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Railway Reform:
Toolkit for Improving Rail Sector Performance

Chapter 2:
Rail Markets and Technology

2 Rail Markets and Technology

2.1 Introduction

Chapter 2 explains the fundamental building blocks of the railway and how these are organized to serve the transport market. Railway markets are discussed first followed by the technologies that railways use to serve these markets.

2.2 Transport Market Characteristics

Rail transport markets can be divided into two major segments—passenger and freight. The infrastructure for each segment is similar or even the same, but the type of transport, the equipment, and the details of the infrastructure are often different.

2.2.1 Passenger services

Typical passenger market segments are *urban*, including metros, trams, and light rail systems, *commuter* or suburban services, and *intercity*, which includes conventional and high-speed trains.

Metro

Urban railways generally serve the city center and immediate environs; within the central business district, metros usually run underground. Typical car capacity is about 100 passengers seated, or crush loads of around 160. Most metros can travel at speeds of up to 100 kph and are electrified at 750 VDC or 1,500 VDC, every second car; metro trains operate with four or six cars, which are usually automated. Metros are best for moving high passenger volumes for short distances around an urban area. Examples include the London Underground and the Paris Metro.

Tram

Trams are another type of urban rail system. Trams often mix with street traffic but some have a reserved right-of-way; they have seating for 80 passengers per car but can carry crush loads of around 120. Most trams operate at 750 VDC; although they have a top speed of 80 kph, their average speed is usually lower. Most trams operate in single or double units with a driver's station on each car. Many European cities operate tram systems and Melbourne, Australia operates one of the largest tram services in the world.

Light Rail

Light rail systems are often indistinguishable from trams, but in modern usage light rail systems are more likely to have a dedicated right-of-way and are designed to service specific routes such as airports or convention centers. Light rail car seating is similar to that of trams; light rail trains usually operate in sets of two or four cars with a driver's station at each end and trains are usually electrified at 750 VDC. Light rail services are relatively new; they have lower capacity than a metro but are generally less expensive. However, light rail systems have higher capacity than trams due to train size, acceleration, and a dedicated right-of-way.

Suburban/Co Commuter Metro

Suburban systems usually provide longer distance commuter services—seating density is lower and they offer more comfort for longer travel times. Often bi-level passenger carriages are used to increase passenger capacity and comfort. Suburban systems are typically hauled by electric or diesel-electric locomotives–the electrification is usually 25 kVAC.

Modern equipment standards blur the boundaries between light rail and suburban services; similar equipment often serves both. If suburban services operate on common infrastructure with freight services, passenger equipment crash standards are high, which is why most are locomotive hauled.


Conventional Intercity

Conventional intercity passenger services are usually locomotive-hauled using 25 kVAC electric or diesel-electric locomotives. Intercity passenger services often share right-of-way with freight services and can be hauled by the same locomotives. Maximum speeds are around 120 kph. Some intercity train services have multiple classes and sleeper cars. Seating is about 80 passengers in conventional coaches, fewer in first class, which sometimes has compartments and sleeper services.


High Speed Rail

High-speed rail (HSR) services operate at 250 kph or more. HSR trains generally operate in eight-car sets. Some have integrated locomotives; others have motors distributed throughout the train with passenger seating in what would otherwise be the 'locomotive section'. Some HSR trains have double deck passenger cars. HSR trains operate on a dedicated right-of-way so train frequencies are usually fairly high—one train per hour is a typical maximum interval. HSR trains sometimes also operate on conventional speed track to gain access to locations where dedicated track cannot be built such as inner city railway station. Trains are always electrified and 25 kVAC is typical.

Passenger trains that have traction motors distributed throughout the train in passenger car 'multiple units'; electric-powered trains are called 'EMUs' while diesel powered trains are often called 'DMUs'. Such trains usually do not have a separate locomotive, though there may be a streamlined car in front and back with drivers stations. Using this classification, metro, tram, light rail, and many high-speed trains are EMUs. All EMUs and DMUs have electric motors on many wheel-sets to provide traction. This is unlike conventional trains and locomotive-hauled suburban trains, where only the locomotive has powered wheel-sets and the rest of the rolling stock is hauled (pulled or pushed).

The figure below summarizes the principal characteristics of equipment used in each market segment.

Figure 2.1 Characteristics of Passenger Rolling Stock

Type of Service	Speed (kph)	Passengers per Car	Passengers per Train	Cars per Train	Typical Distance	Cost/ Train-US$
Tram	40	120	240	2	1-2 km	$4 m
Metro	70	160	720	6	2-4 km	$12 m
Light Rail	80	100	400	4	5-10 km	$6 m
Suburban Commuter	120	80	480	6	15-20 km	$12 m
Conventional Intercity	160	80	640	8	25-120 km	$12 m
High Speed Rail	250-350	70	560	8	250-350 km	$25 m

Rail passenger services are usually measured by passenger trips and passenger kilometers.

Typical measures of passenger services are passenger journeys or trips and passenger-kilometers. A passenger journey or trip is usually counted from the entrance to the passenger system to the exit. In urban trips that may involve several metro lines, one journey may include travel on more than one train. When train lines are under separate management structures, each segment may constitute 'one trip' for accounting purposes. Passenger-kilometers are usually measured on the basis of the rail travel distance between origin and destination multiplied by the number of passengers traveling between each origin and destination.

Passenger revenue calculations are often complex. Charges for passenger services vary by type of service, the means used to collect the fares, and the amount of subsidy provided. For example, many metro systems sell monthly passes that can be used for an unlimited number of trips or trip segments. Special categories of passengers—students, disabled, retired—are often eligible for discounted monthly passes. Other metro systems charge on a segment basis and use rechargeable 'stored value' cards to levy charges for each trip. Stored value cards can be purchased with discounts depending upon advance sales or passenger category—student, disabled, or retired. For special-purpose light-rail lines, such as airport services, a flat fee per trip is the norm.

Typically, charges for suburban services are based on distance and time of day—a surcharge may be applied during peak travel periods. If suburban and urban services are coordinated, the same ticket can be used for both segments and revenues are usually allocated between services on equitable cost-related basis such as passenger-kilometers.

