at almost a crawl, or worse a horse-drawn trolley trying to pull a load up a hill.

This concept partially explains their survival in San Francisco. However, the most extensive cable system in the U.S. was in Chicago, a much flatter city. The largest cable system in the world, in the city of Melbourne, Victoria, Australia, had at its peak 592 trams running on 74 kilometres of track.

The San Francisco cable cars, though significantly reduced in number, continue to perform a regular transportation function, in addition to being a tourist attraction. A single line also survives in Wellington, New Zealand (rebuilt in 1979 as a funicular but still called the "Wellington Cable Car").

Hybrid funicular



Former second generation cable tractor, used between 1978 and 2005, assisting a tramcar on the cable section of the Opicina Tramway.

The Opicina Tramway in Trieste operates a hybrid funicular system where the trams are pushed uphill by cable tractors.

Electric (trolley cars)



Fully restored 1920 Toronto streetcar



Old tram in Kiev, Ukraine



Electric trams in Sydney, Australia, circa 1920s

Multiple functioning experimental electric trams were exhibited at the 1884 World Cotton Centennial World's Fair in New Orleans, Louisiana, but they were not deemed good enough to replace the Lamm fireless engines then propelling the St. Charles Avenue Streetcar in that city.

Electric trams (trolley cars) were first successfully installed in Saint Petersburg, Russia, invented and tested by Fyodor Pirotsky as early as 1880, and in Berlin in 1881 by Werner von Siemens and the company that still bears his name. Another was by John Joseph Wright, brother of the famous mining entrepreneur Whitaker Wright, in Toronto in 1883. Earlier installations proved difficult or unreliable. Siemens' line, for example, provided power through a live rail and a return rail, like a model train, limiting the voltage that could be used, and providing electric shocks to people and animals crossing the tracks. Siemens later designed his own method of current collection, from an overhead wire, called the bow collector, and Thorold, Ontario, opened in 1887, and was considered quite successful at the time. While this line proved quite versatile as one of the earliest fully functional electric streetcar installations, it required horse-drawn support while climbing the Niagara Escarpment and for two months of the winter when hydroelectricity was not available. It continued in service in its original form into the 1950s. Electric trams were first tested in service in the United States in Richmond, Virginia, in 1888, in the Richmond Union Passenger Railway built by Frank J. Sprague, though the first

commercial installation of an electric streetcar in the United States was built in 1884 in Cleveland, Ohio and operated for a period of one year by the East Cleveland Street Railway Company. In 1904 the first double-decker tram in the world was put into operation in Hong Kong, and the Hong Kong Tramway still remains the only tramway in the world that uses exclusively double-decker trams.

Other power sources



The only petrol-driven tram of Stockholms Spårvägar, on line 19 in the 1920s

In some places, other forms of power were used to power the tram. Hastings and some other tramways, for example Stockholms Spårvägar in Sweden and some lines in Karachi, used petrol trams and Lytham St Annes used gas trams. Paris operated trams that were powered by compressed air using the Mekarski system. In New York City some minor lines used storage batteries; a longer battery-operated tramway line ran from Milan to Bergamo (about 60 km) during the 1950s.

Galveston Island Trolley in Texas operates diesel trams due to the city's hurricane-prone location, which would result in frequent damage to an electrical supply system.

Design

Low floor



Entirely low-floor Škoda ForCity in Prague

The latest generation of light rail vehicles is of partial or fully low-floor design, with the floor 300 to 360 mm (11.8 to 14.2 in) above top of rail, a capability not found in older vehicles. This allows them to load passengers, including those in wheelchairs, directly from low-rise platforms that are not much more than raised footpaths/sidewalks. This satisfies requirements to provide access to disabled passengers without using expensive wheelchair lifts, while at the same time making boarding faster and easier for other passengers.



Two Trams in Braunschweig, Germany. The left one is an 1981 high-floor tram, the right one a 2007 low-floor

Various companies have developed particular low-floor designs, varying from part-low-floor (with internal steps between the low-floor section and the high-floor sections over the bogies), e.g. Citytram and Siemens S70, to 100% low-floor, where the floor passes through a corridor between the drive wheels, thus maintaining a relatively constant (stepless) level from end to end of the tram. However, prior to the introduction of the Škoda ForCity, this carried the mechanical penalty of requiring bogies to be fixed and unable to pivot (except for less than 5 degrees in some trams). This creates undue wear on the tracks and wheels. However, passengers appreciate the ease of boarding and alighting from low-floor trams and moving about inside 100% low-floor trams. Passenger satisfaction with low-floor trams is high. Low-floor trams are now running in many cities around the world, including Milan, Dublin, Prague, Riga, Melbourne, Hiroshima, Houston, Vienna, Istanbul and Strasbourg.

Articulated



Articulated tram in Barcelona

Articulated trams, invented and first used by the Boston Elevated Railway in 1912-13 at a total length of about twelve meters long (40 ft) for each pioneering example of twin-section articulated tram car, have two or more body sections, connected by flexible joints and a round platform at their pivoting midsection(s). Like articulated buses, they have increased passenger capacity. In practice, these trams can be up to 53 metres (174 ft) long (such as in Budapest, Hungary), while a regular tram has to be much shorter. With this type, the articulation is normally suspended between carbody sections. In the Škoda ForCity, which is the world's first 100% low floor tram with pivoting bogies, a Jacobs bogie supports the articulation between the two or more carbody sections. An articulated tram may be low-floor variety or high (regular) floor variety. Newer model trams may be up to 72 meters long and carry 510 passengers at a comfortable 4 passengers/m². At crush loadings this would be even higher.

Double decker

Double decker trams operate in Alexandria, Blackpool and Hong Kong.

Tram-train

Tram-train operation uses vehicles such as the Flexity Link and Regio-Citadis, which are suited for use on urban tram lines and also meet the necessary indication, power, and strength requirements for operation on main-line railways. This allows passengers to travel from suburban areas into city-centre destinations without having to change from a train to a tram.

It has been primarily developed in Germanic countries, in particular Germany and Switzerland. Karlsruhe is a notable pioneer of the tram-train.

Cargo trams



CarGoTram run by Volkswagen in Dresden, Germany on a section of grassed track. It delivers parts to the Transparent Factory.

Goods have been carried on rail vehicles through the streets, particularly near docks and steelworks, since the 19th century (most evident on the Weymouth Harbour Tramway in Weymouth, Dorset), and some Belgian vicinal tramway routes were used to haul timber. Several of the US interurbans carried freight. At the turn of the 21st century, a new interest has arisen in using urban tramway systems to transport goods. The motivation

now is to reduce air pollution, traffic congestion and damage to road surfaces in city centres. Dresden has a regular *CarGoTram* service, run by the world's longest tram trainsets (59.4 metres (195 ft)), carrying car parts across the city centre to its Volkswagen factory. Vienna and Zürich use trams as mobile recycling depots. Kislovodsk had a freight-only tram system comprising one line which was used exclusively to deliver bottled Narzan mineral water to the railway station.

In the spring of 2007, Amsterdam piloted a cargo tram operation, aiming to reduce particulate pollution by 20% by halving the number of lorries—currently 5,000—unloading in the inner city during the permitted timeframe from 07:00 till 10:30. The pilot, operated by City Cargo Amsterdam, involved two cargo trams, operating from a distribution centre and delivering to a "hub" where electric trucks delivered to the final destination.

The trial was successful, releasing an intended investment of €100 million in a fleet of 52 cargo trams distributing from four peripheral "cross docks" to 15 inner-city hubs by 2012. These specially built vehicles would be 30 feet (9.1 m) long with 12 axles and a payload of 30 tons. On weekdays, trams are planned to make 4 deliveries per hour between 7 a.m. and 11 a.m. and two per hour between 11 a.m. and 11 p.m. With each unloading operation taking on average 10 minutes, this means that each site would be active for 40 minutes out of each hour during the morning rush hour. In early 2009 the scheme was suspended owing to the financial crisis impeding fund-raising.

Hearse-tram

Specially appointed hearse trams were used for funerals in Milan, Italy, from the 1880s (initially horse-drawn) to the 1920s. The main cemeteries, Cimitero Monumentale and Cimitero Maggiore, included funeral tram stations. Additional funeral stations were located at Piazza Firenze and at Porta Romana.

In the mid-1940s at least one special hearse tram was used in Turin, Italy. It was introduced due to the wartime shortage of automotive fuel.

Tramway operation

There are two main types of Tramways, the classic tramway build in the early 20th century with the tram system operating in mixed traffic and the latter type which is most often associated with the tram system having it own right of way. Tram systems that have their own right of way are often call Light Rail but this does not always hold true. Though these two systems have difference in their operation their equipment is much the same.

Tram and light-rail transit systems around the world



Double-decker trams continue to run in Hong Kong.



Old tram in Milan, Italy.

Throughout the world there are many tram systems; some dating from the late 19th or early 20th centuries. However a large number of the old systems were closed during the mid-20th century because of such perceived drawbacks as route inflexibility and maintenance expense. This was especially the case in North American, British, French and other West European cities. Some traditional tram systems did however survive and remain operating much as when first built over a century ago. In the past twenty years their numbers have been augmented by modern tramway or light rail systems in cities that had discarded this form of transport.

Popularity

Tramways with tramcars (British English) or *street railways with streetcars* (American English) were common throughout the industrialised world in the late 19th and early 20th centuries but they had disappeared from most British, Canadian, French and U.S. cities by the mid-20th century.

By contrast, trams in parts of continental Europe continued to be used by many cities, although there were contractions in some countries, including the Netherlands.

Since 1980 trams have returned to favour in many places, partly because their tendency to dominate the roadway, formerly seen as a disadvantage, is now considered to be a merit. New systems have been built in the United States, Great Britain, Ireland, France and many other countries.

In Milan, Italy, the old "Ventotto" trams are considered by its inhabitants a "symbol" of the city.

Largest tram systems

The Silesian Interurbans in Poland and the Trams in Melbourne, Australia, are claimed to be the largest tram networks in the world. Before its decline the BVG in Berlin operated a very large network with 634 km of route. During a period in the 1980s the world's largest tram system was in Leningrad, USSR, being included in Guinness World Records.

The largest single tram line in the world is the Belgian Coast tram, which runs almost the entire length of the Belgian coast. Other large systems include (but not limited to) Vienna, Leipzig, Prague, Kiev, Warsaw, Amsterdam, Brussels, Basel, Zurich, Bucharest and Toronto.

Until the system started to be converted to trolleybus (and later bus) in the 1930s, the first-generation London network was also one of the world's largest, with 526 km (327 mi) of route in 1934. While the largest streetcar network in the world used to be located in Chicago, with over 850 kilometres (530 mi) of track, all of it was converted to bus service by the late 1950s.

Asia



Toyama Centram, Japan



Tram running on Kolkata Road, India

Tramway systems were well established in the Asian region at the start of the 20th century, but started a steady decline during the mid to late 30s. The 1960s marked the end of its dominance in public transportation with most major systems closed and the equipment and rails sold for scrap; however, some extensive original lines still remain in service in Hong Kong and Japan. In recent years there has been renewed interest in the tram with modern systems being built in Japan, the Philippines, and South Korea.

The first Japanese tram line was inaugurated in 1895 as the Kyoto Electric Railroad. The tram reached its zenith in 1932 when 82 rail companies operated 1,479 kilometers of track in 65 cities. The tram declined in popularity through the remaining years of the 30s, a trend that was accelerated by the damages of the War and continued through the Occupation and rebuilding years. During the 1960s many of the remaining operational tramways were shut down and dismantled in favor of auto, bus, and rapid rail service; however, when one compares the number of operational lines that survived this era to their American counterparts, they can be defined as quite extensive.

Europe



New Berlin MetroTram

In many European cities much tramway infrastructure was lost in the mid-20th century, though not always on the same scale as in other parts of the world such as North America. Most of Eastern Europe retained tramway systems until recent years but some cities are now reconsidering their transport priorities. In contrast, some Western European cities are rehabilitating, upgrading, expanding and reconstructing their old tramway lines. Many Western European towns and cities are also building new tramway lines.

North America



Streetcars in Toronto operate the largest such system in North America.

In North America trams are generally known as streetcars or trolleys; the term *tram* is more likely to be understood as a tourist trolley, an aerial tramway, or a people-mover.

In most North American cities, streetcar lines were largely torn up in the mid-20th century for a variety of financial, technological and social reasons. Exceptions included Boston, New Orleans, Newark, Seattle, Philadelphia (with a much smaller network than once had existed), Pittsburgh, San Francisco and Toronto. In a trend started in the 1980s some American cities have brought back streetcars, examples of these being Memphis, Portland, Tampa, Little Rock and Seattle. Several additional cities, such as Washington, D.C., Tucson and Detroit are planning or proposing to do the same. Pittsburgh kept most of its streetcar system serving the city and many suburbs until January 27, 1967, making it the longest-lasting large-network U.S. streetcar system. In the late 20th century, several cities installed light rail systems, in part along the same corridor as the old streetcars.

Toronto currently has the largest streetcar system in the Americas in terms of track length and ridership, operated by the Toronto Transit Commission. It is the only streetcar system existing in Canada, not including the light rail systems that some Canadian cities currently operate, or heritage streetcar lines operating only seasonally. Toronto's system

uses Canadian Light Rail Vehicles and Articulated Light Rail Vehicles, after a history of using PCCs, Peter Witt cars, and horse-drawn carriages. The system is currently proposing to replace its current fleet with Bombardier's Flexity Outlook models, which is also used in some European tram systems. Streetcars once existed in Edmonton and Calgary, but both cities have since converted their systems to support light rail vehicles instead. Streetcars also once existed in Ottawa, Montreal, Kitchener and Hamilton. Some cities have restored their old streetcars and run them as a heritage feature for tourists, like the Vancouver Downtown Historic Railway.

Australia and New Zealand



A heritage H-Class model (foreground) and modern Flexity tram (background) in Glenelg, Adelaide

In Australasia, trams are used extensively only in Melbourne, and to a lesser extent, Adelaide, all other major cities having largely dismantled their networks by the 1970s. Sydney reintroduced its tram in 1997 as a modern system (Metro Light Rail), while Ballarat, Christchurch and Perth reintroduced their trams as heritage systems. Bendigo had a heritage system for a while which has recently been upgraded to a simple public transport system through an increase in frequency.

A distinctive feature of many Australasian trams was the early use of a lowered central section between bogies (wheel-sets). This was intended to make passenger access easier, by reducing the number of steps required to reach the inside of the vehicle. It is believed that the design first originated in Christchurch in the first decade of the 20th century. Cars with this design feature were frequently referred to as "drop-centres". Trams built since the 1970s have had conventional high or low floors.

The trams made by Boon & Co. of Christchurch, New Zealand in 1906–07 for use in Christchurch may have been the first with this feature; they were referred to as *drop-centres* or *Boon cars*. Trams for Christchurch and Wellington built in the 1920s with an enclosed section at each end and an open-sided middle section were also known as *Boon cars*, but did not have the drop-centre.

South America



Puerto Madero Tramway in Buenos Aires

Buenos Aires in Argentina had once one of the most extensive tramway networks in the world with over 857 km (535 mi) of track, most of it dismantled during the 1960s in favor of bus transportation. Now slowly coming back, the 2 km Puerto Madero Tramway running in the Puerto Madero district is spearheading the move with extensions to Retiro station and La Boca in the planning stages. Another line, the PreMetro line E2 system feeding the Line E of the Buenos Aires Subway has been operating for the past few years on the outskirts of Buenos Aires, and a unique leisure "Tren de la Costa", an artery that

stretches for 15 kilometres by the River Plate, from Olivos to the village of Tigre has also been running in Buenos Aires.

Also in Argentina, in the city Mendoza, a new tramway line is in construction, the Metrotranvía of Mendoza, which will have a route of 12.5 km and will link five districts of the Greater Mendoza conurbation. The opening of the system is scheduled for 2011. Also in Medellín, Colombia, there is a tram line under construction and the opening schedule is for December 2011.

Pros and cons of tram systems

All transit services involve a trade-off between speed and frequency of stops. Services that stop frequently have a lower overall speed, and are therefore less attractive for longer trips. Metros, light rail, monorail, and bus rapid transit are all forms of rapid transit, which generally signifies high speed and widely spaced stops. Trams are often used as a form of local transit, making frequent stops. Thus, the most meaningful comparison of advantages and disadvantages is with other forms of local transit, primarily the local bus.

Advantages

- Unlike buses, but like trolleybuses, (electric) trams give off no exhaust emissions at point of use. Compared to motorbuses the noise of trams is generally perceived to be less disturbing. However, the use of solid axles with wheels fixed to them causes slippage between wheels and tracks when negotiating curves. This produces a characteristic squeal.
- They can use overhead wire set to be shared with trolleybuses (a three wire system).
- Trams can adapt to the number of passengers by adding more cars during rush hour (and removing them during off-peak hours). No additional driver is then required for the trip in comparison to buses.
- In general, trams provide a higher capacity service than buses.
- Multiple entrances allow trams to load faster than suburban coaches, which tend to have a single entrance. This, combined with swifter acceleration and braking, lets trams maintain higher overall speeds than buses, if congestion allows.
- The trams' stops in the street are easily accessible, unlike stations of subways and commuter railways placed underground (with several escalators, stairways etc.) or in the outskirts of the city center.
- Rights-of-way for trams are narrower than for buses. This saves valuable space in cities with high population densities and/or narrow streets.
- Trams can trackshare with mainline railways, servicing smaller towns without requiring special track as in Stadtbahn Karlsruhe and at greater speed than buses.
- Passenger comfort is normally superior to buses because of controlled acceleration and braking and curve easement. Rail transport such as used by trams provides a smoother ride than road use by buses.
- Because the tracks are visible, it is easy for potential riders to know where the routes are.

- Because trams run on rails, the ride is far more comfortable than that of a rubber-tired bus. Blemishes in the road surface are far less noticeable.
- Vehicles run more efficiently and overall operating costs are lower.
- Trams can run on renewable electricity without the need for very expensive and short life batteries.
- Consistent market research and experience over the last 50 years in Europe and North America shows that car commuters are willing to transfer some trips to rail-based public transport but not to buses. Typically light rail systems attract between 30 and 40% of their patronage from former car trips. Rapid transit bus systems attract less than 5% of trips from cars, less than the variability of traffic.

Disadvantages

- Tram infrastructure (such as island platforms) occupies urban space at ground-level, sometimes to the exclusion of other users, including cars.
- The capital cost is higher than for buses, even if a tramcar usually has a much higher lifetime than a bus.
- Trams can cause speed reduction for other transport modes (buses, cars) when stops in the middle of the road do not have pedestrian refuges, as in such configurations other traffic cannot pass whilst passengers alight or board the tram.
- When operated in mixed traffic, trams are more likely to be delayed by disruptions in their lane. Buses, by contrast, can sometimes manoeuvre around obstacles. Opinions differ on whether the deference that drivers show to trams—a cultural issue that varies by country—is sufficient to counteract this disadvantage.
- Tram tracks can be hazardous for cyclists, as bikes, particularly those with narrow tyres, may get their wheels caught in the track grooves. It is possible to close the grooves of the tracks on critical sections by rubber profiles that are pressed down by the wheelflanges of the passing tram but that cannot be lowered by the weight of a cyclist. If not well-maintained, however, these lose their effectiveness over time.
- Steel wheel trams are noisier than rubber-wheeled buses or trolleybuses when cornering if there are no additional measures taken (e.g. greasing wheel flanges, which is standard in new-built systems). Tram wheels are fixed onto axles so they have to rotate together, but going around curves, one wheel or the other has to slip, and that causes loud unpleasant squeals. A related improvement is rubber isolation between the wheel disc and the rim, as used on Boston (Massachusetts, U.S.) Green Line 3400 and 3600 series cars. These cars are much quieter than those with solid metal wheels. (This construction requires a flexible cable to electrically connect the tire to the wheel body.)
- Light rail vehicles are often heavier per passenger carried than heavy rail and monorail cars, as they are designed with higher durability (which means more mass) to survive collisions, since they cannot swerve to avoid oncoming objects in emergencies.
- The opening of new tram and light rail systems has sometimes been accompanied by a marked increase in car accidents, as a result of drivers' unfamiliarity with the physics and geometry of trams. Though such increases may be temporary, long-

term conflicts between motorists and light rail operations can be alleviated by segregating their respective rights-of-way and installing appropriate signage and warning systems.

- Rail transport can expose neighbouring populations to moderate levels of low-frequency noise. However, transportation planners use noise mitigation strategies to minimize these effects. Most of all, the potential for decreased private motor vehicle operations along the trolley's service line because of the service provision could result in lower ambient noise levels than without.
- In the event of a breakdown or accident, or even roadworks and maintenance, a whole section of the tram network can be blocked. Buses and trolleybuses can often get past minor blockages, although trolleybuses are restricted by how far they can go from the wires. Conventional buses can divert around major blockages as well, as can most modern trolleybuses that are fitted with auxiliary engines or traction batteries. The tram blockage problem can be mitigated by providing regular crossovers so a tram can run on the opposite line to pass a blockage, although this can be more difficult when running on road sections shared with other road users. On extensive networks diversionary routes may be available depending on the location of the blockage. Breakdown related problems can be reduced by minimising the situations where a tram would be stuck on route, as well as making it as simple as possible for another tram to rescue a failed one.



Toyama Light rail Portram.



Trams in Helsinki



Tram tracks can be hazardous to cyclists.



Tram accident in Amsterdam



Hong Kong Tramways passing each other at Central



Solaris Tramino on motorshow



Tramways on ice of the River Neva in Saint Petersburg



The San Diego Trolley going through downtown



Trams in Calcutta

In other media

In literature



Tramway de Grenoble, Grenoble, France

One of the earliest literary references to trams occurs on the second page of Henry James's novel *The Europeans*:

From time to time a strange vehicle drew near to the place where they stood—such a vehicle as the lady at the window, in spite of a considerable acquaintance with human inventions, had never seen before: a huge, low, omnibus, painted in brilliant colours, and decorated apparently with jingling bells, attached to a species of groove in the pavement, through which it was dragged, with a great deal of rumbling, bouncing, and scratching, by a couple of remarkably small horses.

Published in 1878, the novel is set in the 1840s, though horse trams were not introduced in Boston till the 1850s. Note how the tram's efficiency surprises the European visitor; how two "remarkably small" horses sufficed to draw the "huge" tramcar.

James also makes comical reference to the novelty and excitement of trams in *Portrait of a Lady* (1881):

Henrietta Stackpole was struck with the fact that ancient Rome had been paved a good deal like New York, and even found an analogy between the deep chariot-ruts traceable in the antique street and the overjangled iron grooves which express the intensity of American life. (page 313 of Penguin edition.)

A quarter of a century later, Joseph Conrad described Amsterdam's trams in chapter 14 of *The Mirror of the Sea* (1906): *From afar at the end of Tsar Peter Straat, issued in the frosty air the tinkle of bells of the horse tramcars, appearing and disappearing in the opening between the buildings, like little toy carriages harnessed with toy horses and played with by people that appeared no bigger than children.*

Danzig trams figure extensively in the early stages of Günter Grass's *Die Blechtrommel* (The Tin Drum). In the last chapter the novel's hero Oskar Matzerath and his friend Gottfried von Vittlar steal a tram late at night from outside Unterrath depot on the northern edge of Düsseldorf.

It is a surreal journey. Von Vittlar drives the tram through the night, south to Flingern and Haniel and then east to the suburb of Gerresheim. Meanwhile, inside, Matzerath tries to rescue the half-blind Victor Weluhn (who had escaped from the siege of the Polish post office in Danzig at the beginning of the book and of the war) from his two green-hatted would-be executioners. Mazerath deposits his briefcase, which contains Sister Dorotea's severed ring finger in a preserving jar, on the dashboard "where professional motorman put their lunchboxes". They leave the tram at the terminus and the executioners tie Weluhn to a tree in von Vittlar's mother's garden and prepare to machine-gun him. But Matzerath drums, Weluhn sings, and together they conjure up the Polish cavalry, who spirit both victim and executioners away. Matzerath asks von Vittlar to take his briefcase in the tram to the police HQ in the Fürstenwall, which he does.

The latter part of this route is today served by tram route 703 terminating at Gerresheim Stadtbahn station ("by the glassworks" as Grass notes, referring to the famous glass factory).

In his 1967 spy thriller *An Expensive Place to Die*, Len Deighton misidentifies the Flemish coast tram: "The red glow of Ostend is nearer now and yellow trains rattle alongside the motor road and over the bridge by the Royal Yacht Club..." [Chapter 38, page 198 of the Companion Book Club edition.]

In scale modelling

Model trams are popular in HO scale (1:87) and O scale (1:48 in the US and generally 1:43 in Europe and Asia). They are typically powered and will accept plastic figures inside. Common manufacturers are Roco and Lima, with many custom models being made as well. The German firm Hödl and the Austrian Halling specialize in 1:87 scale.

In the US, Bachmann Industries is a mass supplier of HO trams and kits. Bowser Manufacturing has produced white metal models for over 50 years. There are many

boutique vendors offering limited run epoxy and wood models. At the high end are highly detailed brass models which are usually imported from Japan or Korea and can cost in excess of \$500. Many of these run on 16.5 mm gauge track, which is correct for the representation of 4 ft 8 1/2 in (1,435 mm) (standard gauge) in HO scale as in US and Japan, but incorrect in 4 mm (1:76.2) scale, as it represents 4 ft 1 1/2 in (1,257 mm). This scale/gauge hybrid is called OO scale. O scale trams are also very popular among tram modellers because the increased size allows for more detail and easier crafting of overhead wiring. In the US these models are usually purchased in epoxy or wood kits and some as brass models. The Saint Petersburg Tram Company produces highly detailed polyurethane non-powered O Scale models from around the world which can easily be powered by trucks from vendors like Q-Car.

In the US, one of the best resources for model tram enthusiasts is the East Penn Traction Club of Philadelphia.

It is thought that the first example of a working model tramcar in the UK built by an amateur for fun was in 1929, when Frank E. Wilson created a replica of London County Council Tramways E class car 444 in 1:16 scale, which he demonstrated at an early Model Engineer Exhibition. Another of his models was London E/1 1800, which was the only tramway exhibit in the Faraday Memorial Exhibition of 1931. Together with likeminded friends, Frank Wilson went on to found the Tramway & Light Railway Society in 1938, establishing tramway modelling as a hobby.

Chapter 2

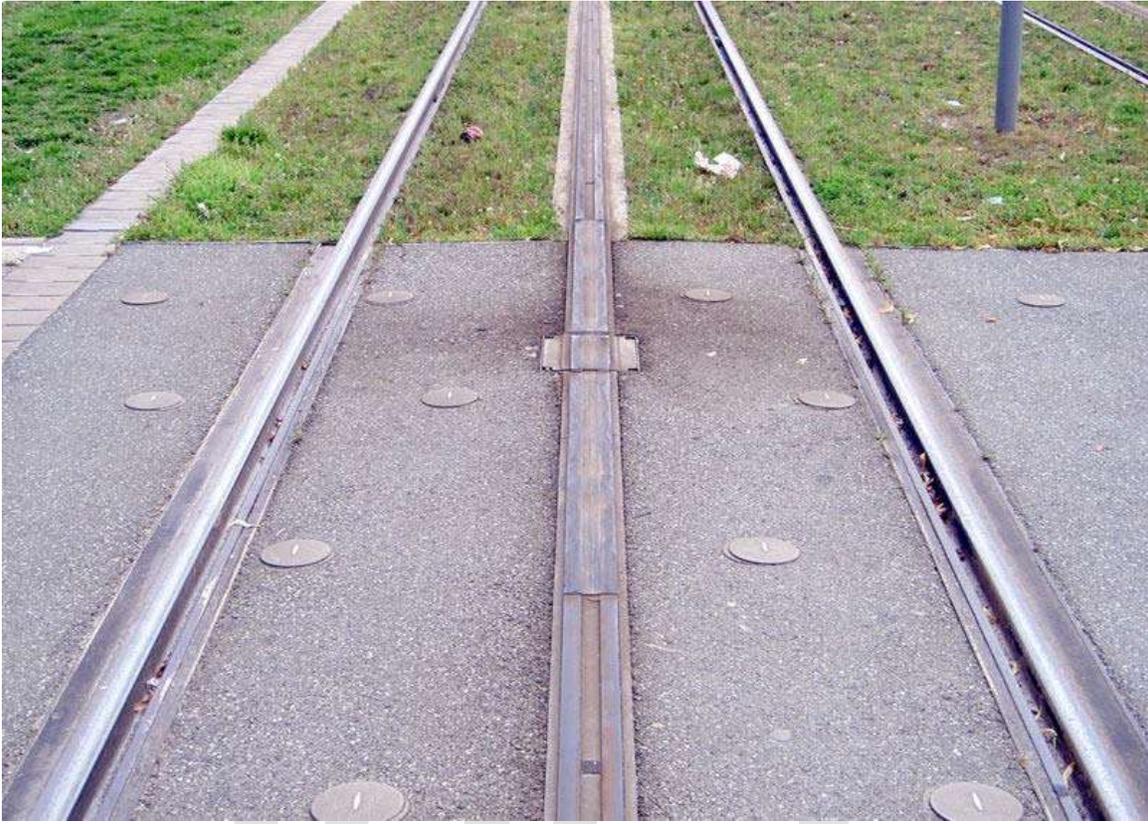
Ground-Level Power Supply



Bordeaux trams run without overhead wires



Track with APS under construction in Place Paul Doumer, Bordeaux



A section of APS track showing the neutral sections at the end of the powered segments plus one of the insulating joint boxes which mechanically and electrically join the APS rail segments



Bordeaux tram using APS on route B near the Roustaing tramstop



The channel of Stream system at Trieste

Ground-level power supply, also known as **surface current collection** and **Alimentation par Sol (APS)** is a modern method of third-rail electrical pick-up for street trams. It was invented for the Bordeaux tramway, which was constructed from 2000 and opened in 2003. Currently, this is the only place it is used but there were and are proposals to install it elsewhere.

Technology

Ground-level power supply is used, primarily for aesthetic reasons, as an alternative to overhead lines. It is different from the conduit current collection system which was one of the first ways of supplying power to a tram system by burying a third and fourth rail in an underground conduit ('vault') between the running rails. Conduit current collection was used in historic tram systems in Washington, Manhattan, Paris, Berlin, Marseilles, Budapest, Prague, and London. It fell into disuse because overhead wires proved much less expensive and troublesome for street railways and because in Manhattan, Paris, Washington and West Berlin all trams were replaced by buses for reasons unrelated to the power supply issue.

Unlike the track-side third rail used by most metro trains and some main-line railways, APS does not pose a danger to people or animals and so can be used in pedestrian areas and city streets.

APS uses a third rail placed between the running rails, divided electrically into eight-metre segments with three-metre neutral sections between. Each tram has two power collection skates, next to which are antennae that send radio signals to energise the power rail segments as the tram passes over them. At any one time, no more than two consecutive segments under the tram should actually be live.

Use in Bordeaux

Modern ground-level current collection was pioneered by the recent Bordeaux tramway in France, E.U.. The public had assumed that the new system would use a traditional conduit system, like that of the Bordeaux trams which ran prior to 1958 and objected when they learned that it was not considered safe and that overhead wires were to be used instead. Facing complaints both from the public and the French Ministry of Culture, planners developed APS as a modern way of replicating the conduit system.

APS was developed by Innorail, a subsidiary of Spie Enertrans but was sold to Alstom when Spie was acquired by Amec.

There are 12 km of APS tramway in the three-line network of 43.3 km as of 2008. Sources suggest that APS adds about €100,000 to the cost of the trams, whilst the infrastructure is about 300% more expensive than overhead wires. Bordeaux Citadis trams use pantographs and electric overhead lines in outlying areas.

Before use in Bordeaux, APS was tested and proved viable on a short section of reserved-track tramway in the French city of Marseilles. Nevertheless, Bordeaux has experienced problems, with APS being so temperamental that, at one stage, the Mayor issued an ultimatum that if reliability could not be guaranteed, it would have to be replaced with overhead wires. Although things have improved, in October 2005, it was announced that 1 km of APS tramway is to be converted to overhead wires.

Problems have included water-logging, when the water does not drain quickly enough after heavy rain.

In other cities

In summer 2006, it was announced that two new French tram systems would be using APS over part of their networks. These will be Tramway d'Angers and Tramway de Reims, with both systems expected to open in 2011. A couple of months later, another French city was added to the list, this being Orléans, which will use APS on a section of its second tram line. The planned Al Sufouh Tramway in Dubai will use APS.. Another French City will use APS and that City is Tours.

Other cities to propose the use of APS include:

- Nice, E.U. (abandoned in favour of nickel metal hydride batteries)
- TRAMMET, Barcelona, Spain, E.U.

- Florence, Italy, E.U.
- Tramway de Marseille, France, E.U.
- Gold Coast Rapid Transit, Queensland, Australia
- DC Streetcar, Washington, D.C.
- Brasília, Brazil
- Al Sufouh Tramway, Dubai, United Arab Emirates
- Tours, France

Similar systems

Stud contact

The predecessors of APS (known as Stud contact systems) were developed around 1900, and used on several tramway companies in Paris and in England. Associated with these systems were the inventors Dolter and Diatto.

There were two main differences from APS:

- Power was supplied not from rails but from studs, set in the road at intervals
- Switching in of the contacts was done by strong electromagnets beneath each car. Each contact contained a fuse, which would be blown by an earthed safety shoe on the rear of the tram should the contact not have switched out. This proved to be unsatisfactory, because the strong currents melted down the switch contacts, resulting in contacts frequently remaining 'live'.

Budapest

Another system of ground-level power supply was used by Budapest trams from 1887. Overhead lines were considered an eyesore, so builder Siemens developed the following system: on the inner side of one rail, a powered third rail is hidden underground in a half-covered ditch, with a narrow slit opening upwards, through which a trolley pole reaches downward from the trams. The Budapest system was generally safe and water-protected. However, there was no defence against snow and ice, dirt filled up the ditches and trolley poles suffered intense wear. Overhead wire replaced the "Budapest system" everywhere by the 1920s.

Conduit

Conduit current collection has the power supply carried in a channel under the roadway, between and underneath the running rails, much in the same fashion as the cable for cable cars.

Stream system

Stream is an Acronym that stood for **TR**asporto **E**lettrico ad **A**ttrazione **M**agnetica" dell'allora ("System of Transport Electric by Magnetic Attraction"). The channel made of

composite material was thus insulating the vehicle equipped with a special shoe on the passing magnetic channel raised the band allowing contact with the copper strip and then the electrical connection.

WWT

Chapter 3

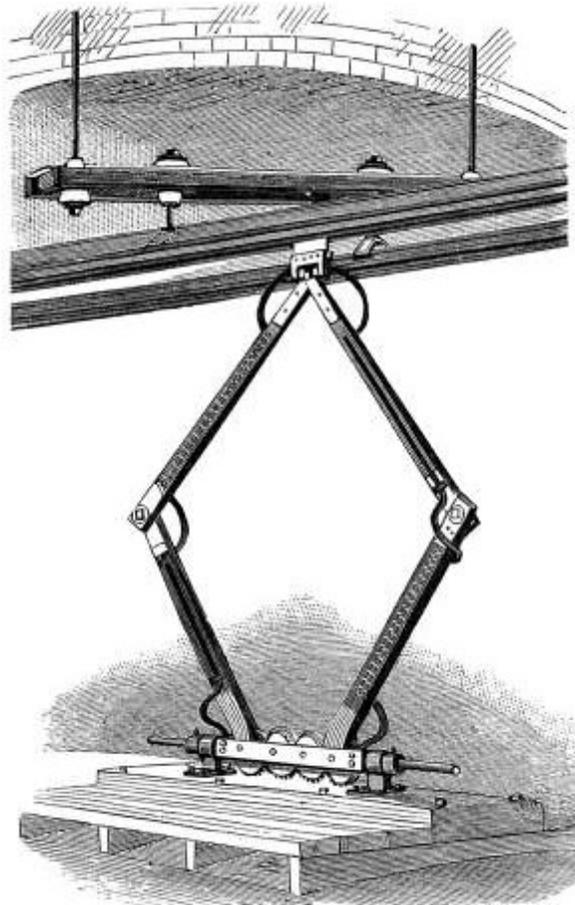
Pantograph (Rail)



The diamond-shaped pantograph of the Swiss cogwheel loco in Schynige Platte, built in 1911.

A **pantograph** is a device that collects electric current from overhead lines for electric trains or trams. The term stems from the resemblance to pantograph devices for copying writing and drawings.