Urban passenger services are operated as a public service; long distance services generally cover their operating costs.

Fares for intercity services are usually related to class of service and distance. However, many HSR systems have airline-type pricing related to advance ticket sales, class of service, time of day, and distance. In many countries with extensive HSR and conventional provincial services, ticketing is integrated to provide competitive and compensatory services between each service type. Revenue sharing between intercity and metro services is rare but occurs in some places.

Typically, urban services are operated as public services subsidized by government. Some urban systems, such as the Hong Kong MTR, and London Underground, operate at break-even for operating costs. Rarely are they expected to cover capital costs.

Rail passenger transport is particularly good for rapid movement of massive volumes of people, thus urban rail is an essential element in urban planning. Urban rail systems define population centers and dramatically affect urban development patterns. Similarly, commuter and suburban passenger services are an effective and relatively inexpensive way to connect suburban communities with the city center and one another. Urban and suburban rail systems can provide significant public benefits, including substantial savings that accrue to all levels of government and private citizens—reduced congestion and pollution, fewer accidents, and improved spatial planning. Furthermore, urban and suburban rail systems generate financial benefits from rising property values and higher quality development patterns. Some urban and suburban rail systems, notably in Japan, have tapped into property value increases successfully enough to finance their rail systems as well as generating all the above-mentioned public benefits.

Intercity passenger service revenues often cover operating costs, but few are expected to cover their capital costs. Most of SNCF's TGV services operate at a profit, including equipment costs, but its provincial or conventional services rarely do. Thus, most passenger services infrastructure costs are subsidized; sometimes government provides rolling stock.

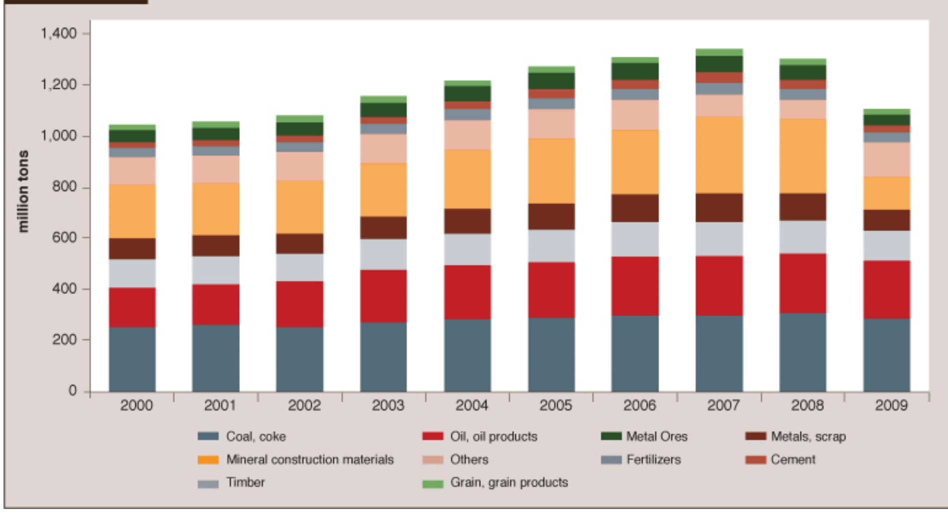
Rail passenger services generate significant public benefits in the form of rapid travel times, reduced road congestion, reduced air pollution and CO2 emissions, and reduced losses from accidents. If passenger demand is high for intercity train services, governments can avoid the cost of additional highway construction, which boosts overall energy efficiency. Sometimes rail transport is the sole means of mobility for distant populations. However, if fewer than 1,000 passengers per day are being transported, long distance bus services are typically cheaper and offer similar or better energy efficiency, depending on train frequency and load factor.

Most rail passenger services have excellent safety records; the number of accidents per passenger-kilometer is lower than most other means of passenger transport. The accidents that do occur often involve a road/rail interface at level crossings.

2.2.2 Freight services

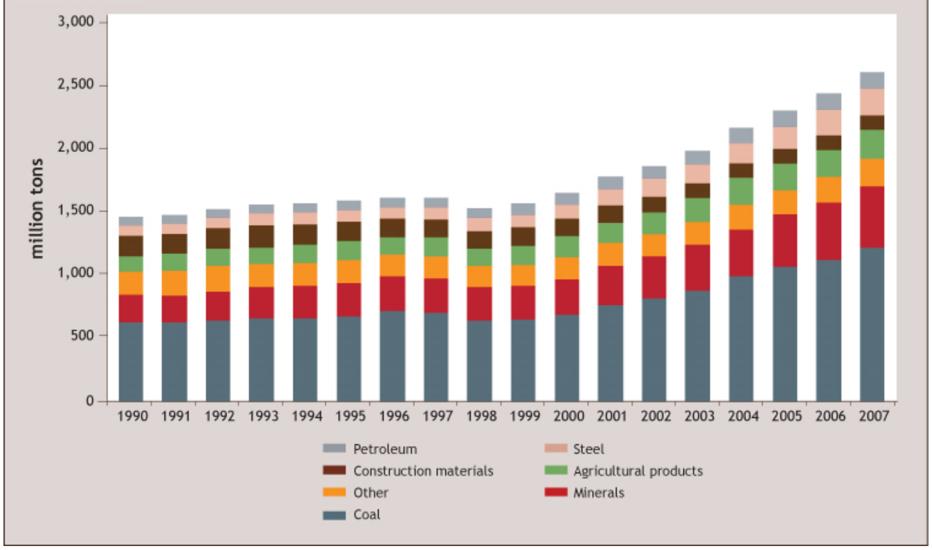
Rail freight services are important to economic growth in many countries and regions. As discussed above, rail freight services are efficient, and can move massive volumes of cargo over long distances effectively at reasonable prices. Rail freight services are dominated by bulk commodity movements—coal, iron ore, phosphates, grains and cereals, lumber, gravel, sand, and other construction materials.

Figure 2.2 Russian Railways - Tons by Commodity



Russian Railways' commodity mix, shown in the bar chart above, is typical of many large rail networks; similar data for China Rail are shown on the lower chart. In both cases, coal, mineral products, agricultural products and construction materials dominate the mix of traffic on these large networks.

Figure 2.3 China Rail – Tons by Commodity



Container Ship

Mixed Freight Train

If navigable inland waterways are unavailable, rail transport is the only effective means to move high volumes of bulk commodities. Often, bulk goods move in trains that consist entirely of one commodity—from the same origin to the same destination—from a mine to a power plant or steel mill, or from a grain elevator to a port. These trains are highly efficient since no intermediate handling occurs; however, often the freight wagons return empty.[11]

Rail transport is also an effective means of transporting general freight, automobiles, and heavy objects. Most of this freight traffic must be moved to a marshaling yard to be sorted by destination and grouped into train-load quantities for shipping. Although sorting the heavy freight wagons takes time, rail transport is still an efficient means to move mixed freight since trains can carry from 50 to 150 wagons, depending on the infrastructure.

Rail container transport is expanding. Since containerization began in 1959,[12] it has become important in shipping manufactured goods, including liquid and granular commodities, especially imports and exports associated with ocean transport movements.

Prior to containerization, the shipping industry could load and unload about 0.6 tons per person/hour; by 1976, that figure was 4,235 tons per person/hour; now it is over 8,000 tons per person/hour at a typical container port. Typically, a break-bulk ship that handles crates, barrels, and bags of miscellaneous freight, would be in port for several weeks, and in 1959, a general commercial cargo vessel could carry 10,000 tons of freight at a speed of 16 knots (29 kph). By 2009, container ships could carry 77,000 tons at 25 knots (46 kph) and would be in port for only

[11] Trains moving from a single origin to a single destination transporting one commodity are often called unit trains or circus trains, and typically use rolling stock and other mechanisms for fast loading and unloading such as loop tracks with automated loading of open-top hopper cars, rotary couplers that permit cars to be dumped without uncoupling, or automated discharge doors on hopper cars.

[12] Malcolm McLean is credited with the invention of container shipping; he shipped the first containerized freight from Newark New Jersey to Houston Texas in 1959.


Double-stack Container Train

16 hours to unload and load. Some of these same efficiencies apply to rail transport of general freight. Box wagons can hold more goods than a container and are useful for many commodities, but they can be used only by shippers located on rail lines. Other shippers must load goods into containers and use road transport to move them to a container terminal where they are transferred to a ship or train for transport over longer distances. In many markets, rail transport competes fiercely with road transport for container shipments; most time-sensitive freight moves by road transport from origin to destination. However, containerized rail transport is increasingly preferred to move general freight to and from ports and distant inland logistics centers.

Rail freight services are usually measured in tons of freight, and by net and gross ton-kilometers.

Freight traffic on any mode is typically measured in tons and ton-kilometers. A ton-kilometer = cargo weight transported X distance transported—also reported as net ton-kilometers (NTK). Another frequently reported measure is revenue ton-kilometers, which refers to revenue-producing freight tons and excludes non revenue-producing freight such as rail, ballast, or other goods transported for railway company use. For railways, an important measure of work performed is gross ton-kilometers, this measure includes rail wagons' empty weight for both empty and loaded movements. This measure of gross ton-kilometers is also called 'trailing tons' or the total tons being hauled. Sometimes gross ton-kilometer measures include the weight of locomotives used to haul freight trains.

Energy and fuel consumption in railways is closely related to gross-ton-kilometers since this is a nearly direct measure of work performed. Geography plays an important role in energy consumption as well. Whether trains must be hauled over a mountain range or rolled downhill has a direct effect on energy use of any particular railway line. But, given the geography, energy consumption is usually related to gross-ton-kilometers.

2.3 What Railways Do Best

Railways are an efficient and cost-effective means to transport large volumes of passengers and freight over various distances, particularly between originating and terminating points with large volumes. Rail transport cost effectiveness increases as volumes and distances increase. When traffic demand involves smaller passenger and freight volumes that must be distributed over a larger number of points, road transport is usually more efficient and cost effective.

Railways are best at moving high volumes of passengers or freight between common points.

For high volumes, railways deliver much more significant cost savings, environmental, energy, land use, and other social benefits than road transport, although in some cases, rail can be slower. Water transport can be more energy efficient and lower cost than rail transport, depending on waterway circuitry and availability, but typically, water transport is much slower. Rail passenger and freight transport are competitive with road and air transport at some distances.

Rail transport is generally the most effective mode of transport available for larger volumes over longer distances, for example, to transport coal or minerals from a mine or production center deep in the interior of a country to distant markets. Rail infrastructure requires relatively little land—a strip of land 100 meters across is usually more than generous and a typical rail right-of-way can be as narrow as 10

Railways moving bulk goods should be designed with low gradients. High speed passenger lines can have higher grades.

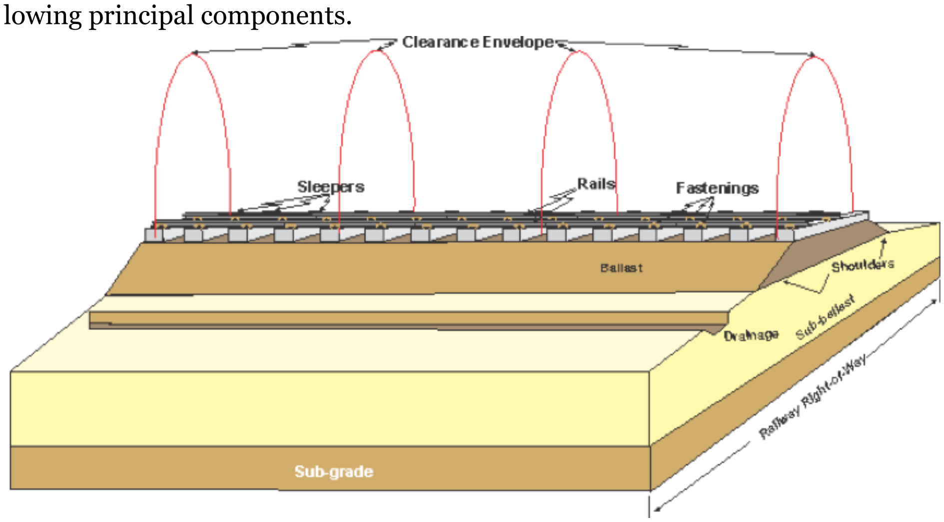
meters. However, freight railways require relatively gentle grades and curves, especially for transporting minerals—grades should not exceed 2.0 percent. By contrast, high-capacity roadways can have grades as steep as 5.0 percent or more. Therefore, railway lines between two points can be more circuitous than road transport.