Invention



Early (1895) flat pantograph on a Baltimore & Ohio Railroad electric locomotive. The contact ran inside the \cap section bar, so both lateral and vertical flexibility was necessary

A flat side-pantograph was invented in 1895 at the Baltimore & Ohio Railroad and in Germany in 1900 by Siemens & Halske. The familiar diamond-shaped roller pantograph was invented by John Q. Brown of the Key System shops for their commuter trains which ran between San Francisco and the East Bay section of the San Francisco Bay Area in California. They appear in photographs of the first day of service 26 October 1903. For many decades thereafter, the same diamond shape was used by electric rail systems around the world and remains in use by some today.

The pantograph was an improvement on the simple trolley pole which prevailed up to that time primarily because it allowed an electric rail vehicle to travel at higher speeds without losing contact with the catenary.

Modern use



The (asymmetrical) 'Z'-shaped pantograph of the electrical pickup on the Berlin Straßenbahn. This pantograph uses a single-arm design.



The (asymmetrical) 'Z'-shaped pantograph of the Desiro Class 360/2 EMU on the Suvarnabhumi Airport Rail Link

The most common type of pantograph today is the so called half-pantograph (sometimes 'Z'-shaped), which has evolved to provide a more compact and responsive single-arm design at high speeds as trains get faster. The half-pantograph can be seen in use on everything from very fast trains (such as the TGV) to low-speed urban tram systems. The design operates with equal efficiency in either direction of motion, as demonstrated by the Swiss and Austrian railways whose newest high performance locomotives, the Re 460 and Taurus respectively, operate with them set in opposite directions.

Technical details



Pantographs easily adapt to various heights of the overhead wires by partly folding. The tram line pictured here runs in Vienna.

The electric transmission system for modern electric rail systems consists of an upper weight carrying wire (known as a catenary) from which is suspended a contact wire. The pantograph is spring loaded and pushes a contact shoe up against the contact wire to draw the electricity needed to run the train. The steel rails on the tracks act as the electrical return. As the train moves, the contact shoe slides along the wire and can set up acoustical standing waves in the wires which break the contact and degrade current collection. This means that on some systems adjacent pantographs are not permitted.

Pantographs are the successor technology to trolley poles, which were widely used on early streetcar systems. Trolley poles are still used by trolleybuses, whose freedom of movement and need for a two-wire circuit makes pantographs impractical, and some streetcar networks, such as the Toronto Streetcar System, which have frequent turns sharp enough to require additional freedom of movement in their current collection to ensure unbroken contact.

Pantographs with overhead wires are now the dominant form of current collection for modern electric trains because, although more expensive and fragile than a third-rail system, they allow the use of higher voltages.

Pantographs are typically operated by compressed air from the vehicle's braking system, either to raise the unit and hold it against the conductor or, when springs are used to effect the extension, to lower it. As a precaution against loss of pressure in the second case, the arm is held in the down position by a catch. For high-voltage systems, the same air supply is used to "blow out" the electric arc when roof-mounted circuit breakers are used.

Single- and double-arm pantographs



High-performance pantograph for measurements on the ICE S

Pantographs may have either a single or a double arm. Double arm pantographs are usually heavier, requiring more power to raise and lower, but may also be more fault tolerant. For example, "... [New Jersey Transit] encountered numerous wire downings on

the Northeast Corridor Branch (New York City - Trenton, NJ) before they decided to replace the pantographs on Arrow-III trains with a more forgiving dual arm design, possibly in 1991..."

On railways of the former USSR, the most widely used pantographs are those with a double arm ("made of two rhombs"), but since the late 1990s there have been some single-arm pantographs on Russian railways. Some streetcars use double-arm pantographs, among them the Russian KTM-5, KTM-8, LVS-86 and many other Russian-made trams, as well as some Euro-PCC trams in Belgium. American streetcars use either trolley poles or single-arm pantographs.

Metro systems and overhead lines



Symmetrical, diamond shaped pantographs on trams in Prague.

Most rapid transit systems are powered by a third rail, but some use pantographs, particularly ones that involve extensive above-ground running. Hybrid metro-tram or 'pre-metro' lines whose routes include tracks on city streets or in other publicly-accessible areas, such as the MBTA Green Line, must of course use overhead wire, since a third rail would normally present too great a risk of electrocution.

The only current exception to this is the new Bordeaux tram system that uses an underground system called alimentation par sol, which only applies power to segments of track that are completely covered by the tram. This system is used in the historic centre of Bordeaux where an overhead wire system would cause a visual intrusion.

Overhead pantographs are sometimes used as alternatives to third rails because third rails can ice over in certain winter weather conditions. The MBTA Blue Line or the Wonderland Line uses pantograph power for all of its surface route. The entire Metro system of Barcelona, Spain, uses overhead wiring and pantographs.

Until 2010 the Oslo metro line 1 changed from third rail to overhead line power at Frøen station. Due to the many level crossings, it was deemed difficult to install a third rail on the rest of the older line 1 tracks.



Chapter 4

Tram Controls



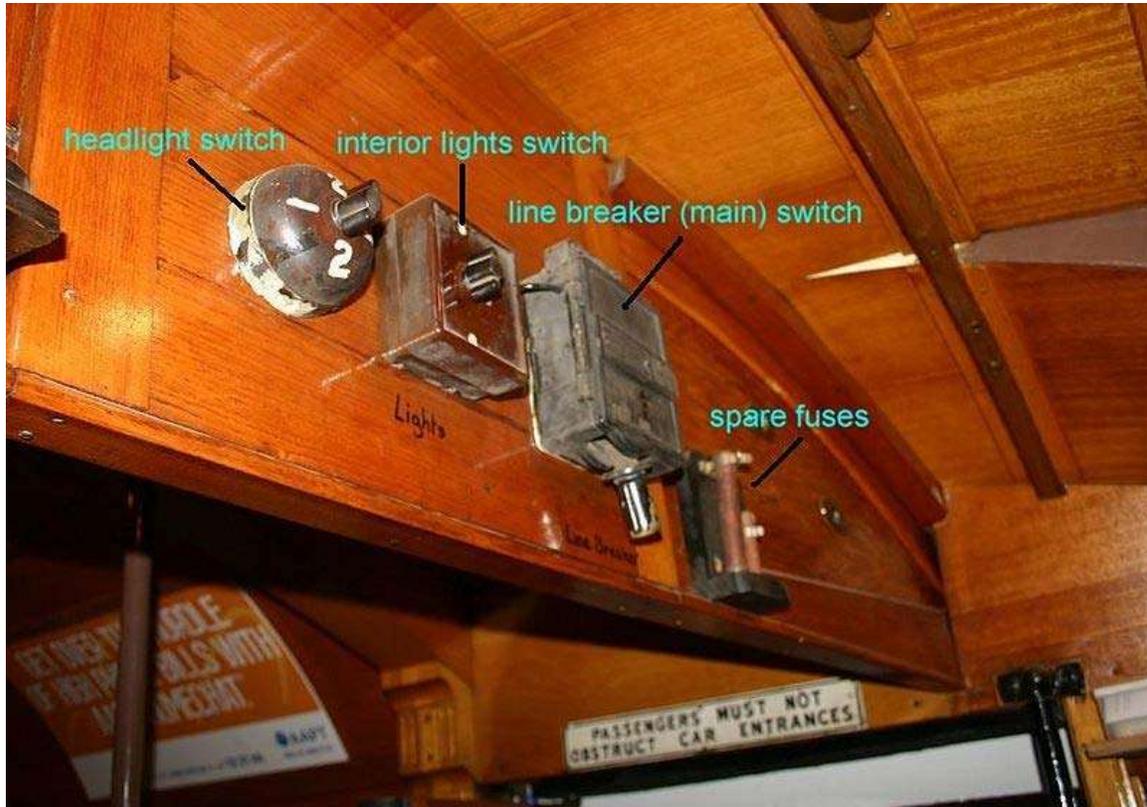
The controls are from an older style tram (a Melbourne SW6 class tram)

Overview

The operation of trams is relatively simple. As trams run on rails, they do not require steering controls. However they do require controls for the smooth application of power and for braking and to control forward and reverse running. Different controls were operated by the motorman's (driver's) hands or feet. In more modern vehicles controls are generally located on a driver console panel. Some controls can be used to do a variety of tasks. Trams do not have clutches or variable gears, although they do have fixed gears

between their motors and wheels. Thus trams have no need for controls to operate their gears. Most of the important controls on a tram are actually electrical switches.

Power supply switches



Overhead Switches. These are located on the bulkhead behind the driver. This tram only has a single pole, so it does not have a pole circuit switch.

Before a tram can be operated the main electrical circuit must be closed. This is done by the motorman moving a large overhead switch, usually located on the bulkhead behind the driving position, from the "off" to the "on" position.

Trams fitted with air brakes have a separate switch to operate the air compressor. This is sometimes located near the compressor (which is normally located under the floor of the passenger compartment) rather than in the driver's cabins.

Lighting and pole circuit switches

Usually located close to the overhead switch will be the light switches, which normally switch on both the interior lighting and the headlights. Double ended trams also have a switch to energise only the headlights at the end of the tram facing forwards. Trams with two trolley-poles, may also have a pole circuit switch which ensures that only the pole on the overhead wire carries a current. Trams with pantographs will have a console switch or button to raise or lower the pantograph.

The "Key" - for forward and reverse operation

Forward and reverse operation is controlled by the key, which is usually the smaller of the two handles and located on the right-hand side of the top of the controller. Typically the key is pushed forward for forward operation, and backwards for reverse operation. There is usually a neutral or "off" position between forward and reverse positions. The key can only be removed from the controller at the neutral position.

The "Handle" - for power application

The "handle", which is normally the larger of the two levers on the controller is the device whereby the motorman controls the amount of power to be applied to the motors. It is normally located in the centre of the top of the controller. It can only be operated when the key is in the forward or reverse position. When the key is in the off position, or is removed, the handle is locked. Interlocking devices also normally ensure that the key can only be removed when the handle is in the off position.





The driver has the handle in the "full series" position. The black device on the side of the window is an air-operated windscreen wiper motor, described below.

In most traditional trams increased power is applied by turning the handle clockwise through a series of steps (or "notches") until full power is applied. Power is cut off by turning the handle anti-clockwise.

DC traction motors have the advantage of being able to deliver their full torque virtually immediately, but this comes with the risk of either the wheels slipping or rough, jerky starts, which is both uncomfortable to passengers and can damage the vehicle. The power must be gradually applied to the motors. On older trams, this was achieved by the use of a number of resistors, which are interposed between the controller and the motors and which are normally located under the car, or on its roof. The more resistors that are

activated, the less power is available for traction purposes. As fewer resistors are activated, more power is available for the motors.

The activation of all or some of the resistors is achieved by opening and closing various electrical circuits between the controller, resistors and motors. By operating the handle on the controller, the motorman is actually opening and closing those circuits. On older vehicles the driver opens and closes circuits directly (sometimes called "direct control") and on newer vehicles the circuits are opened and closed by relays (sometimes called "remote control").

In both direct and remote control systems the handle is connected to a vertical shaft inside the controller and circuits are connected to the shaft by means of copper contactors or "fingers". Direct control controllers have larger contactors and fingers, owing to the larger electrical currents flowing through these components, while remote control controllers, relying on relays (and thus smaller currents), can utilise smaller contacts and fingers. The handle is rotated around the axis of this shaft to redirect the power to different circuits. Notches in the shaft allow the motorman to know when he or she has cleanly opened the correct circuit. A notch or "position" corresponds to a circuit. Different controllers have different numbers of circuits attached to different numbers of resistors and therefore different numbers of notches.



The interior of a "direct control" Controller box

In addition, the motors can be operated in series circuits for slow speed or in parallel circuits for higher speeds.

While acceleration requires the gradual application of power to the motors, the opposite is the case when slowing the tram down. Moving the handle slowly back through the notches (called "back-notching") can result in damage to the controller circuits caused by electrical arcing. Instead the handle is quickly rotated anti-clockwise back to the off position and the brakes used to slow the tram.



The driver has the handle in the "full parallel" position. This photo also shows the "Key", in the forward position. The driver's right hand is on the air brake handle, which in the "off" position.

Running a tram in anything but full series or full parallel wastes electricity and runs the risk of overheating the resistors and thereby causing a fire. The normal operating positions on the controller are therefore either full series or full parallel, with speed being controlled by judicious application of power, coasting (with no power applied) and braking.

From a standing start the motorman moves the handle from the off position, releases the brake, and then turns it through the series notches, thereby reducing the amount of power to the resistors and increasing the amount of power to the motors. When the "full series" notch is reached all power is routed to the motors running in series (effectively half speed). The motorman may safely continue to operate the tram in full series. If greater speed is required the motorman continues to turn the handle past a "transition point" between series and parallel notches and the motorman progresses gradually through the parallel notches. Power is again partially diverted to the resistors, until "full parallel" is reached, when all power is again routed to the motors, this time running in parallel.

PCC type controllers



The controls of a SEPTA PCC streetcar at the Philadelphia shops in 1993.

PCC type controllers work using the same principle except that the circuits are opened and closed **automatically** (similar controllers exist on the Gothenburg M28, older Düwag built trams, some later British tram designs and Melbourne's Z1/Z2 class). This is controlled by a spring loaded "governor" on the armature shaft of the motor. In this system, the accelerator (pedal) or controller (handle) controls the rate of acceleration, and since full series and full parallel are still the normal operating positions, speed is controlled by automatically cutting power above a speed which depends on the position of the accelerator/controller and then automatically coasting and braking as above.

Power supply in modern trams

On modern trams, power supply is controlled with thyristors (which can switch power supply on and off much faster than a motorman could), freewheel diodes which supply power when it is not supplied via the thyristor, and lowpass filters, known as line filters, which attempt to remove any remaining AC "ripple". Sometimes, when more than one traction motor is used, an individual chopper is provided for each traction motor, operating out of phase, to cancel out as much interference as possible.

In simple terms the thyristors supply power to the motors by the very rapid switching on and off of the power supply. As more power is required, the "on" period is increased and

the "off" period is decreased. This is handled automatically by the thyristors and the driver makes no conscious decision to switch the power on and off.

Because of the rapid on/off switching, in any setting between neutral and full power, undesirable "AC ripple" in the current can cause the motor housings to vibrate, increase the risk of motor bearing failure through shaft induced voltage and waste energy through eddy currents and switching losses. Ripple can also cause electrical interference (this is why modern trams tend to generate electrical "hum" at low speed). Although lowpass filters attempt to overcome this problem, modern trams are best run in full series or full parallel, as is the case with trams with older technology.

Pointswitching

In some tramway systems points (switches) could be activated by the motorman from inside the tram, while the tram was still moving. In a commonly used and simple arrangement, the points would be operated by the motorman "cutting off" (i.e. returning the handle to the off position) or keeping power on while the tram passed beneath a special contactor in the overhead wires. The contactor would sense whether the tram was drawing electricity from the overhead. If the motorman cut off power the points were to be set for straight ahead. If the motorman kept the power on, the contactor sensed power was being drawn and the points would be set for the branch line. Because of their heavier demand on power, even when coasting, modern all-electric trams tend not to rely on this form of point switching.

In other more sophisticated systems the points are activated by a button on the driver's console, which sends a small electric ripple signal through the overhead to the points activator. Another system requires a transponder under the tram being recognised by a sensor which then sets the points for the appropriate track, depending on the route the tram is intending to take and which has been pre-programmed into the transponder.

Braking controls

Generally trams will have a number of braking systems, for use in three situations - general (or service) use, emergency use and immobilisation when the tram is not in use.

Originally electric trams only had hand operated braking systems, similar to horse trams from which they evolved. Hand brakes tended to be hard to use and slow to activate. As trams became larger and heavier, other braking systems, such as air brakes, or rheostatic brakes were adopted. Magnetic track brakes were sometimes adopted as an emergency braking system and always are on modern trams.

Hand brakes - brake wheels, "goosenecks" and pawls

All older types of trams were fitted with a hand brake which could be used to safely immobilise the tram when it was switched off, or when the power was disconnected from it for some other reason. Often this "park brake" took the form of a small, vertically

mounted wheel, often with a handle. As the wheel was turned the braking mechanism forced brake shoes down onto the wheels.

When used as a service brake, the hand brake is typically connected to a gooseneck handle, which, like the controller's key and handle described above, rotates around a vertically mounted shaft and thus turns in the horizontal plane. It is normally operated with the right hand.

By turning the gooseneck handle clockwise the brake shoes are applied to the wheels. Brakes are released by operation of strong springs. To enable sufficient pressure to be applied to the brake shoes and also to overcome the resistance provided by the release springs, the base of the hand brake normally consists of a small gear under the floor of the tram, which is permanently meshed to a much larger gear which then connects to the rest of the braking mechanism. This means that the motorman must turn the brake handle many times to have any effect.

A major risk in operating the hand brake is the possibility of the handle slipping from the motorman's hand and the brake releasing uncontrollably. To minimise the possibility of this occurring, the motorman can knock a locking pawl into place using his right foot. With this in place the brake can be tightened but not released, until the motorman knocks the pawl out of the way.

Air-operated brakes

Older style trams frequently use a simplified form of Westinghouse railway brake. The brake is applied by allowing compressed air to enter a large brake cylinder (or cylinders), which pressed brake shoes onto the wheels. The brake system is operated by means of a valve, usually operated by the motorman's right hand. In most systems the brake is applied by turning the brake valve handle anti-clockwise, although in Sydney, Australia this operation was reversed.

Older brake valves were "manual lapping", where the driver had to constantly adjust the position of the valve handle to maintain pressure in the brake cylinder. Newer valves are "self-lapping" where the driver holds the valve handle in one place in order to hold the brake pressure constant. Moving the handle on self-lapping valves will increase or decrease the braking pressure.

Many trams with air brakes had an emergency brake handle in the passenger compartment which could be operated by the conductor or passengers. These operate by means of a simple valve which dumps all available pressure into the brake cylinder.

Track brakes

This form of braking applied the brakes to the track, rather than the wheels. Originally they were operated by means of a large lever which was pulled back towards the driver, similar to the track brakes on cable cars. They were comparatively rare on older electric

trams. Modern trams use electromagnets to force heavy blocks down onto the track. These were activated by means of a button or switch, or in some more recent systems by simply releasing the "dead man's handles" while the vehicle is moving.

Rheostatic and regenerative brakes

Rheostatic brakes used the motors as generators, dissipating the energy so created in additional resistor banks located underneath or on the roof of the tram. Trams fitted with rheostatic brakes had special circuits in their controllers and special handles. The motorman would move the handle anticlockwise, past the "off" position to a series of braking positions. The tram would be brought to a complete halt by applying the hand brake.

Regenerative brakes are more modern version which feed the electricity back into the power network.

Use of motors as emergency brakes

There are two ways in which the motors could be used to slow the tram in emergencies. First it is possible to use the motors effectively as generators and thereby slow the tram. This is normally done by simply moving the "handle" to the off position and then moving it back to a low series notch.

A more radical form of emergency braking is to move the "key" from forward to reverse. Depending on how the tram has been wired this may also require the motorman to first switch the tram's overhead switch off and then move the handle to a parallel notch.

In any emergency braking event drivers are trained to first apply sand to the track. This is discussed below.

Sanders

Sand is used by trams to stop wheels slipping, or to assist wheel grip in emergency braking situations. Usually sand was stored in bins under the seats in the passenger cabins close to the wheels. Generally in older vehicles the sander was operated by a small pedal in the floor. The pedal operated to open the sanders either mechanically or by air pressure. In more modern vehicles the sanders are operated electrically by pressing a button on the operator's console. Normally the sand is dropped in front of the wheels onto the track, but in some trams in Brisbane, Australia sand could also be dropped behind the wheels, in case the tram was slipping backwards on steep track. In these trams the driver depressed the sand pedal lightly to drop the sand in front of the wheels, but fully depressed the pedal to drop sand behind the tram wheels.

Warning and communication devices



Conductor's bell. These are normally situated on the ceiling above the driver. They are operated by pulling on the leather cord, which runs the length of the car

The traditional warning device on trams is a large gong (not unlike the gongs used to start and stop boxing fights). Tram gongs were pulsed by depressing a foot pedal, with the gong located directly below the pedal, under the floor. In some later trams the gong was operated by air pressure, again activated by depressing a floor pedal or by pushing a console button. In some areas, particularly in Europe an electric bell was employed, controlled by floor pedal or console button, these bells would ring continuously with the button/pedal depressed and thus were not unlike alarm bells.

Many modern trams in both Melbourne and many European cities – especially low floored models – use an amplified, digital recording of a tram gong, rather than an actual gong under the tram, with the use of a supplementary horn common.

An additional means of communication are the conductor's bells. These are smaller bells, or buzzers, usually ceiling or wall mounted, located above or beside the motorman. They were either operated by the conductor pulling a leather or rope cord which ran the length of the tram, or in the case of electric buzzers, operated by the conductor pressing a button in the passenger cabin (or rarely on the outside of the tram). In some systems passengers were allowed to ring the conductor's bell to let the driver know that they wanted to be let off at the next stop. Drivers could also communicate to the conductor using the bells.

The number of times the conductor's bell was rung would indicate what was required to be done. The following is a typical code as operated in Brisbane Australia:

conductor to motorman -

- one ring - stop at next stop
- two rings - all clear, driver may proceed
- three rings - emergency stop
- four rings - tram is full, do not stop to pick up additional passengers

motorman to conductor -

- one ring - release the hand brake
- two rings - I have control of the hand brake
- three rings - emergency stop
- four rings - come here

Safety equipment

Generally older trams did not include "dead man's handles", although in some parts of the United States and United Kingdom their use became mandatory in the 1930s after a number of court cases involving trams that had run out of control and crashed. A similar court case was held in the 1930s in NSW involving a run-away tram and the court recommended that dead man's handles be fitted to NSW trams, but the government forgot to implement the recommendation. Being very difficult and expensive the case was forgotten after the war, although Sydney did experiment with deadmans' which cut the power without applying the emergency brake. Where no deadman's handle was provided, the conductor would be responsible for stopping the tram in the event of the driver becoming incapacitated. This would usually be carried out from the rear platform, with the conductor opening the circuit breaker to cut power and then applying the brakes. On mechanically braked trams this would usually be done by winding on the mechanical brake, air braked trams an emergency brake handle would usually be provided for this purpose. Many trams have "lifeguards", which are devices in front of their bogies designed to prevent persons being caught between the wheels. Typically the lifeguard has a mechanism close to the front of the tram which, when triggered, causes a large grill or scoop to drop down onto the road in front of the tram's leading bogie. Once the emergency has passed, or if the lifeguard was accidentally tripped, it needs to be reset. In many older trams there is a third foot pedal which the motorman can depress to reset the mechanism.

Gauges

Pre-war trams rarely had speedometers fitted. Generally the only gauge in the driver's cabin indicated air pressure. Modern trams (which do not rely on compressed air to operate doors or brakes) do not need pressure gauges but always have speedometers.

Windscreen wipers

As with any vehicle with windscreens, trams require windscreen wipers to enable the driver to see through the windscreen in wet or snowy conditions. The earliest versions of wipers were spring loaded and operated manually by the driver. Later versions were operated by bleeding a small amount of compressed air, via a small pipe, off the air brake system. Normally the control for the air operated windscreen wipers was a small valve located on the wiper mechanism, with the speed of the wiper controlled by the amount of compressed air allowed into the wiper mechanism. Modern trams that do not have air brake systems instead use small electric motors to operate the wipers. The control switch for electric wipers will generally be found on the driver's console.

The fronts of very early trams were open to the elements and did not have windscreens. However all modern trams have enclosed fronts.

WWT

Chapter 5

Light Rail



Light rail car in Newark, New Jersey



Like most light rail systems, the Tranvia de Tenerife (Tenerife, Spain) includes some operation at street level, but separated from other traffic



DART Light Rail (Dallas, Texas) Mockingbird Station



Some lines of the Metro de Madrid are light rail



Sydney's Metro Light Rail



Manchester Metrolink Tram in Piccadilly Gardens, Manchester UK

Light rail or light rail transit (LRT) is a form of urban rail public transportation that generally has a lower capacity and lower speed than heavy rail and metro systems, but higher capacity and higher speed than traditional street-running tram systems. The term is typically used to refer to rail systems with rapid transit-style features that usually use electric rail cars operating mostly in private rights-of-way separated from other traffic but sometimes, if necessary, mixed with other traffic in city streets. If this is the case, then under the law of many countries such systems are then legally tramways, although the vehicles which run on them are sometimes designated "supertrams". Modern light rail technology is flexible and adaptable, and whether any given system is considered a true rapid transit system or not depends on its characteristics.

Definition of light rail

The term *light rail* was devised in 1972 by the U.S. Urban Mass Transportation Administration (UMTA) to describe new streetcar transformations that were taking place in Europe and the United States. In Germany the term *Stadtbahn* (to be distinguished from *S-Bahn*, which stands for *Stadtschnellbahn*) was used to describe the concept, and

many in the UMTA (now called the Federal Transit Administration) wanted to adopt the direct translation, which is *city rail* (the Norwegian term, *bybane*, means the same). However, the UMTA finally adopted the term *light rail* instead. *Light* in this context is used in the sense of "intended for light loads and fast movement", rather than referring to physical weight, since the vehicles often weigh more than those on so-called heavy rail systems. The investment in infrastructure is also usually lighter than would be found for a heavy rail system.

The American Public Transportation Association (APTA) in its Glossary of Transit Terminology defines *light rail* as: "An electric railway with a 'light volume' traffic capacity compared to heavy rail. Light rail may use shared or exclusive rights-of-way, high or low platform loading and multi-car trains or single cars." However, some diesel powered transit calls itself light rail, such as the O-Train in Ottawa, Canada and River Line in New Jersey, United States, which use diesel multiple unit cars. In traditional transit terminology, these would perhaps be considered commuter rail lines, or branch lines, or interurbans. (If those lines had been electric, they would clearly be interurbans.)

Light rail is similar to the British English term *light railway*, long used to distinguish railway operations carried out under a less rigorous set of regulation using lighter equipment at lower speeds from mainline railways. *Light rail* is a generic international English phrase for these types of rail systems, which means more or less the same thing throughout the Anglosphere.

The use of the generic term *light rail* avoids some serious incompatibilities in British and American English. The word *tram*, for instance, is generally understood in the UK and many former British colonies as a synonym for streetcar, but in North America it can instead refer to an aerial tramway. (The usual British term for an aerial tramway is *cable car*, which in the U.S. usually refers to a ground-level car pulled along by subterranean cables.) The word trolley is often used as a synonym for *streetcar* in the United States, but is usually taken to mean a cart, particularly a shopping cart, in the UK and elsewhere. Many North American transportation planners reserve *streetcar* for traditional vehicles that operate exclusively in mixed traffic on city streets, while they use *light rail* to refer to more modern vehicles operating mostly in exclusive rights of way, since they may operate both side-by-side targeted at different passenger groups.

The difference between British English and American English terminology arose in the late nineteenth century when Americans adopted the term "street railway", rather than "tramway", with the vehicles being streetcars rather than trams. Some have suggested that the Americans' preference for the term "street railway" at that time was influenced by German emigrants to America (who were more numerous than British immigrants in the industrialized Northeast), as it is the same as the German term for the mode, *Straßenbahn* (meaning "street railway"). A further difference arose because, while Britain abandoned all of its *trams* except Blackpool after World War II, seven major North American cities (Toronto, Boston, Philadelphia, San Francisco, Pittsburgh, Newark, and New Orleans) continued to operate large *streetcar* systems. When these cities upgraded to new technology, they called it *light rail* to differentiate it from their existing *streetcars* since

some continued to operate both the old and new systems. Since the 1980s, Portland, Oregon has built all three types of system: a high capacity light rail system in dedicated lanes and rights-of-way, a low capacity streetcar system integrated with street traffic, and an aerial tram system.

The opposite phrase *heavy rail*, used for higher capacity, higher speed systems also avoids some incompatibilities in terminology between British and American English, as for instance in comparing the London Underground to the New York Subway. Conventional rail technologies including high-speed, freight, commuter/regional, and metro/subway/elevated urban transit systems are considered to be "heavy rail". People movers and personal rapid transit are even "lighter," at least in terms of capacity. Monorail is a separate technology that has been more successful in specialized services than in a commuter transit role.

Categories of light rail

The most difficult distinction to draw is that between light rail and streetcar or tram systems. There is a significant amount of overlap between the technologies, many of the same vehicles can be used for either, and it is common to classify streetcars/trams as a subtype of light rail rather than as a distinct type of transportation. The two general versions are:

1. The traditional type, where the tracks and trains run along the streets and share space with road traffic. Stops tend to be very frequent, but little effort is made to set up special stations. Because space is shared, the tracks are usually visually unobtrusive.
2. A more modern variation, where the trains tend to run along their own right-of-way and are often separated from road traffic. Stops are generally less frequent, and the vehicles are often boarded from a platform. Tracks are highly visible, and in some cases significant effort is expended to keep traffic away through the use of special signaling, level crossings with gate arms or even a complete separation with non-level crossings. At the highest degree of separation, it can be difficult to draw the line between light rail and metros, as in the case of Wuppertal's Schwebbahn hanging rail system or London's Docklands Light Railway, which would likely not be considered "light" were it not for the contrast between it and the London Underground; many consider these not to be "light rail" lines but light metros. However, in Europe, the term light rail is increasingly being used to describe any rapid transit system with a fairly lower frequency or shorter trains compared to heavier mass rapid systems such as the London Underground or the Mass Rapid Transit in Singapore. For instance, the Putra LRT and Star LRT in Kuala Lumpur are often referred to as "light rail", despite being fully segregated mostly-elevated railways. In North America, such systems are not considered to be light rail.

Many light rail systems—even fairly old ones—have a combination of the two, with both on-road and off-road sections. In some countries (esp. in Europe), only the latter is

described as light rail. In those places, trams running on mixed right-of-way are not regarded as light rail, but considered distinctly as streetcars or trams. However, the requirement for saying that a rail line is "separated" can be quite low—sometimes just with concrete "buttons" to discourage automobile drivers from getting onto the tracks.

There is a significant difference in cost between these different classes of light rail transit. The traditional style is often less expensive by a factor of two or more. Despite the increased cost, the more modern variation (which can be considered as "heavier" than old streetcar systems, even though it is called "light rail") is the dominant form of urban rail development in the United States.

Some systems, such as the AirTrain JFK in New York City and DLR in London and Kelana Jaya Line in Kuala Lumpur, Malaysia have dispensed with the need for an operator. The Vancouver SkyTrain was an early adopter of driverless vehicles, while the Toronto Scarborough rapid transit operates the same trains as Vancouver, but uses drivers. In most discussions and comparisons, these specialized systems are not considered to be light rail.

History



Streetcar built by Preston Car Company in Ontario

Many original tram and streetcar systems in the United Kingdom, United States, and elsewhere, were decommissioned in the 1950s and onward as the popularity of the automobile increased. Britain abandoned its last tram system, except for Blackpool, by

1962. Although some traditional trolley or tram systems still exist to this day, the term "light rail" has come to mean a different type of rail system. Modern light rail technology has primarily German origins, since an attempt by Boeing Vertol to introduce a new American light rail vehicle was a technical failure. After World War II, the Germans retained their streetcar networks and evolved them into model light rail systems (*Stadtbahnen*). Except for Hamburg, all large and most medium-sized German cities maintain light rail networks.

The basic concepts of light rail were put forward by H. Dean Quinby in 1962 in an article in *Traffic Quarterly* called "Major Urban Corridor Facilities: A New Concept". Quinby distinguished this new concept in rail transportation from historic streetcar/tram systems as:

- Having the capacity to carry more passengers
- Appearing like a train, with more than one car connected together
- Having more doors to facilitate full utilization of the space
- Faster and quieter in operation

The term **light rail transit** (LRT) was introduced in North America in 1972 to describe this new concept of rail transportation.

The first of the new light rail systems in North America began operation in 1978 when the Canadian city of Edmonton, Alberta adopted the German Siemens-Duewag U2 system, followed three years later by Calgary, Alberta and San Diego, California. The concept proved popular, and although Canada has few cities big enough for light rail, there are now at least 30 light rail systems in the United States.



Los Angeles's mass transit expansion has been driven in large part by light rail

Britain began replacing its run-down local railways with light rail in the 1980s, starting with Tyneside and followed by the Docklands Light Railway (DLR) in London. The historic term light railway was used because it dated from the British Light Railways Act 1896, although the technology used in the DLR system was at the high end of what Americans considered to be *light rail*. The trend to light rail in the United Kingdom was firmly established with the success of the Manchester Metrolink system in 1992.

Historically, the rail gauge has had considerable variations, with narrow gauge common in many early systems. However, most light rail systems are now standard gauge. Older standard gauge vehicles could not negotiate sharp turns as easily as narrow gauge ones, but modern light rail systems achieve tighter turning radii by using articulated cars. An important advantage of standard gauge is that standard railway maintenance equipment can be used on it, rather than custom-built machinery. Using standard gauge also allows light rail vehicles to be moved around conveniently using the same tracks as freight railways. Another factor favoring standard gauge is that accessibility laws are making low-floor trams mandatory, and there is generally insufficient space for wheelchairs to move between the wheels in a narrow gauge layout.

Comparison to other rail transit modes

With its mix of right-of-way types and train control technologies, LRT offers the widest range of latitude of any rail system in the design, engineering, and operating practices.

The challenge in designing light rail systems is to realize the potential of LRT to provide fast, comfortable service while avoiding the tendency to overdesign that results in excessive capital costs beyond what is necessary to meet the public's needs.

Rapid rail transit

Light rail vehicles (LRVs) are distinguished from rapid rail transit (RRT) vehicles by their capability for operation in mixed traffic, generally resulting in a narrower car body and articulation in order to operate in a traffic street environment. With their large size, large turning radius, and often an electrified third rail, RRT vehicles cannot operate in the street. Since LRT systems can operate using existing streets, they often can avoid the cost of expensive subway and elevated segments that would be required with RRT.

Streetcars or trams

Conversely, LRVs generally outperform streetcars in terms of capacity and top end speed, and almost all modern LRVs are capable of multiple-unit operation. Particularly on exclusive rights-of-way, LRVs can provide much higher speeds and passenger volumes than a streetcar. Thus a single-unit streetcar capable of only 70 kilometres per hour (43 mph) operating on an shared right of way is not generally considered “light rail”. The latest generation of LRVs is considerably larger and faster, typically of length of 29 metres (95 ft) with maximum speed around 105 kilometres per hour (65 mph).

Heritage streetcar

A variation many cities consider is to use historic or replica cars on their streetcar systems instead of modern LRVs. A heritage streetcar may not have the capacity and speed of an LRV, but it will add to the ambiance and historic character of its location.

Typical rolling stock

Type	Rapid Transit	Light Rail	Tram / Streetcar	Heritage Streetcar
Manufacturer	Rohr	Siemens	Skoda	Gomaco Trolley Co.
Model	BART A-Car	S70	10T	Replica Birney
Width	3.2 metres (10 ft)	2.7 metres (8.9 ft)	2.6 metres (8.53 ft)	2.62 metres (8.6 ft)
Length	22.9 metres (75 ft)	27.7 metres (91 ft) (articulated)	20.13 metres (66.0 ft)	15.16 metres (49.7 ft)
Capacity	150 max	220 max	157 max	88max

Top Speed	125 kilometres per hour (78 mph)	106 kilometres per hour (66 mph)	70 kilometres per hour (43 mph)	48 kilometres per hour (30 mph)
Typical Consist	8-10 vehicles	1-4 vehicles	1 vehicle	1 vehicle

Light metro

A derivative of LRT is light rail rapid transit (LRRT), also referred to as *Light Metro*. Such railways are characterized by exclusive rights of way, advanced train control systems, short headway capability, and floor level boarding. These systems approach the passenger capacity of full metro systems, but can be cheaper to construct by using the ability of LRVs to turn tighter curves and climb steeper grades than standard RRT vehicles.

Interurbans

The term *interurban* (German *Überland(strassen)bahn*) is mainly used about rail-cars that run through the streets like ordinary streetcars (trams), but also between cities and/or towns, often through rural environments. In the period 1900-1930, interurbans were very common in the U.S., especially in the Midwest. Some of them, like the Red Devils, the J.G.Brill Bullets, and the Electroliners, belonged to this time's high-speed railcars, with a commercial speed of up to about 145 km/h (90 mph).