2.4 Railway Technology and Terminology

When working on rail industry reforms or investment projects, it is useful to understand railway jargon and terminology and to be familiar with the rail industry technology, technical standards, and common practices. This section covers railway basics.

2.4.1 Infrastructure

Typically, railway infrastructure includes fixed physical facilities including the following principal components.



Railway Infrastructure

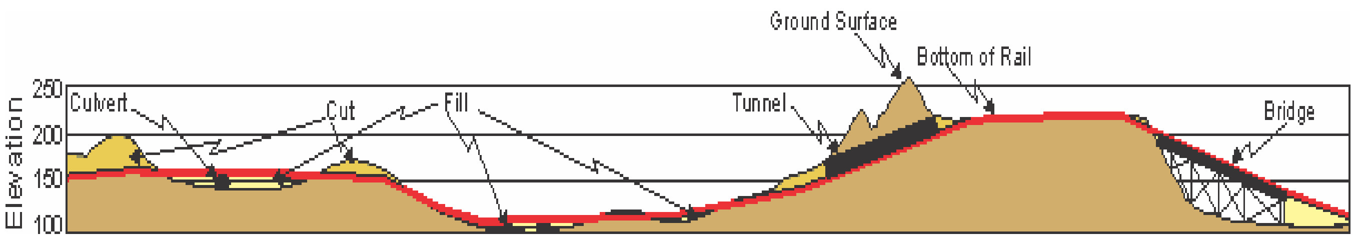
Basic railway infrastructure includes the sub-grade, sub-ballast, ballast, sleepers (also known as crossties), rail, and track fastenings that secure the rail in position relative to the sleepers and to each other.[13] These systems, the foundation for railway infrastructure, should be designed for the proposed purpose of the railway. Railways intended to carry heavy loads will require a solid sub-grade without underlying problems such as soft marshy soils, for example, and a substantial sub-ballast cross section of hard angular rock, typically granite. The ballast section must also be hard angular rock; the rock depth must be sufficient to distribute load stresses throughout the sub-ballast and the rock size must be sufficient to permit rapid water drainage into drainage structures built adjacent to the shoulders of the top ballast section.

Railways take advantage of the very low energy required to roll steel wheels over steel rails. But, because there is little friction between steel wheels and steel rail,

[13] Track fastenings include plates, spikes, bolts, clips and anchors – all devices that keep rail and sleepers together and maintain the spacing between sleepers.

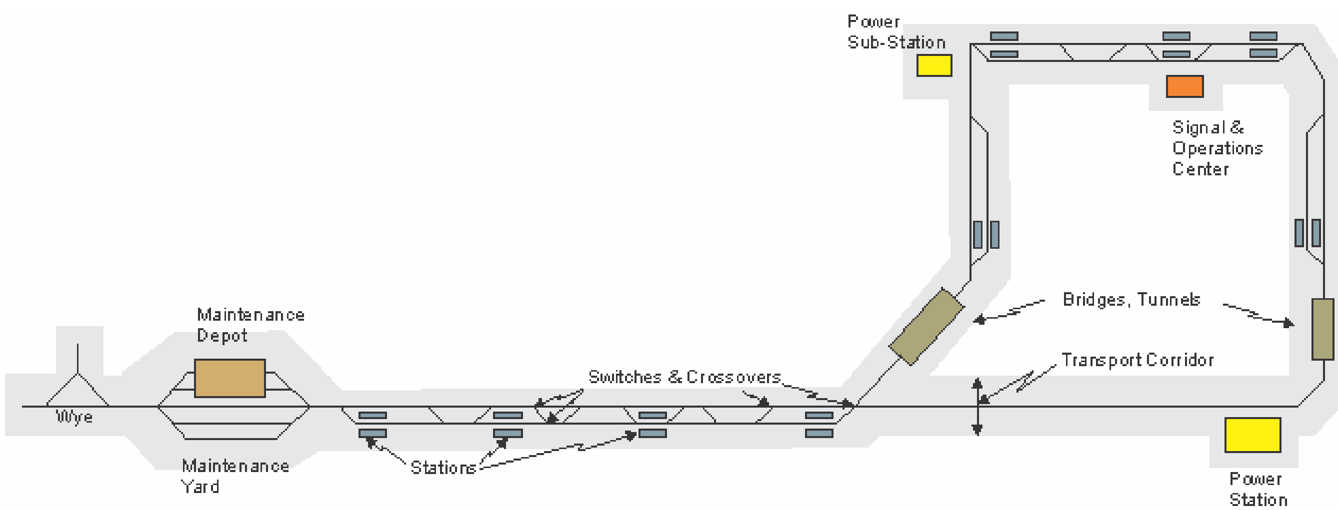
railways must have low gradients—gentle up and down slopes. As mentioned earlier, railways generally are engineered to have grades of 1.0 to 2.0 percent (10-20 meters per kilometer).[14] Railway designers use many techniques to minimize vertical grades; some are shown below in the cross section diagram. Designers use bridges and tunnels to traverse vertically challenging territory, cuts through rolling hills, and fills in low spots, often with material taken from cuts, to keep tracks as level as possible. They add drainage structures such as culverts—concrete

Track Structures for Easing Grade



pipes or box-like structures that conduct water flows under the tracks—and common ditches.

Other terminology commonly found in railway projects is shown below in the schematic of a short railway line:



Infrastructure Components

This plan includes infrastructure component structures—maintenance depots, and switches (also called turnouts) and crossovers, which allow trains to change from one track to another, and maintenance and sorting yards, where freight and passenger cars are arranged in the correct order for the outbound train. A device known as a 'Wye' is used to turn locomotives, and even whole trains, to face in the opposite direction, replacing turntables that were used in the past.

Single and double track

Many railways are built as single track lines. Trains leave a station or a yard with multiple tracks and move to the next station or yard over a single track. Only one

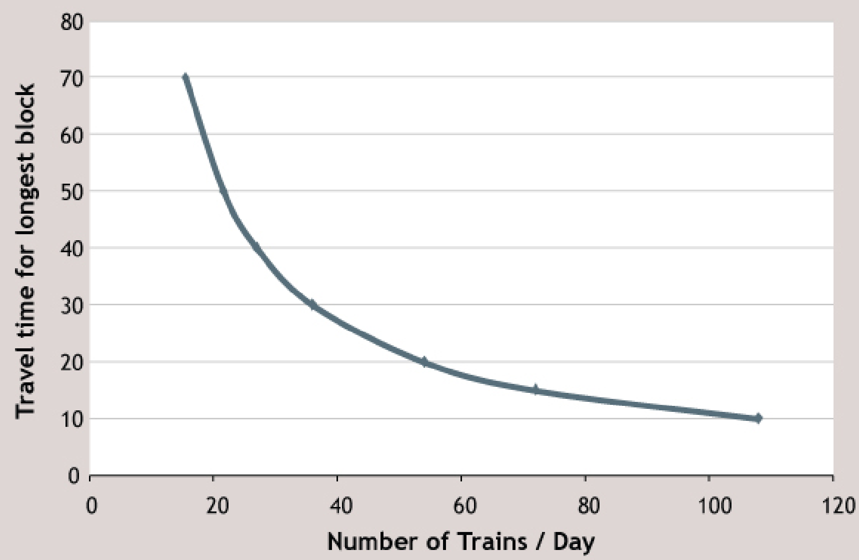
[14] Except for high-speed rail lines, which have very high power-to-weight ratios to achieve high speeds, these can be built with higher gradients of as much as 5 percent.

train can operate over single track line at the same time. Single track lines often have sidings at various points where trains moving in opposite directions can meet and pass each other (passing sidings). The capacity of a railway line is determined by the longest time for trains to move between passing sidings. As a rule of thumb, railway engineers estimate capacity in trains per day using "Scott's Formula" (Figure 2.4) which states:

N = (E x 24 x 60) / T where

N = Number of trains/day
E = Efficiency of signaling system (usually between 0.7 and 0.9)
T = longest Travel and stopping time in minutes between passing sidings on a given line

Figure 2.4 Scott's Formula for Train Capacity



Trains are usually heavy and the same thing that make them energy efficient – low friction losses – make them hard to stop. Each freight car and passenger carriage has air brakes at each wheel to slow and stop trains, but it still takes a lot of distance to stop a train – often a kilometer or more. The higher the speed of the train, and the heavier the train, the longer it takes to bring it to a stop. Similarly, it takes a long time and distance to bring a heavy train out of a passing siding and up to track speed. These factors are taken into account in determining the value of "**T**" in the equation above. For single track lines with track speeds around 100 kph, with a modern signal system and using passing sidings (passing sidings can hold a typical train) a single track line can typically handle 30 trains a day at most (assuming half are in each direction). As the number of trains increases, interference between trains increases and delays to all trains on the line tend to get larger as well. Railway engineers do many things to increase capacity – increase the speed of trains (this reduces **T** in the equation), build more sidings (also tending to reduce **T**), modernize signal systems (increasing **E**).

As the number of trains increases further, railways will connect passing sidings to provide piece of double track, permitting trains to pass while still moving and saving on the stopping and starting times. Eventually, to create more capacity, the entire line will be double tracked. Capacity can also be an issue with double track lines. Trains can follow each other no closer than the stopping distance for the slowest train; in mixed freight, some trains may be slow – either stopping at many small stations or very heavy, other trains may be fast. Large speed differences between trains tend to limit line capacity even on double track, since trains have to switch tracks to get out of each other's way. Some urban rail systems need as many as six tracks to allow the train frequencies needed in dense urban areas.

Signaling and train control

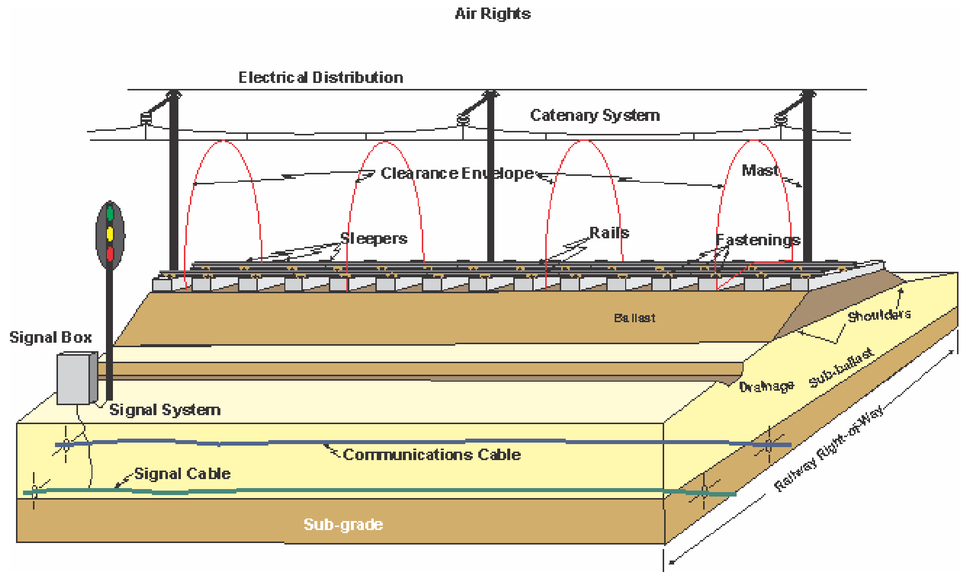
Most busy railways install signals to control train movements; these are akin to road traffic lights and they allow trains to operate in both directions on single or multiple track railways. On a single track signal systems may work only at the siding or station. Modern signal systems have train presence detection and their indications are interlocked with switch positions to prevent trains from moving onto a track if there is oncoming traffic. 'Automatic block' is a common signal term for systems that are interlocked with the current siding and with sidings ahead and behind to prevent unsafe train movements.