Train operation

An important factor crucial to LRT is the train operator. Unlike rail rapid transit, traveling unattended with automatic train operation (ATO), the operator is a key element in a safe, high-quality LRT operation. The reason that the operator is so important is because the train tracks often run on roads with cars. If trains were automated on roads, a person wouldn't be there to stop the train if a car pulled in front of it. Light rail trains are actually very heavy to prevent damage from impacts with cars. Thus, a train with ATO is not "light rail". The philosophy of light rail is that a qualified person should be on each train to deal with emergencies, and while that person is there, he or she might as well operate the train.

Floor height

The latest generation of LRVs has the advantage of partial or fully low-floor design, with the floor of the vehicles only 300 to 360 mm (11.8 to 14.2 in) above top of rail, a capability not found in either rapid rail transit vehicles or streetcars. This allows them to load passengers, including ones in wheelchairs, directly from low-rise platforms that are not much more than raised sidewalks. This satisfies requirements to provide access to disabled passengers without using expensive wheelchair lifts, while at the same time making boarding faster and easier for other passengers as well.

Power sources

Overhead lines supply electricity to the vast majority of light rail systems. This avoids the danger of passengers stepping on an electrified third rail. The Docklands Light Railway uses an inverted third rail for its electrical power which allows the electrified rail to be covered and the power drawn from the underside. Trams in Bordeaux, France use a special third-rail configuration where the power is only switched on beneath the trams, making it safe on city streets. Several systems in Europe, as well as a few recently-opened systems in North America use diesel-powered trains.

Pros and cons of light rail

All transit service involves a trade-off between speed and frequency of stops. Services that stop frequently have lower overall speed and are therefore less attractive for longer trips but are more likely to go where the user wants. Light rail, monorail, and Bus Rapid Transit are all forms of rapid transit, which generally signifies high speed and widely-spaced stops. Trams are a form of local transit, making more frequent stops.

Tram and light-rail transit systems around the world



Tren de la Costa in Buenos Aires

Around the world there are many tram systems. Some date from the early 20th century, but many of the old systems were closed down in the mid-20th century, with the exceptions of many Eastern Europe countries. Even though many of the systems have closed down over the years there are still tram systems that have been operating much as

they did when they were first built over a century ago. Some cities (such as Los Angeles and Jersey City) that once closed down their tram networks are now in the stages of reconstructing, or have rebuilt, some of their tramways. Most light rail services are currently committed to articulated vehicles like modern LRVs, i.e. trams, with the exception of large underground metro systems.

Capacity of light rail versus roads

One line of light rail has a theoretical capacity of up to 8 times more than one lane of freeway (not counting buses) during peak times. Roads have ultimate capacity limits that can be determined by traffic engineering. They usually experience a chaotic breakdown in flow and a dramatic drop in speed (colloquially known as a traffic jam) if they exceed about 2,000 vehicles per hour per lane (each car roughly two seconds behind another). Since most people who drive to work or on business trips do so alone, studies show that the average car occupancy on many roads carrying commuters is only about 1.2 people per car during the high-demand rush hour periods of the day. This combination of factors limits roads carrying only automobile commuters to a maximum observed capacity of about 2,400 passengers per hour per lane. The problem can be mitigated by using high-occupancy vehicle (HOV) lanes and introducing ride-sharing programs, but in most cases the solution adopted has been to add more lanes to the roads. Simple arithmetic shows that in order to carry 20,000 automobile commuters per hour per direction, a freeway must be at least 18 lanes wide.

By contrast, light rail vehicles can travel in multi-car trains carrying a theoretical ridership up to 20,000 passengers per hour in much narrower rights-of-way, not much more than two car lanes wide for a double track system. They can often be run through existing city streets and parks, or placed in the medians of roads. If run in streets, trains are usually limited by city block lengths to about four 180-passenger vehicles (720 passengers). Operating on 2 minute headways using traffic signal progression, a well-designed two-track system can handle up to 30 trains per hour per track, achieving peak rates of over 20,000 passengers per hour in each direction. More advanced systems with separate rights-of-way using moving block signalling can exceed 25,000 passengers per hour per track.

Most light rail systems in the United States are limited by demand rather than capacity (by and large, most North American LRT systems carry less than 4000 persons per hour per direction), but Boston and San Francisco light rail lines carry 9,600 and 13,100 passengers per hour per track during rush hour. Elsewhere in North America, the Calgary C-Train, Toronto streetcar system, and Monterrey Metro have higher light rail ridership than Boston or San Francisco. Systems outside North America often have much higher passenger volumes. The Manila Light Rail Transit System is one of the highest capacity ones, having being upgraded in a series of expansions to handle 40,000 passengers per hour per direction, and having carried as many as 582,989 passengers in a single day on its Line #1. It achieves this volume by running 4-car trains of up to 1350 passengers at a frequency of up to 30 trains per hour. It is important to note, however, that the Manila light rail system has full grade separation and as a result has many of the operating

characteristics of a Metro system rather than a light rail system. 1350 passengers per train is more similar to heavy rail than light rail.

A bus line using its own lanes can have a capacity of 7,000 per hour (30 buses per direction, 120 passengers in articulated buses). Bus traffic is the traditional alternative to light rail, at least if very high capacity is not needed. Using buses, roads can get a high transit capacity. To have 30 buses per direction and hour, they must have priority in traffic lights and have their own lanes, as must trams to reach this density. Buses can go closer to each other than rail vehicles because of better braking capability. However, each bus vehicle requires a single driver, whereas a light rail train may have three to four cars of the same capacity in one train under the control of one driver, increasing labor costs of high-traffic BRT systems.

Costs of light rail construction and operation

The cost of light rail construction varies widely, largely depending on the amount of tunneling and elevated structures required. A survey of North American light rail projects shows that costs of most LRT systems range from \$15 million per mile to over \$100 million per mile. Seattle's new light rail system is by far the most expensive in the U.S. at \$179 million per mile, since it includes extensive tunneling in poor soil conditions, elevated sections, and stations as deep as 180 feet (55 m) below ground level. These result in costs more typical of subways or rapid transit systems than light rail. At the other end of the scale, four systems (Baltimore MD, Camden NJ, Sacramento CA, and Salt Lake City UT) incurred costs of less than \$20 million per mile. Over the U.S. as a whole, excluding Seattle, new light rail construction costs average about \$35 million per mile. By comparison, a freeway lane expansion typically costs \$20 million per lane mile (a lane mile is a mile-long lane) for two directions. Since a light rail track can carry up to 20,000 people per hour as compared with 2,000-2,200 vehicles per hour for one freeway lane, light rail could theoretically deliver significantly more congestion-reduction potential per dollar as incremental freeway lanes in congested urban areas. For example, in Boston and San Francisco, light rail lines carry 9,600 and 13,100 passengers per hour, respectively, in the peak direction during rush hour.

Combining highway expansion with LRT construction can save costs by doing both highway improvements and rail construction at the same time. As an example, Denver's T-REX (Transportation Expansion) project rebuilt interstate highways 25 and 225 and added a light-rail expansion for a total cost of \$1.67 billion over five years. The cost of 17 miles (27 km) of highway improvements and 19 miles (31 km) of double-track light rail worked out to \$19.3 million per highway lane-mile and \$27.6 million per LRT track-mile. The project came in under budget and 22 months ahead of schedule.

LRT cost efficiency improves dramatically as ridership increases, as can be seen from the numbers above: the same rail line, with similar capital and operating costs, is far more efficient if it is carrying 20,000 people per hour than if it is carrying 2400. The Calgary, Alberta C-Train used many common light rail techniques to keep costs low, including minimizing underground and elevated trackage, sharing transit malls with buses, leasing

rights-of-way from freight railroads, and combining LRT construction with freeway expansion. As a result, Calgary ranks toward the less expensive end of the scale with capital costs of around \$24 million per mile.

However, Calgary's LRT ridership is much higher than any comparable U.S. light rail system at 300,000 passengers per weekday, and as a result its efficiency of capital is also much higher. Its capital costs were $\frac{1}{3}$ that of the San Diego Trolley, a comparably sized U.S. system built at the same time, while by 2009 its ridership was approximately three times as high. Thus, Calgary's capital cost per passenger was much lower than that of San Diego. Its operating cost per passenger was also much lower because of its higher ridership. A typical C-Train vehicle costs only \$163 per hour to operate, and since it averages 600 passengers per operating hour, Calgary Transit estimates that its LRT operating costs are only 27 cents per ride, versus \$1.50 per ride on its buses.

Variations

Trams operating on mainline railways

Around Karlsruhe, Kassel and Saarbrücken in Germany, dual-voltage light rail trains partly use mainline railroad tracks, sharing these tracks with heavy-rail trains. In the Netherlands, this concept was first applied on the RijnGouweLijn. This allows commuters to ride directly into the city centre, rather than taking a mainline train only as far as a central station and then having change to a tram. In France similar tram-trains are planned for Paris, Mulhouse and Strasbourg; further projects exist.

Some of the issues involved in such schemes are:

- Compatibility of the safety systems
- Power supply of the track in relation to the power used by the vehicles (frequently different voltages, rarely third rail vs overhead wires)
- Width of the vehicles in relation to the position of the platforms
- Height of the platforms

There is a history of what would now be considered light-rail vehicles operating on heavy-rail rapid transit tracks in the U.S., especially in the case of interurban streetcars. Notable examples are Lehigh Valley Transit trains running on the Philadelphia and Western Railroad high-speed third rail line (now the Norristown High Speed Line). Such arrangements are almost impossible now, due to the Federal Railroad Administration refusing (for crash safety reasons) to allow non-FRA compliant railcars (i.e. subway and light rail vehicles) to run on the same tracks at the same times as compliant railcars, which includes locomotives and standard railroad passenger and freight equipment. Notable exceptions in the USA is the New Jersey Transit River Line from Camden to Trenton and Austin's Capital MetroRail, which have received exemptions on the provision that light rail operations occur only during daytime hours and Conrail freight service only at night, with several hours separating one operation from the other. The O-train in Ottawa also has freight service at certain hours.

Third-rail power for trams

When electric streetcars were introduced in the late 19th century, conduit current collection was one of the first ways of supplying power, but it proved to be much more expensive, complicated, and trouble-prone than overhead wires. When electric street railways became ubiquitous, conduit power was used in those cities that did not permit overhead wires. In Europe, it was used in London, Paris, Berlin, Marseilles, Budapest and Prague. In the United States, it was used in parts of New York City and Washington DC. Third rail technology is being investigated for use on the Gold Coast of Australia for the Gold Coast Rapid Transit system.

In the French city of Bordeaux, Citadis trams are powered by a third rail in the city center, where the tracks are not always segregated from pedestrians and cars. The third rail (actually two closely spaced rails) is placed in the middle of the track, and divided into eight-metre sections, each of which is powered only while it is completely covered by a tram. This minimises the risk of a person or animal coming into contact with a live rail. In outer areas, the trams switch to conventional overhead wires. In practice, the Bordeaux power system costs about three times as much as a conventional overhead wire system, and took 24 months to achieve acceptable levels of reliability, requiring replacement of all the main cables and power supplies. Operating and maintenance costs of the innovative power system still remain high. However, despite numerous service outages, the system was a success with the public, gaining up to 190,000 passengers per day.

Chapter 6

Bow Collector & Conduit Current Collection

Bow Collector



An old tram with a bow collector built in 1907 still running in Bolzano, Bolzano-Bozen, Italy

A **bow collector** is one of the three main devices used on tramcars to transfer electric current from the wires above to the tram below. While once very common in continental Europe, it has now been largely replaced by the pantograph.

Origins

When the bow collector was first conceived by German inventor Ernst Werner von Siemens in the late 1880s, American inventor Frank J. Sprague of Virginia had just patented his trolley pole system of current collection from an overhead wire. To avoid contravening this patent, the Siemens company was forced to design its own, unique form of current collection, namely the bow collector. The bow collector was first used by the Siemens electric company in its early electric tramcars in either the late 1880s or early 1890s. The Hobart electric tramway system - the first of its kind in the Southern Hemisphere, opened in 1893 - used Siemens cars with very early bow collectors. Many other continental European and some English tramway systems also used this method.

Construction



A historical tram with a bow collector in Plauen, Germany

The bow collector is one of the simplest and most reliable methods of current collection used on tramways. The very earliest versions were simply very heavy-gauge wire or steel

bars bent into a rectangular shape and mounted long-side-down on the tramcar roof. The height of the collector was such that its top edge would scrape along the wire above. The top section is made of a 1 inch broad (or thereabouts) steel rod, machined to have a bow-shaped cross section, hence the name. This bow shaped rod is referred to as the 'collector plate', and in later models may be up to several inches wide. Unlike many trolley poles, the bow collector does not normally have a revolving base (one exception was in Rome, where the entire assembly could be revolved), but is rather fixed centrally to the tramcar roof.

In the late 1900s the simple framing methods mentioned above were gradually replaced by more complex and sophisticated methods, but the general mode of operation remained the same. The changes of design are most noticeable on systems where both double- and single-deck cars were used on the same system. Single deck trams usually have tall and lightly constructed collectors with complicated frames to support the heavy cast-steel collector plate, while double deck cars usually have heavier collectors with less complicated frames.

To maintain good electrical contact, the bow collector must exert quite strong pressure on the wire above, and so complicated systems of springs or weights were put into use to ensure good electrical contact, and hence efficient operation was maintained.

The steel rails on the tracks act as the electrical return.

Operation

Properly the bow collector should be mounted in such a way so that the top edge of the collector plate would rise several inches above the wire when the collector frame is standing straight up. Thus the collector usually leans opposite to the direction of travel; when the time comes to travel in the opposite direction, the collector must be swung over. To allow this to happen, the overhead wire must be raised by several inches at places where the bows are swung over, such as terminals and turn-outs. This operation is usually achieved by ropes and pulleys. The collector is folded down to a horizontal position when the car is not in use.

Some early cars had no means to swing the bows over. It was thought that this would happen automatically when the tramcar started travelling the other way, but collectors such as these were a failure.

Most Soviet trams (of which some are still in use in ex-USSR) had no means to swing the bows over. These trams were not designed to travel two ways. Another example is KTV-55-2 tramcar which had two bow collectors for the two directions of travelling.

Advantages and Modern Usage

The bow collector has fewer moving parts than the trolley pole, but is heavier and sometimes more complicated to construct. The construction of overhead wires for bow

collectors is simpler than trolley pole wiring. As bow collectors do not have revolving mountings, the collector cannot jump off the wire or follow the wrong one at intersections, as trolley poles sometimes do. Thus overhead 'frogs' and guides for trolley poles are not necessary with bow collectors. Bow collectors are, however, much noisier than trolley poles.

The overhead wires for bow collectors are stretched tighter than for trolley poles, and straight sections are 'staggered', that is, the wire does not run completely straight down the centreline of the track, but rather zig-zags slightly across a small distance. This distributes wear across the bow collector's collector plate, and extends the collector's life.

In addition to some vintage tramways, bow collectors are still used in some tram systems in ex-USSR, e. g., in Kazan, Minsk,

Conduit Current Collection



Abandoned conduit trackage at the Kingsway Tramway Subway in London

Conduit current collection is a system of electric current collection used by electric trams, where the power supply is carried in a channel under the roadway, rather than located overhead.

Description

The power rails for conduit cars are contained in a vault between and underneath the running rails, much in the same fashion as the cable for cable cars. The vault contains two "T" section steel power rails of opposite polarity facing each other, about 12 inches (30.5 cm) apart and about 18 inches (45.7 cm) below the street surface. Power reached the car by means of an attachment, called a plough (US - plow), that rode in the conduit beneath the car. The plough had two metal shoes that pushed sideways against the power rails and connected to the car's controller and motor(s). The running rails are not part of the electrical circuit. In the United States, the cars were sometimes popularly but incorrectly called trolleys but did not typically draw power through a trolley pole from an overhead wire as (strictly defined) trolley cars do.



Usage



A conduit tramcar from Blackpool, on display at the National Tramway Museum

Conduit current collection was one of the first ways of supplying power to electric tramcars but it proved to be much more expensive, complicated and trouble-prone than overhead wires. When electric street railways became ubiquitous, it was only used in those cities which did not permit overhead wires. These included London, Paris, Berlin, Marseilles, Budapest and Prague in Europe and parts of New York City and Washington DC in the United States.

In Denver, Colorado, the world's second electrically operated street railway, starting in 1885, pioneered the use of conduit current collection. Difficulties with the conduit and

the electric streetcars led to the replacement of all conduit cars and lines with cable cars by 1888.

New York City had the largest installation of conduit cars, due to the prohibition of stringing overhead wires on Manhattan Island, although a few Bronx-based trolley lines entered the northern reaches of Manhattan using overhead wire. Trolley lines from Brooklyn and Queens also entered Manhattan under wire, but did not use city streets. The primary reason for the initial adoption of the conduit "plow" in Manhattan was the fact that return currents from conventional overhead wires using track return grounds were eroding gas mains.

The expense of creating conduit lines in New York was reduced to where it was possible to convert the cable vaults from discontinued cable car lines to conduit use. The huge expense of building new conduit, however, gave New York the distinction of having one of the last horsecar lines (the Bleecker Street Line) in the U.S., not closing until 1917. (Pittsburgh actually ran the very last U.S. horsecar, with service ending finally in 1923.)

In some old photographs, two "slots" may be seen between the rails. In New York City, sometimes one slot was used for a cable line and the other for electrical purposes. Occasionally, two competitive lines would share a common track and would have independent slots for the ploughs of the respective cars.

In New York City, the Queensboro Bridge between Manhattan and Queens had tracks installed on the outer lanes with conduit, for Manhattan cars in addition to overhead wire. The conduit allowed them to run to Queens Plaza terminus without need for removing the plough and raising the poles. In later years the conduit was removed and only trolley wire remained.

In the centre of Brussels, a number of tram lines were fitted with conduit, the last ones being converted to overhead operation during World War II.

The system was tried in the beachside resort of Blackpool, UK but was soon abandoned as sand and saltwater was found to enter the conduit and cause breakdowns and there was a problem with voltage drop. Some sections of tramway track still have the slot rails visible.