Train Control Center

Advanced signal systems rely on centralized systems to control a large territory. Still more advanced systems have computer controls that help dispatchers make sophisticated decisions about which trains to advance and which to delay. Modern signal systems are computerized train controls that require complex digital communication technology. These systems can enforce control indications and stop trains automatically when they detect unsafe conditions. Pictured at left is part of a modern train control system.

Electrification

High speed or very busy railways are often electrified; they use electric locomotives and draw electrical power, usually from overhead power distribution systems, but sometimes, in urban railways, via a third rail system at ground level. The diagram below shows components for the electrical distribution system and the wayside signals. Major signal system components include signal boxes, display systems (on some railways, the signal display is inside the locomotive, not along the wayside), and the signal and communications cables needed to control these systems. Electrification system components include masts or poles, and a catenary system that delivers electrical current to the locomotive. In overhead systems, such as the one shown below, locomotives have a pantograph on top to collect the electrical current. The pantograph slides along the catenary as the train rolls underneath. Several electrification standards are used to power railways; today, the most popular is 25-kVAC for main-line railways but many kilometers



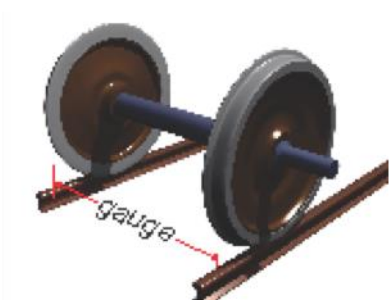
Electrification and Signaling Systems

of 3-kVDC systems, some 15-kVAC systems, and a few 1.5-kVDC systems exist. Many urban railways use 1.5-kVDC electrical power but most now use 750-VDC. Most electrification uses an overhead distribution system like that shown in the diagram, but some use third-rail systems, which are more compact, have smaller urban clearances, and use smaller tunnels; most are 600-750-VDC.

For main line passenger railways, electrification has the advantage of a high power-to-weight ratio–a lot of power (kilowatts or horsepower) available with a relatively light locomotive since locomotives do not require a diesel engine and generator. This is especially useful if trains need to move fast (faster than say 150 kph, and if a high acceleration rate is needed for station stops and departures. Electrification can be attractive in freight lines, as well, especially those with high volumes (at least 40 million gross-tons per year) ***and*** high diesel-fuel prices relative to electricity prices.

Railway electrification is expensive, typically US$3.0-5.0 million/kilometer, including sub-stations. Electrification may also require substantial modification to existing railway signal systems, bridges, and tunnels for the higher clearance required for overhead catenary systems. High initial costs and continuing maintenance costs encourage most commercial railways to carefully consider the implications of electrification. Despite this, about 25 percent of global railway lines are electrified and more than 50 percent of all rail transport is moved by electric traction, according to some reports.

Electric railways can reduce rail transport's environmental footprint, depending on the electricity source, such as low-emission power plants, and distance to the railway, since up to 30 percent of power plant output can be lost in transmission.



Railway Gauge

Railway gauge

Railway engineers often discuss railway 'loading gauge', generally defined as a combination of track gauge, physical clearance envelope, and axle load capacity. Track gauge refers to the distance between the inner surfaces of the rail, illustrated at left. Although there are many different rail track gauges in use around the world, the most predominant gauges are shown in Figure 2.5 below.

Figure 2.5 Railway Gauges

Common Gauge Name	Metric Measure	English Measure	% of Worlds Rail lines	Example Countries Using
Standard	1,435	4' 8-1/2"	57%	US, Canada, Europe, China
CIS/Russian*	1,525	5'	18%	Russia, Ukraine, Kazakhstan
Cape	1,067	3' 6"	9%	South Africa, Indonesia, Japan
Meter	1,000	3' 3-3/8"	8%	Brazil, India, Argentina
Indian	1,676	5' 6"	6%	India, Pakistan, Argentina, Chile
Iberian	1,668	5' 5-2/3"	1%	Portugal, Spain
Irish	1,600	5' 3"	1%	Irland, Australia, Brazil

* 1,520 mm gauge is also commonly used in CIS countries and Finlandv

Two things are responsible for the gauge of a railway – either heritage or cost.

Many countries have railway lines built to several different gauges. Why is one gauge selected over another? There are two main reasons—heritage and cost. Many railways were built by foreign engineers who used a gauge that was common in their country of origin. The second reason is cost—narrow gauge is cheaper to build than a broader gauge because cuts and fills are smaller, less earth moving or blasting is required, tunnels can be smaller, and narrower gauges require less ballast and can use smaller, less expensive sleepers. Investors often built narrower gauge railways to keep investment costs down during the early days of railways that were built to exploit natural resources. For example, some Latin American railways built to move banana harvests are only 560 mm, a size that could be built quickly and cheaply and easily relocated.

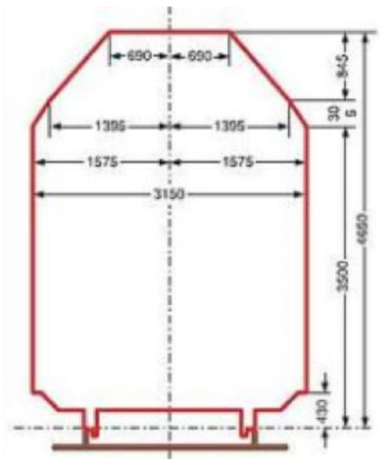
The best gauge is the one that already exists; but new standalone railways can be built to any gauge that makes sense. Standard gauge is a good compromise in most cases.

What are the advantages of various size gauges? Broader track gauges are better for railways that are planned for hauling heavy tonnages; broader gauges provide stability, lower track stresses, and a longer lifespan for track components. During the mid-1980s, Vale (CVRD) built a new 1,000 kilometer broad gauge railway line in the Amazon to move massive quantities of minerals. However, lesser gauges can also effectively haul heavy freight. Vale operates another railway in Brazil, a very fine Cape gauge railway (EFVM) that hauls more than 120 million tons of iron ore concentrate from the mountains in the state of Bello Horizonte to an Atlantic port. This railway serves passengers and general freight customers, too. Cape gauge railways in South Africa efficiently haul millions of tons of coal.

Most of the world's heavy-haul railways are standard gauge, probably due to the large base of rolling stock and many suppliers of standard gauge components, systems, and associated equipment. Standard gauge appears to be a good compromise between cheaper-to-build narrower gauges and more expensive-to-build broader gauges. Gauge may be an important consideration during design (because of construction costs), but is less important for railway operations once a rail line is built.

A new railway line should match the specifications of the predominant gauge in the region if it is to be part of a national network. However, if a new line is independent of other railway lines and has a specific purpose, gauge choice depends on other design considerations. While there are high-speed passenger services using different gauges, a new railway line for high-speed passenger services would likely be built using standard gauge because most of the specialized rolling stock these railways require are built to (and originally designed for) standard gauge. For example, Spain's national railway is Iberian gauge—1,668 mm, but Spain used standard gauge when it built high-speed rail lines so the trains could interconnect with French and European lines.

Since most of the world's railways are standard gauge, there is a wider supply of standard gauge rolling stock, track maintenance and track building machinery. Generally, new lines should be built to standard gauge unless the new line is to be connected to a national network of a different gauge or if there is another compelling reason to select a different gauge.



Clearance Envelope

Clearance envelope or loading gauge

Railway 'loading gauge' also refers to the physical clearance envelope (shown in the diagram at left) available for rolling stock. The clearance envelope also determines the size of openings in tunnels and under bridges and the distance from the centerline of the track to station platforms, signs, signal lights, and other trackside devices. Railways with overhead electrification will require more vertical clearance but the maximum size of rolling stock still determines the loading gauge. Generally, the physical clearance envelope takes account of sharp curves and long cars and allows for the swaying or rocking motion of rolling stock. Physical clearance envelope is a critical consideration when railways want to introduce an unusual size of new rolling stock such as bi-level passenger cars or double-stack container equipment that may need clearance envelope expansion.

Axle loads

Axle load—the total permitted weight of a loaded rail wagon or a locomotive divided by the number of axles on the piece of rolling stock—is a critical measure of infrastructure physical capacity and strength. Axle loads are an important element of railway loading gauge and permitted axle loads and the weight of empty freight wagons are key determinants of rail transport efficiency and sustainability.

Many older railways were built to a standard of 16 to 18 tons/axle. India, Russia, and China used 22.5 to 23.5 tons as design limit. Heavy haul railways operate at 32.5 tons/axle (standard in North America with some lines operating at 36 tons/axle); and a new special-purpose heavy-haul railway in Australia has been designed to achieve 40 tons/axle.[15]

The weight of empty freight wagons can affect railway efficiency significantly. Early railway rolling stock design was less precise and metallurgy in steel and castings were of poorer quality, resulting in larger and heavier freight wagon components. However, modern engineering and design systems and high-strength steels and aluminum components now allow much lighter freight wagons with higher capacities.

[15] The railway will open at 32.5 metric tons to wear harden the rail and compact the subgrade and rail infrastructure and loadings will be moved to 40 tons/axle over a period of years to provide time to determine the effects of such high axle loads under sustained and frequent train movements.

Figure 2.6 Axle Load

	Lading (tons)	Empty Weight	Axle Load	Avg Haul	% Empty Haul	NTK	GTK	GTK/NTK Ratio
Light Rail Freight	45	25	17.50	1,000	30%	45,000	77,500	1.72
General Rail Freight	65	25	22.50	1,000	30%	65,000	97,500	1.50
Bulk Unit Train	75	25	25.00	1,000	100%	75,000	125,000	1.67
Heavy Haul	110	22.5	33.13	1,000	100%	110,000	155,000	1.41
Container Car-one	40	20	15.00	1,000	25%	40,000	65,000	1.63
Double Stack	80	20	25.00	1,000	25%	80,000	105,000	1.31
Light Road Transport	15	9	6.00	1,000	20%	15,000	25,800	1.72
Heavy Road Transport	33	8	8.20	1,000	30%	33,000	43,400	1.32

* These are theoretical optimum values, in practice, mistakes, repairs, re-routes and other factors increase these ratios

The figure above shows the best GTK to NTK ratios that could be achieved in the given circumstances. In practice, railways do not average such high ratios because of the normal "Brownian" motion of railway assets – they move the wrong direction, or get re-directed, move to be cleaned before the next load, and move to and from repair and inspection facilities. Typical gross to net ratios for freight railways average in the 1.8-1.9 range. Railways with light axle load limits (e.g., 17.5 tons in one of the examples) typically have a GTK to NTK ratio above 2.0. In contrast, the most efficient types of freight are heavy haul and double stack containers. For heavy haul, freight wagon design and high axle loads compensate for returning most freight wagons empty for reloading. Double stack achieves low GTK to NTK ratio due high axle loads, low empty weight, the universality of containers, and the need to return even empty containers. The values for General Rail Freight, with an axle load of 22.5 tons/axle and a 30 percent empty miles rate are typical of Russia, China, and India and in practice average around 2.0. By this measure, light road transport, perhaps for local delivery, is not particularly efficient; but heavy road transport can achieve good efficiency.

Track modulus

Typically, infrastructure strength is measured by track modulus–of the degree of stiffness or resistance to vertical deflection under loads. Higher track modulus values mean greater stiffness, generally higher axle-load capacities, and lower infrastructure wear rates. Track modulus is determined by many factors—gauge, rail weight, sleeper type and spacing, ballast type and thickness, and sub-grade quality. Sample values appear in the figure below. Higher values denote greater track stiffness and more stable infrastructure conditions.