Hybrid installations

Washington, D.C. had a large network of conduit lines, to save the capital city from unsightly wires. Some lines used overhead wires when they approached rural or suburban areas. The last such line ran to Cabin John, Maryland. The current collector "plow" as it was called, was mounted underneath the car on fitting just forward of the rear truck on D.C. Transit's PCC cars. It had two cables with female connectors on cables to attach to matching cables of the car's electrical system. A "plowman" was assigned at each changeover point from overhead trolley wire to conduit point to remove the cable attachments to the car and stow the plow, which would not remain with the car, but which

would be reattached in an incoming car running on overhead wire. The lower section of the plow "board" was drawn by the moving car above within the cavity of the conduit. Because of this usage, many of Washington's streetcars carried trolley poles, which were lowered while operating in the central part of the city; when the cars reached a point where they switched to overhead operation, they stopped over a *plow pit* where the conduit plows were detached and the trolley poles raised, the reverse operation taking place on inbound runs. The 'pit' here has the meaning analogous to racing circuit pits rather than a depression in the road.

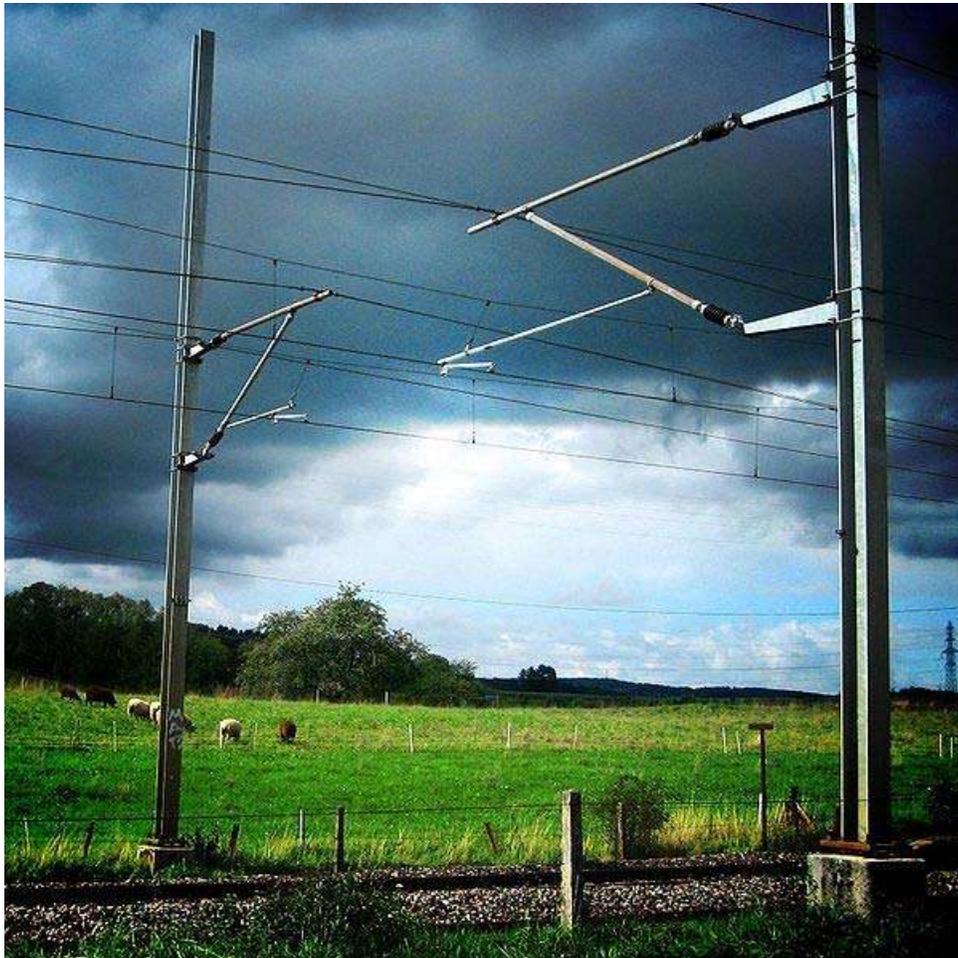
In the UK, London also had a hybrid network of double-deck trams: overhead collection was used in the outer sections and conduit in the centre. At the change over from conduit to overhead wire (at what was known as the 'change pit') the change process was largely automatic. The conductor released the trolley pole onto the wire then, as the tram moved forward, the conduit channel veered sideways to outside the running track automatically ejecting the collector plough. The tram was said to be 'shooting the plough'. At the change-over between overhead wire and conduit, the process was a little more complicated. The tram pulled up alongside a ploughman who engaged a two-pronged guide (known as a 'plough fork') over the plough in a short length of un electrified conduit and into the plough channel underneath the centre of the tram. As the tram drew forward, the conduit channel moved under the tram carrying the plough into position. The conductor could then pull down the trolley pole and stow it. The process is illustrated here. The ploughman's job was a fairly skilled one because, if he failed to locate the plough fork correctly, it or the plough itself could jam in the plough channel and cause lengthy delays. Some tram designs required an extra carrier to be located with the plough and these frequently caused problems for ploughmen not used to the design (particularly if the tram had been diverted from its normal route).

New track was laid as late as 1951 for the Festival of Britain, which commemorated the Great Exhibition of 1851. The last tram was withdrawn in June 1952 and virtually all the tracks had been removed by the 1970s, although a short section can still be seen in the Holborn area at the entrance to the former Kingsway Tramway Subway.

Other European hybrid tramway networks included Paris, Nice, Lyon, Lille and Bordeaux in France; Berlin, Vienna and Budapest. In Paris, the conduit sections were frequently very short, requiring cars to change from overhead to conduit and back several times in one journey. The last conduit line in Paris closed in 1936, while the last Bordeaux conduit car ran in 1953. The conduit systems in Berlin, Vienna and Budapest were very short-lived. All three were replaced by overhead working before World War I.

Chapter 7

Overhead Lines



Overhead lines on Swiss Federal Railways



The overhead lines in China

Overhead lines or **overhead wires** are used to transmit electrical energy to trams, trolleybuses or trains at a distance from the energy supply point. These overhead lines are known variously as

- **Overhead contact system (OCS)**—Europe, except UK and Spain
- **Overhead line equipment (OLE or OHLE)**—UK
- **Overhead equipment (OHE)** — UK, India, Pakistan and Malaysia
- **Overhead wiring (OHW)**—Australia
- **Catenary**—United States, India, UK, Singapore (North East MRT Line) , Canada and Spain.

Here the generic term *overhead line* is used.

Overhead line is designed on the principle of one or more overhead wires or rails (particularly in tunnels) situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid.

Overview

Electric trains that collect their current from an overhead line system use a device such as a pantograph, bow collector, or trolley pole. The device presses against the underside of the lowest wire of an overhead line system, the **contact wire**. The current collectors are electrically conductive and allow current to flow through to the train or tram and back to the feeder station through the steel wheels on one or both running rails. Non-electric trains (such as diesels) may pass along these tracks without affecting the overhead line, although there may be difficulties with overhead clearance. Alternative electrical power transmission schemes for trains include third rail, Aesthetic Power Supply, batteries, and electromagnetic induction.



Construction



Linemen on a maintenance of way vehicle repairing overhead lines

To achieve good high-speed current collection, it is necessary to keep the contact wire geometry within defined limits. This is usually achieved by supporting the contact wire from above by a second wire known as the **messenger wire** (US & Canada) or **catenary** (UK). This wire approximates the natural path of a wire strung between two points, a catenary curve, thus the use of *catenary* to describe this wire or sometimes the whole system. This wire is attached to the contact wire at regular intervals by vertical wires known as **droppers** or **drop wires**. The messenger wire is supported regularly at structures, by a pulley, link, or clamp. The whole system is then subjected to a mechanical tension.

As the contact wire makes contact with the pantograph, the carbon surface of the insert on top of the pantograph is worn down. Going around a curve, the "straight" wire between supports will cause the contact wire to cross over the whole surface of the pantograph as the train travels around the curve, causing an even wear and avoiding any notches. On straight track, the contact wire is zigzagged slightly to the left and right of centre at each successive support so that the pantograph wears evenly.

The zigzagging of the overhead line is not required for trams using trolley poles or for trolleybuses.

Depot areas tend to have only a single wire and are known as **simple equipment**. When overhead line systems were first conceived, good current collection was possible only at low speeds, using a single wire. To enable higher speeds, two additional types of equipment were developed:

- **Stitched equipment** uses an additional wire at each support structure, terminated on either side of the messenger wire.
- **Compound equipment** uses a second support wire, known as the **auxiliary**, between the messenger wire and the contact wire. Droppers support the auxiliary from the messenger wire, and additional droppers support the contact wire from the auxiliary. The auxiliary wire can be constructed of a more conductive but less wear-resistant metal, increasing the efficiency of power transmission.

Dropper wires traditionally only provide physical support of the contact wire, and do not join the catenary and contact wires electrically. Contemporary systems use current-carrying droppers, which eliminate the need for separate wires.

The present transmission system originated about 100 years ago. A simpler system was proposed in the 1970s by the Pirelli Construction Co consisting of a single wire embedded at each support for 2.5 metres (8 ft 2 in) of its length in a clipped extruded aluminum beam with the wire contact face exposed. With a somewhat higher tension than used before clipping the beam yielded a deflected profile for the wire which could be easily handled at 250 miles per hour (400 km/h) by a pneumatic servo pantograph with only 3 G accelerations. This cut about 40% from the total track overhead equipment cost but required a pantograph development period which was not accepted by British Rail.

For tramways there is often just a simple contact wire and no messenger wire.

In situations where there is limited clearance to accommodate wire suspensions systems such as in tunnels, the overhead wire may be replaced by rigid overhead rail. This was done when the overhead line had to be raised in the Simplon Tunnel to accommodate taller rail vehicles.

Parallel overhead lines

An electrical circuit requires at least two conductors. Trams and railways use the overhead line as one side of the circuit and the steel rails as the other side of the circuit. For a trolleybus there are no rails to send the return current along—the vehicles use rubber tyres and the normal road surface. Trolleybuses use a second parallel overhead line for the return, and two trolley-poles, one contacting each overhead wire. The circuit is completed by using both wires.

Germany



A twisting pylon of a single phase AC 110 kV power line near Bartholomä in Germany. Lines of this type are used in Germany to supply electric railways with single phase AC at $16\frac{2}{3}$ Hz

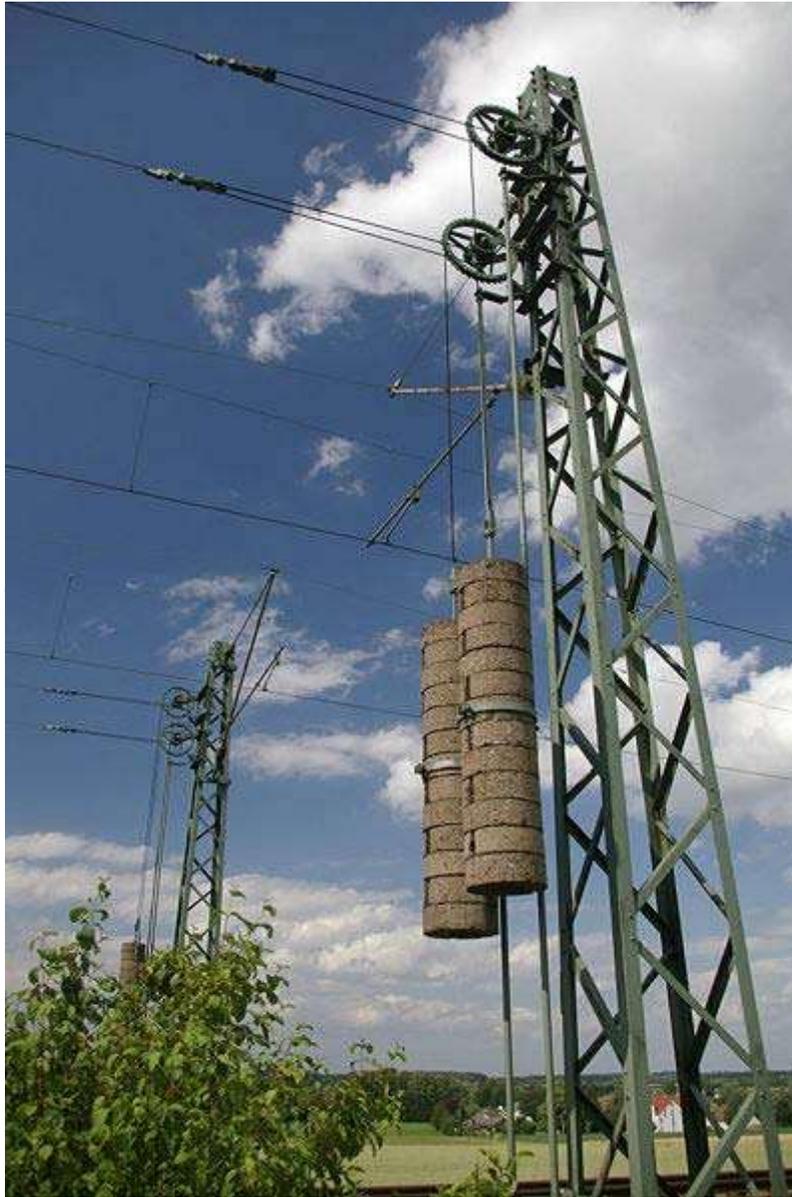
In Germany there are special overhead power lines for single phase AC traction current with a frequency of $16\frac{2}{3}$ hertz. All operate at a voltage of 110 kV (the voltage of the railway overhead lines is 15 kV) and have four conductor cables for two circuits. As a rule at traction current lines, a single-level arrangement of conductor cables is used.

A traction current pylon is a type of electricity pylon with at least one electric circuit for traction current. For traction current lines with four circuits (eight conductor cables) usually two-level arrangements of conductors are used, in which one pylon crossbar carries four conductor cables. For traction current lines used to supply high-speed rail tracks, three-level arrangements of conductors are employed; thereby four conductor cables are mounted on the lowest crossbar, and two on the upper crossbars. The three-level arrangement is also used for traction current lines with six electric circuits (12 conductor cables).

There are other overhead line pylons with crossbars for 110 kV traction voltage. For example the power supplies of rapid transit railways. Additionally there are pylons that transmit both electric power for railway traction current as well as three-phase alternating current for the public power grid.



Tensioning



Line tensioning

Catenary wires are kept at a mechanical tension because the pantograph causes oscillations in the wire and the wave must travel faster than the train to avoid producing standing waves that would cause the wires to break. Tensioning the line makes waves travel faster.

For medium and high speeds, the wires are generally tensioned by means of weights or occasionally by hydraulic tensioners. Either method is known as **auto-tensioning (AT)**, or **constant tension** and ensures that the tension in the equipment is virtually independent of temperature. Tensions are typically between 9 and 20 kN (2,000 and 4,500 lbf) per

wire. Where weights are used, they slide up and down on a rod or tube attached to the mast, to stop the weights from swaying.

For low speeds and in tunnels where temperatures are constant, **fixed termination (FT)** equipment may be used, with the wires terminated directly on structures at each end of the overhead line. Here the tension is generally about 10 kN (2,200 lbf). This type of equipment will sag on hot days and hog on cold days.

Where AT is used, there is a limit to the continuous length of overhead line which may be installed. This is due to the change in the position of the weights with temperature as the overhead line expands and contracts. This movement is proportional to the **tension length**, i.e. the distance between anchors. This leads to the concept of maximum tension length. For most 25 kV OHL equipment in the UK, the maximum tension length is 1970 m.

An additional issue with AT equipment is that, if balance weights are attached to both ends, the whole tension length will be free to move along track. To rectify this issue, a **midpoint anchor (MPA)**, close to the centre of the tension length, restricts movement of the messenger wire by anchoring it; the contact wire and its suspension hangers can move only within the constraints of the MPA. MPAs are sometimes fixed to low bridges; otherwise, they are anchored to the typical vertical catenary poles or portal catenary supports. Therefore, a tension length can be seen as a fixed centre point, with the two half tension lengths expanding and contracting with temperature.

Most overhead systems include a brake to stop the wires from unravelling completely should a wire break or tension be lost for any other reason. German systems usually use a single large tensioning pulley with a toothed rim, mounted on an arm hinged to the mast. Normally the downward pull of the weights, and the reactive upward pull of the tensioned wires, lifts the pulley so its teeth are well clear of a stop on the mast. The pulley can turn freely while the weights move up or down as the wires contract or expand. If a wire breaks or tension is otherwise lost, the pulley falls back toward the mast, and one of its teeth will jam against the stop. This stops further rotation, limits the damage, and keeps the undamaged part of the wire intact until it can be repaired. Other systems use various other braking mechanisms, usually with multiple smaller pulleys in a block and tackle arrangement.

Breaks

Section Break



A section insulator installed at a section break in Amtrak's 12 kV catenary.

To allow maintenance to sections of the overhead line without having to turn off the entire system, the overhead line system is broken into electrically separated portions known as **sections**. Sections often correspond with tension lengths as described above. The transition from section to section is known as a **section break** and is set up so that the locomotive's pantograph is in continuous contact with the wire.

For bow collectors and pantographs, this is done by having two contact wires run next to each other over a length about four wire supports: a new one dropping down and the old one rising up until the pantograph smoothly transfers from one to the next. The two wires never touch (although the bow collector/pantograph is briefly in contact with both wires). In normal service, the two sections are electrically connected (to different substations if at or near the halfway mark between them) but this can be broken for servicing.

On overhead wires designed for trolley poles this is done by having a neutral section between the wires, requiring an insulator. The driver of the tram or trolleybus must turn

off the power when the trolley pole passes through, to prevent arc damage to the insulator.

Pantograph equipped locomotives may never run through a section break when one side is de-energized. Of course the locomotive would then become trapped, but as it passes the section break, the pantograph will briefly short the two catenary lines together. If the opposite line is de-energized, this voltage transient may trip supply breakers. If the line is under maintenance, personnel injury may occur as the catenary is suddenly energized. Even if the catenary is properly grounded, the arc generated across the pantograph will likely cause damage to the pantograph, the catenary insulator, or both.

Phase Break



Neutral Section Indication Board used on railways in the UK

Sometimes on a larger electrified railway, tramway or trolleybus system, it is necessary to power different areas of track from different power grids, the synchronisation of the phases of which cannot be guaranteed. (Sometimes the sections are powered with different voltages or frequencies.) There may be mechanisms for having the grids synchronised on a normal basis but events may cause desynchronisation. This is no problem for DC systems but, for AC systems, it is highly undesirable to connect two unsynchronised grids. A normal section break is insufficient to guard against this, since the pantograph briefly connects both sections.

Instead, a **phase break** or neutral section is used. This consists of two section breaks back-to-back so that there is a short section of overhead line that belongs to neither grid. If the two grids are synchronized, this stretch of line is energized (by either supply) and trains run through it normally. If the two supplies are not synchronized, the short isolating section is disconnected from the supplies, leaving it electrically dead, ensuring that the two grids cannot be connected to each other.

The sudden loss of power over the phase break would jar the train if the locomotive was at full throttle, so special signals are set up to warn the crew. When synchronization is lost and the phase break is deenergized, the train's operator must put the controller (throttle) into neutral and coast through an isolated phase break section.

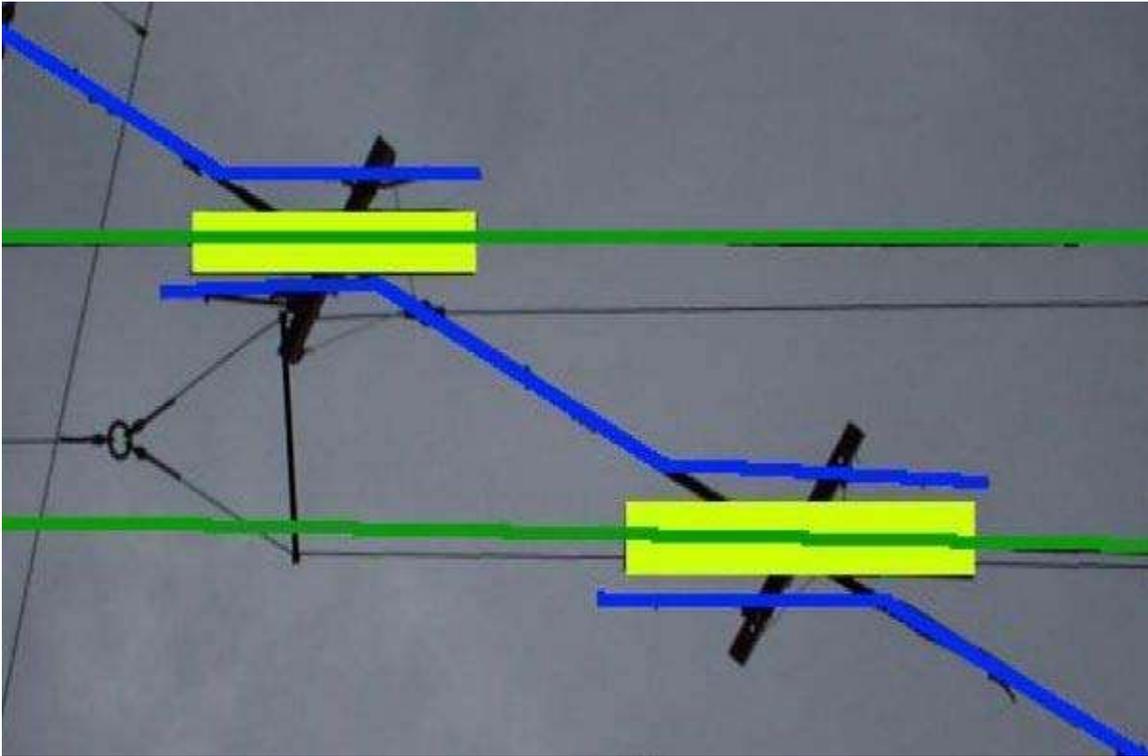
On the Pennsylvania Railroad, phase breaks were indicated by a position light signal face with all eight radial positions filled by lenses and no center light. When the phase break was active (that is when the catenary sections were out of phase), all lights were lit. The position light signal aspect was originally devised by the Pennsylvania Railroad but was continued by its successor Amtrak and has been adopted by Metro North. Metal signs were also hung from the catenary supports with the letters *PB* created by a pattern of drilled holes.

Transnet Freight Rail in South Africa has permanent magnets between the rails at both sides of the neutral section where two phases are separated. These are detected by equipment on the locomotive, which disconnect and reconnect power from the pantographs.

Dead Section

A special category of phase break was also developed in American practice, primarily by the Pennsylvania Railroad. Since its traction power network was centrally supplied, and only segmented by abnormal conditions, phase breaks were normally not active. Phase breaks which were always activated came to be known as *Dead Sections*. They often were to separate boundaries between power systems (for example, the Hell's Gate Bridge boundary between Amtrak and Metro North's electrification systems), which would never be in-phase. Since a dead section is, by definition, always dead, no special signal aspect was developed to warn engineers of its presence. A simple metal sign with *DS* in drilled-hole letters was hung from the catenary supports.

Crossings



An annotated version of the above.

- tram conductor
- trolley bus wires
- insulated trough

Trams draw their power from a single overhead wire at about 500 to 750 V, while trolleybuses draw their power from two overhead wires at a similar voltage. Because of that, at least one of the trolleybus wires must be insulated from tram wires. This is usually solved by the trolleybus wires running continuously through the crossing, with the tram conductors a few centimetres lower. Close to the junction on each side, the wire merges into a solid bar running parallel to the trolleybus wires for about half a metre. Another bar similarly angled at its ends is hung between the trolleybus wires. This is electrically connected above to the tram wire. The tram's pantograph bridges the gap between the different conductors, providing it with a continuous pickup.

Where the tram wire crosses, the trolleybus wires are protected by an inverted trough of insulating material extending 20 or 30 mm below.

Until 1946, there was a level crossing in Stockholm, Sweden between the railway south of Stockholm Central Station and a tramway line. The tramway operated on 600-700 V DC and the railway on 15 kV AC. Some crossings between tramway/light rail and railways are still extant in Germany. In Zürich, Switzerland the VBZ trolleybus line 32 has a level crossing with the 1,200 V DC railway to mount Uetliberg; at many places in

the town, trolleybus lines cross the tramway. In the Swiss village of Suhr, the WSB tramway operating at 1,200 V DC crosses the SBB line at 15 kV AC. In some cities, trolleybuses and trams have shared the same positive (feed) wire. In such cases, a normal trolleybus frog can be used.

Another system that has been used is to coincide section breaks with the crossing point so that the crossing is electrically dead.

Australia

Many cities had trams and trolleybuses both using trolley pole current collection. They used insulated crossovers which required tram drivers to put the controller into neutral and coast through. Trolleybus drivers had to either lift off the accelerator or switch to auxiliary power.

In Melbourne, Victoria, tram drivers put the controller into neutral and coast through section insulators, indicated by insulator markings between the rails.

Melbourne has four level crossings between electrified suburban railways and tram lines. They have complex switching arrangements to separate the 1,500 V DC overhead of the railway and the 650 V DC of the trams, called an overhead square. Proposals have been put forward which would see these crossings grade separated or the tram routes diverted.

Queensland uses 25 kV AC overhead traction with booster transformers in the Brisbane suburban area and auto transformers elsewhere.

Western Australia (Perth city) uses 25 kV AC overhead traction with booster transformers.

Greece

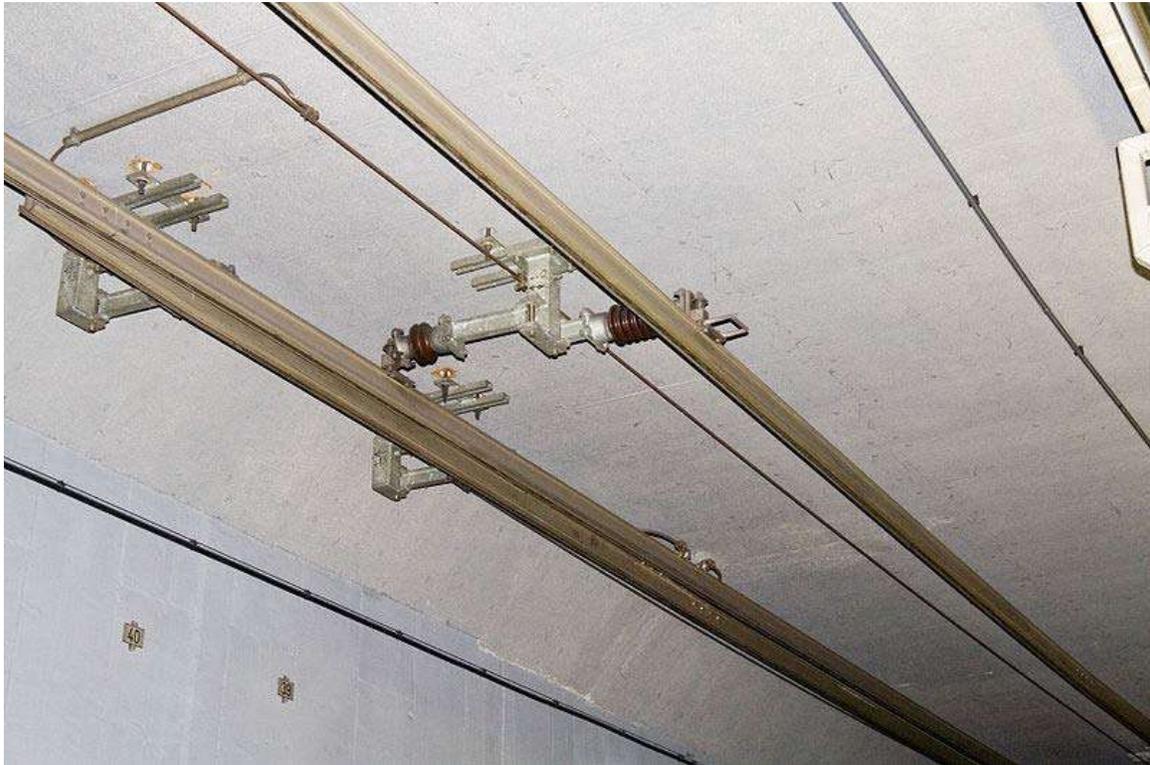
In Athens, there are two crossings between tram and trolleybus wires, at Vas. Amalias Avenue and Vas. Olgas Avenue, and at Ardittou Street and Athanasiou Diakou Street. They use the above-mentioned solution.

From the opening of the tram system in the summer of 2004, trams and trolleybuses in the direction of Pagrati shared the same exclusive lane, about 400m long, on the far right side of Vas. Olgas Avenue, with tram and trolleybus wires side-by-side above a narrow lane of road. The trolleybus wires were on the far right of the lane, away from the trams' (very wide) pantographs. Trolleybus drivers were required to drive very slowly because the trolley poles were extended to their limits. A change of route for trolleybuses was implemented in mid-2005, ending this arrangement.

Italy

In Milan, most of the city's tram lines cross its circular trolleybus line once or twice, so crossings between overhead tram and trolleybus wires are quite commonplace. Trolleybus and tram wires run parallel in some streets, like viale Stelvio and viale Tibaldi.

Multiple overhead lines



Two overhead conductor rails for the same track. Left, 1,200 V DC for the Uetliberg railway (the pantograph is mounted asymmetrically to collect current from this rail); right, 15 kV AC for the Sihltal railway

There are and were some railways that used two or three overhead lines, usually to carry three-phase current to the trains. Nowadays, three-phase AC current is used only on the Gornergrat Railway and Jungfrauoch Railway in Switzerland, the Petit train de la Rhone in France, and the Corcovado Rack Railway in Brazil; until 1976, it was widely used in Italy. On these railways, the two conductors of the overhead lines are used for two different phases of the three-phase AC, while the rail was used for the third phase. The neutral was not used.

Some three-phase AC railways used three overhead wires. These were an experimental railway line of Siemens in Berlin-Lichtenberg in 1898 (length: 1.8 kilometres), the military railway between Marienfelde and Zossen between 1901 and 1904 (length: 23.4

kilometres) and an 800-metre-long section of a coal railway near Cologne, between 1940 and 1949.

On DC systems, bipolar overhead lines were sometimes used to avoid galvanic corrosion of metallic parts near the railway, such as on the Chemin de fer de la Mure.

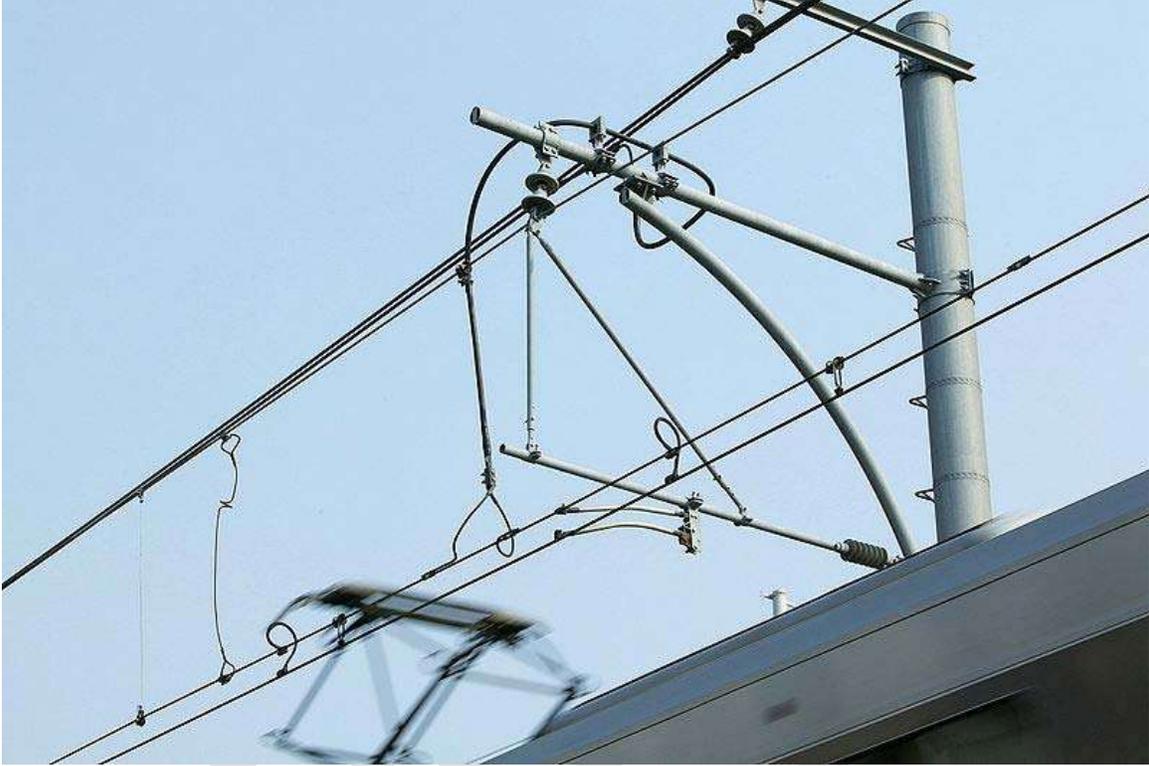
All systems of multiple overhead lines have the disadvantage of high risk of short circuits at switches and therefore tend to be impractical in use, especially when high voltages are used or when trains run through the points at high speed.

The Sihltal Zürich Uetliberg Bahn is the result of a merge of two railways with different electrification. To be able to use different electric systems on shared tracks one of the railways (Sihltalbahn) has overhead wire right above the train, and the other line (Uetlibergbahn) has overhead wire a bit off to one side.

Overhead catenary



Overhead feeding rail on the RER Line C trenches and tunnels in central Paris



Compound catenary equipment of JR West



Overhead lines now mean that historic images are no longer recreatable on many lines, such as in this recreation of a 1960s scene of a steam express in Berwick-upon-Tweed, United Kingdom.

A catenary is a system of overhead wires used to supply electricity to a locomotive, streetcar, or light rail vehicle which is equipped with a pantograph.

Unlike simple overhead wires, in which the uninsulated wire or cable is attached by clamps to closely spaced crosswires, themselves supported by line poles, catenary systems use at least two wires. One wire, called the catenary or messenger wire, is hung at a specific tension between line structures. A second wire is held in tension by the messenger wire, and is attached to it at frequent intervals by clamps and connecting wires. The second wire is straight and level, parallel to the rail tracks, suspended over it as the roadway of a suspension bridge is over water.

Simple wire installations are common in light rail applications, especially on city streets, while more expensive catenary systems are especially suited to high-speed operations.

The Northeast Corridor in the United States features electrified catenary over a 600-mile or 1000 km distance between Boston, Massachusetts and Washington, D.C., providing power for Amtrak's high-speed Acela Express and other trains. Several commuter rail agencies, including MARC, SEPTA, NJ Transit, Metro-North utilize the catenary to provide local service along the Northeast Corridor.

In Cleveland, Ohio the interurban/light rail lines use overhead wires, and the heavy rail line also uses overhead wires, instead of a third rail. This was due to a city ordinance intended to limit air pollution from the large number of steam trains passing through the Cleveland between the east coast and Chicago. Trains switched from steam to **overhead catenary** electric locomotives at the Collinwood Rail Yards about 10 miles (16 km) east of Downtown Cleveland and similarly at Linndale on the west side. When Cleveland constructed its rapid transit (heavy rail) line between the airport, Downtown Cleveland and beyond it employed similar overhead catenary technologies that the railroads used, and were able to utilize railroad electrification equipment left over after railroads switched from steam to diesel locomotives. Consequently, light and heavy rail public transit systems share trackage for about 3 miles (4.8 km) along the Cleveland Hopkins International Airport Red (heavy rail) line, Blue and Green interurban/light rail lines between Cleveland Union Terminal and just past East 55th Street station, where the heavy- and light-rail line tracks separate.

The Blue Line, running through suburbs northeast of Boston, Massachusetts, uses overhead power lines.

Height

The height of overhead wiring can create hazards at level crossings, where it may be struck by road vehicles. The wiring in most countries is too low to allow double stack container trains. The Channel Tunnel has an extended height overhead line to accommodate double-height car and truck transporters. India is proposing a network of freight only lines, which would almost certainly be electrified with extra height wiring and pantographs that can reach it.

Technical advances lower running costs

The introduction of supercapacitors has promised to drop electrical running costs for trains powered by overhead lines or third rails. Kinetic braking energy is reclaimed by storing electrical energy in supercapacitors onboard the vehicle. This stored energy is used when accelerating the train, when high current is needed. The supplementing supercapacitors reduce current drawn through the electrical supply during acceleration and puts less strain on the distribution system.

Later developments locate banks of supercapacitors at track side. All trains on the system can then use the stored energy in the supercapacitors to supplement the energy drawn through a third rail or overhead wires. Trackside location reduces vehicle weight and creates more onboard space. However, such locations would require additional equipment to charge the supercapacitors from the overhead line voltage and to generate supplementary power at the voltage and frequency of the overhead line from the stored energy.

Claimed energy reduction is around 30%. Electric railway systems can be more competitive and a real economical alternative to automobiles.

The technology can be used equally well for diesel electric locomotives, where 25% to 40% reduction in energy consumption is claimed, however only onboard location of supercapacitor banks is feasible. (This technology equally applies to road vehicles that use electric motors for propulsion, such as hybrid cars and buses.) Any electrical equipment that requires regular braking can reduce operating costs using supercapacitors. Reduced operating costs of elevators on underground railways would be a great benefit to operators and adding to their economic competitiveness.

An additional benefit is that emissions from generating plants and diesel-electric locomotives will be decreased.

Since 2003, the Mannheim Stadtbahn in Germany has operated a light-rail vehicle using electric double-layer supercapacitors to store braking energy.

A number of companies are developing electric double-layer supercapacitor technology. Siemens AG is developing mobile energy storage based on double-layer supercapacitors called Sibac Energy Storage. Citras SES, are developing stationary trackside version. The company Cegelec is also developing an electric double-layer capacitor-based energy storage system.

History

In 1881 the first tram with overhead lines was presented by Werner von Siemens on the International Electric Exposition in Paris 1881 but the installation was removed after that event. In October 1883, the first permanent tram service with overhead lines was started on Mödling and Hinterbrühl Tram in Austria. These trams had bipolar overhead lines,

consisting of two U-pipes, in which the pantographs hung and ran like shuttles. In April to June 1882, Siemens had tested a similar system on his Electromote, an early precursor of the trolleybuses.

Much simpler and more functional was an overhead wire in combination with a pantograph borne by the vehicle and pressed at the line from below. This system, for rail traffic with a unipolar line, was invented by Frank J. Sprague in 1888. Since 1889, it was used at the Richmond Union Passenger Railway in Richmond, Virginia. That was the onset of worldwide use of electric traction.



Chapter 8

Trolley Pole & Tramway Track

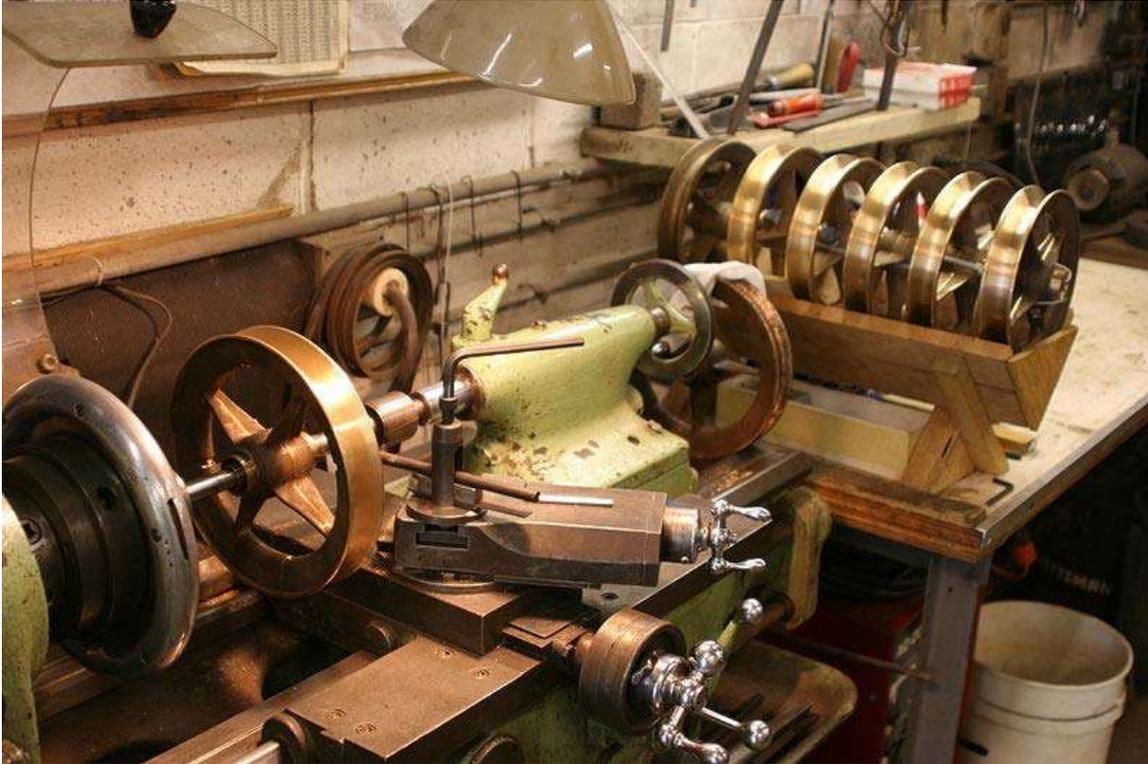
Trolley Pole



Trolley Wheel on TCRT 1300

A **trolley pole** is a tapered cylindrical pole of wood or metal, used to transfer electricity from a "live" overhead wire to the control and propulsion equipment of a tram or trolley bus. The use of overhead wire in a system of current collection is reputed to be the 1880 invention of Frank J. Sprague.

Origin of the term



Machining trolley wheels

The term 'trolley' predates the invention of the trolley pole. The earliest electric cars did not use a pole, but rather a system in which each car dragged behind it an overhead cable connected to a small cart that rode on a 'track' of overhead wires. From the side, the dragging lines made the car seem to be 'trolling' as in fishing. Later, when a pole was added, it came to be known as a trolley pole.

The term trolley is also used to describe the pole or the passenger car using the trolley pole is derived from the grooved conductive wheel (*trolley* or *troller*) attached to the end of the pole that "trolls" the overhead wire.

An early development of an experimental tramway in Toronto, Ontario was built in 1883, having been developed by John Joseph Wright, brother of the mining entrepreneur Whitaker Wright. While Wright may have assisted in the installation of electric railways at the Canadian National Exhibition (CNE), and may even have used a pole system, there's no hard evidence to prove it. Likewise, Wright never filed or was issued a patent. Official credit for the invention of the electric trolley pole has gone to an American, Frank J. Sprague, who installed a working system in Richmond, Virginia, in 1888. Known as the Richmond Union Passenger Railway, this 12 mile system was the first large-scale trolley line in the world, opening to great fanfare on February 12, 1888.

The grooved trolley wheel was used on many large city systems through the 1940s and 1950s; it was generally used on systems with "old" style round cross sectional overhead wire. The trolley wheel was problematic at best; the circumferential contact of the grooved wheel bearing on the underside of the overhead wire provided minimal electrical contact and tended to arc (spark) excessively and maximized overhead wire wear . The newer sliding carbon trolley shoe was generally used with a "newer" grooved overhead trolley wire of a figure "8" cross section; the great advantage of the sliding trolley shoe was threefold; it provided far better electrical contact with a great reduction in arcing (sparking), it dramatically reduced overhead wire wear as well. Many systems began converting to the sliding trolley shoe in the 1920s; Milwaukee, Wisconsin converted its large system in the late 1920s. Curiously, Philadelphia did not convert its trolley wheels on its remaining streetcars until 1978. Although a streetcar with a trolley wheel may evoke a look of old fashionedness, the trolley shoe is "modern" and far more practical as well as economical in use.

Description of the device



Modern trolley poles as installed on Vancouver's low floor electric trolley buses.

A trolley pole is *not* "attached" to the overhead wire. The pole sits atop a sprung base on the roof of the trolley vehicle, the springs maintaining the tension to keep the trolley wheel or shoe in contact with the wire. If the pole is made of wood, a cable brings the electrical current down to the vehicle. A metal pole may use such a cable, or may itself be electrically "live", requiring the base to be insulated from the vehicle body.

On systems with double-ended railway cars capable of running in both directions, the trolley pole must always be pulled behind the car and not pushed, or dewiring is very likely, and it can also cause damage to the overhead wires. At terminus points therefore, the conductor must turn the trolley pole around to face the correct direction, pulling it off the wire either with a rope or a pole and walking it around to the other end. In many cases, two trolley poles are provided, one for each direction, so in this case it is just a matter of raising one and lowering the other. Since the operator could raise the pole at

one end whilst the conductor lowered the other, this saved time and was much easier for the conductor. Care must be taken to raise the downed pole first, to eliminate the damage caused by arcing between the pole and wire. In the United States, the dual-pole system was the most common arrangement on double-ended vehicles. However, pushing of the pole (termed "back-poling" in the US or "spear-poling" in Australia), was quite common where the trams were moving at slow speeds, such as at wye terminals (also known as reversers) and whilst backing into the sheds.

Trolley poles are usually raised and lowered manually by a rope from the back of the vehicle. The rope feeds into a spring reel mechanism, called a *trolley catcher* or "trolley retriever". The trolley catcher contains a detent, like that in an automotive shoulder safety belt, which "catches" the rope to prevent the trolley pole from flying upward if the pole is *dewired*. The similar looking retriever adds a spring mechanism that yanks the pole downward if it should leave the wire, pulling it away from all overhead wire fittings. Catchers are commonly used on trams operating at lower speeds, as in a city, whilst retrievers are used on suburban and interurban properties to limit damage to the overhead at speed.

On some older systems, the poles were raised and lowered using a long pole with a metal hook. Where available, these may have been made of bamboo due to its length, natural straightness and strength, combined with its relative light weight and the fact that it is an insulator. Trolleybuses usually carried one with the vehicle, for use in the event of dewirement, but tram systems usually had them placed along the route at locations where the trolley pole would need reversing.

The poles used on trolleybuses are typically longer than those used on trams, so as to allow the bus to take fuller advantage of its not being restricted to a fixed path in the street (the rails), by giving a degree of lateral steerability that enables the trolleybus to load passengers at curbside, as do all buses.

Single and double pole usage

When used on a *trolley car* or *tram*, i.e., a railway vehicle, a single trolley pole usually collects current from the overhead wire, and the steel rails on the tracks act as the electrical return. Trolleybuses, on the other hand, must use two trolley poles and dual overhead wires, one pole and wire for the positive "live" current, the other for the negative or neutral return. The tramway system in Havana, Cuba also utilised the dual wire system, as did the Cincinnati (Ohio) streetcar system. To aid in the reduction of spread-out electrolytic damage to underground pipes and metallic structures, most tram lines operated with the wire positive with respect to the rails.

Decline in usage on railway



Toronto's CLRVs are equipped with trolley poles.

All trolleybuses use trolley poles, and thus trolley poles remain in use worldwide, wherever trolleybuses are in operation (currently, some 340 cities), and several manufacturers continue to make them, including Vossloh-Kiepe, Škoda and Lekov.

However, on most railway vehicles using overhead wire, the trolley pole has given way to the bow collector or, later, the pantograph, a folding construction of metal that presses a wide contact pan against the overhead wire. While more complex than the trolley pole, the pantograph has the advantage of being almost free from dewiring, being more stable at high speed, and being easier to raise and lower automatically. Also, on double-ended trams, they eliminate the need to manually turn the trolley pole when changing direction. The use of pantographs (or bow collectors) exclusively also eliminates the need for wire frogs (switches in the overhead wiring) to make sure the pole goes in the correct direction at junctions.

Apart from heritage streetcar lines, very few tram/streetcar systems worldwide continue to use trolley poles on vehicles used in normal service. Among the largest exceptions are the streetcar systems of Toronto, Ontario; Philadelphia (the "Subway-Surface" lines and route 15); Rio De Janeiro, Brazil; Kolkata (formerly Calcutta), India and Riga, Latvia.

Hong Kong Tramways is one of the smaller systems using trolley poles for regular service.

These systems and a few others worldwide retain use of trolley poles, even on new streetcars, in order to avoid the difficulty and expense of modifying long stretches of existing overhead wires to accept pantographs. Trams or light rail cars equipped with pantographs normally cannot operate on lines with overhead wiring designed for trolley-pole collection. It is possible to construct overhead wiring that is capable of accommodating both trolley poles and pantographs, but such designs are more expensive to maintain and are generally seen only in cities where modern streetcars or light rail cars share tracks with preserved historic cars.

The image shows a large, light gray logo consisting of the letters 'WWT'. The 'W' is formed by three vertical strokes, and the 'T' is a simple horizontal bar on top of a vertical stem.

Tramway Track



Cross section of tram rail

Tramway track is used on tramways or light rail operations. Grooved rails (or girder rails) are often used in order to make street running feasible. Like standard rail tracks, tram tracks consist of two parallel steel rails.

Tram rails can be placed in several surfaces, such as with standard rails on sleepers like railway tracks, or with grooved rails on concrete sleepers into street surfaces (pavement) for street running. Another environmentally-friendly or ecologically-friendly alternative is to lay tracks into grass turf surfaces; this is known as *grassed track* (or *track in a lawn*), first used in Liverpool in 1924.

History

The first tramways were laid in 1832 in New York by John Stephenson, to assist horses pulling buses through dirt roads, especially in wet weather when muddy. By laying rails, a horse could easily pull a load of 10 tonnes rather than 1 tonne on a dirt road. The evolution of street tramway tracks paralleled the development from horse power to mechanical, especially electric power. In a dirt road, the rails needed a foundation, usually a mass concrete raft. Highway authorities often made tramway companies pave the rest of the road, usually with granite or similar stone blocks, an extra cost.

The first tramways had a rail projecting above the road surface, or a step set into the road, both of which were apt to catch the narrow tyres of horse drawn carriages. The invention by Alphonse Loubat in 1852 of grooved rail enabled tramways to be laid without causing a nuisance to other road users, except unsuspecting cyclists, who could get their wheels caught in the groove.

Electrification

Electrification needed other developments, most notably heavier rails to cope with electric tramcars weighing 12 tonnes rather than the 4 tonne horse-drawn variety; switching points, as electric trams could not be pulled onto the correct track by horses; and the need for electrical connections, to provide the return path for the electric current, which was usually supplied through an overhead wire.

Cable haulage

Prior to the universal introduction of electric power, many tramways were cable hauled, with a continuous cable carried in a conduit under the road, and with a slot in the road surface through which the tram could clasp the cable for motion. This system can still be seen in San Francisco in California as well as the system of the Great Orme in Wales. These needed a rather more substantial track formation.

Conduit and stud systems

In some cities where overhead electric cables were deemed intrusive, underground conduits with electrical conductors were used. Examples of this were New York, Washington DC, Paris, London, Brussels and Budapest. The conduit system of electrical power was very expensive to install and maintain, although Washington did not close until 1962. Attempts were made with alternative systems not needing overhead wires. There were many systems of “surface” contact, where studs were set in the road surface, and energised by a passing tram, either mechanically or magnetically to supply power through a skate carried under the tram. Unfortunately these systems all failed due to the problem of reliability and not always turning off after the tram had passed, resulting in the occasional electrocution of horses and dogs. In the last five years a new system of surface contact has been installed in the Bordeaux tramway by Alstom.

Grooved rail



Cross-section of LR55 rail

A **grooved rail**, **groove rail**, or **girder rail** is a special rail designed for tramway or railway track in pavement or grassed surfaces (grassed track or track in a lawn). This was invented in 1852 by Alphonse Loubat, a French inventor who developed improvements in tram and rail equipment, and helped develop tram lines in New York City and Paris.

Other tram track profiles

An alternative to the conventional girder profiled grooved track is the LR55 profile. This is considerably cheaper and easier to install and maintain than conventional girder rail as it requires a smaller footprint foundation and existing utility services need not be disturbed.



Light rail tracks with concrete railroad ties (sleepers)



Laying tram tracks on Sydney's original tram network.



Grooved rail Gauntlet track on a tramway in Mannheim, Germany

Chapter 9

Tram Engine

A **tram engine** is a locomotive specially built, or modified, to work on a street, or roadside, tramway.

Steam tram engines



Steam tram locomotive of Geldersche Tramwegen, Netherlands

In the steam locomotive era, tram engines had to comply with certain legal requirements, although these varied from country to country:

- The engine must be governed to a maximum speed of 10 miles per hour (8 mph in the UK)

- No steam or smoke may be emitted
- It must be free from noise produced by blast or clatter
- The machinery must be concealed from view at all points above 4 inches from rail level

To avoid smoke, the fuel used was coke, rather than coal. To prevent visible emission of steam, two opposite systems were used:

- condensing the exhaust steam and returning the condensate to the water tank
- superheating the exhaust steam to make it invisible

Builders

Henry Hughes

Henry Hughes of the Falcon Works, Loughborough started building tram engines in 1876. His engines were of the saddle-tank type and exhaust steam was condensed in a tank under the footplate by jets of cold water from the saddle-tank.

Kitson & Co

Kitson & Co. started to build tram engines in 1878. They used a roof-mounted, air-cooled, condenser of thin copper tubes in which the exhaust steam was condensed. This is rather like the radiator on a modern road vehicle. The air-cooled system eventually became standard for steam tram engines.

William Wilkinson

William Wilkinson of Wigan patented the superheating system about 1881. It now seems bizarre to superheat steam after, rather than before, use because it would involve considerable waste of fuel. Despite this, the Wilkinson system was popular for a time and engines of the Wilkinson type continued to be built up to about 1886.

Others

Other British builders of steam tram engines included:

- Aveling and Porter
- Beyer-Peacock
- Charles Burrell & Sons
- Dick, Kerr & Co.
- Thomas Green & Son
- Manlove, Alliott & Co. Ltd.
- Manning Wardle
- Merryweather & Sons

Decline

Steam tram engines faded out around 1900, being replaced by electric trams or buses.

Preservation

- Kitson 0-4-0 steam tram engine (Portstewart Tramway No,1) at Streetlife Museum of Transport, Kingston upon Hull
- Kitson 0-4-0 steam tram engine (Portstewart Tramway No.2) at the Ulster Folk and Transport Museum, Cultra, County Down.
- Beyer Peacock 0-4-0 steam tram engine at National Tramway Museum, Crich, Derbyshire

Other types of propulsion



An electric tram locomotive, Střešovice, Prague, the Czech Republic

Diesel tram engines

Four of the British Rail Class 04 diesel locomotives were fitted with sideplates and cowcatchers for working on the Wisbech and Upwell Tramway.

Electric tram engines

There are a few examples of electric tram locomotives designed to pull traditional railway carriages through streets.

Stored energy types

Tram engines have been built to run on stored energy in various forms, including:

- Fireless steam
- Compressed air,
- Electric storage batteries

These engines have not met with great success because of their limited range.

WWT