Figure 2.7 Track Modulus

Rail	Sleeper Spacing	Ballast Type and Depth	Track Modulus[1]
R42	1,800 / km	150 mm cinder ballast on clay sub-grade	375
R42	1,800 / km	150 mm limestone on clay sub-grade	760
R42	1,800 / km	300 mm limestone on clay sub-grad	780
R42	1,800 / km	600 mm limestone on clay sub-grade	850
R50	1,800 / km	600 mm limestone on compacted clay sub-grade	2,000
R60	1,660 / km	600 mm limestone on compacted clay sub-grade	2,100
R60	1,660 / km	600 mm limestone ballast on crushed stone compactedlimestone sub-grade	3,600
R65	1,660 / km	650 mm granite ballast on crushed granite sub-grade	4.200

Railway reforms and investments that encourage increases in axle loads, acquisition of modern light-weight rolling stock, improvements in rolling stock management and operations, and strengthening of the infrastructure, all work to improve the returns and sustainability of railways.

2.4.2 Rolling stock

Railway rolling stock comes in a variety of forms. The most common types of passenger services railway rolling stock are described below.

Bombardier TRAXX Electric

GE Evolution Diesel-electric

Locomotives

The sole purpose of locomotives is to pull or push trains; they carry no passengers or freight. Locomotives are distinguished by the prime mover or energy source used to propel them. Modern locomotives are either electric or diesel-electric. Electric locomotives draw power from an overhead wire or third rail, and use electric motors to turn the wheels. The prime-mover is a transformer on the locomotive that converts the overhead electricity to the type of electricity needed in electric traction motors that turn the wheels. Instead of a transformer, diesel-electric locomotives use a diesel engine to drive an alternator and generate electricity that powers traction motors that turn the wheels.

Some diesel locomotives use a hydraulic torque converter rather than electric motors—these are referred to as diesel-hydraulic locomotives. Older generation steam locomotives, powered by coal, oil, or wood, are now used only in tourist operations or for occasional work on smaller railways or in museums.

Passenger rolling stock

Descriptions of passenger rolling stock types can be found in Section 2.2.1. "Multiple-unit" passenger rolling stock is an important category, with two basic types—electric multiple-units, called EMUs and diesel multiple-units, called DMUs. The MU equipment has no locomotive; multiple cars can be connected and operated from a single location. Some multiple-unit cars have powered axles; the cars that do not are called 'trailer' cars. Typically, the first car has a driver's station and accommodates passengers. Multiple unit (MU) equipment is popular for many reasons.

- MU trains can respond to changes in demand levels because cars can be added to or dropped from a train.

EMU in Queensland

- MU trains can be driven from either end so two person crews can quickly prepare for return trip, making MUs popular for commuter services.
- MU trains offer more passenger space per track length, since they operate without a locomotive.
- MUs distribute traction and braking power throughout the train, achieving higher power-to-weight ratios, and greater acceleration and braking rates.

The MUs' flexibility and design characteristics are also ideal for high-speed train services because higher power levels are needed to overcome aerodynamic drag.[16]

DMU in the Netherlands

Some TGV and ICE[17] trains are considered push-pull trains with power cars at each end, some with as much as 16,300 horsepower (12,200 kW). For example, the EuroStar train service has a configuration (1 power set,[18] 18 trailer cars, 1 power set) with a total of 24,400 kW (32,600 hp) that can carry 794 passengers in bi-level coach configurations.

Freight wagons

Railway freight wagons come in a variety of designs aimed at accomplishing specific freight tasks most efficiently.

Class A US Boxcar, 89'

Box Wagons are commonly used for many commodities such as auto-parts, canned goods, bags of cement, and even loose grains. Some box wagons offer interior loading restraints (equipped boxes), a range of door types and sizes, insulation, refrigeration, and temperature control so goods will not overheat or freeze, and a range of grades—high-grade wagons are used to ship food or other products that must avoid contamination by other commodities.

CSX 100-ton Open Top Hopper

'Open-top' Hopper Wagons can be loaded in many different ways and carry commodities that will not be damaged by exposure to weather such as aggregates, coal, and mineral ores. The name derives from the 'hoppers' at the bottom of the wagons that are opened to discharge contents easily and quickly.

UP 100-ton Covered Grain Hopper

Covered Hopper Wagons haul commodities such as grains, cement, sand, fertilizers, flour and sugar, or chemical or powdery materials that may be damaged by exposure to weather. Some covered hopper wagons are 'unload-assist' and have vibrating sides or air injection systems to aid unloading. Covered hopper wagons are often categorized by size (cubic meters/feet) and larger wagons are used for lighter density commodities such as flour or grains; smaller wagons are used for high-density products such as cement and sand.

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[16] Modern locomotives can operate in MU configurations too – many can be "MU'd" together to operate as a single locomotive unit with one driver controlling all connected locomotives.

[17] TGV, or Train à Grande Vitesse, is the French design-standard high-speed integrated train set; ICE, or Inter-City-Express, is a German design-standard high-speed integrated train set.

[18] Here a power set refers to two matched locomotives permanently coupled together.

High-sided Gondola Car

Rotary Dumper for Gondola cars

Gondola Wagons have open tops but no bottom hoppers for unloading. Most gondolas are unloaded by a crane or bucket but some have drop floors; often they are unloaded using a rotary dumping device (see photo at left). High-sided gondolas are used for aggregates, coal, and other relatively low-density materials, including cement in 10-ton bags. Low-sided gondola wagons are used for heavier materials such as steel slabs, steel structural members, machinery, and other materials that can tolerate exposure to the weather.

Center-beam Flat Car for Plywood

Trailers and Containers on Flat Cars

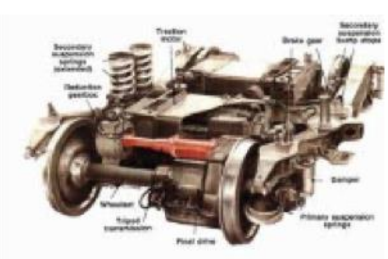
Flat Wagons carry machinery, logs, plywood, containers, and road transport trailers. Many flat wagons include special features to extend their utility—for example, an automobile rack converts it to an automobile carrier; stakes added to the sides can contain pipes and lengths of raw timber; bulkheads can be added to transport logs, or lumber. Trucks, tanks, turbines, and other commodities are carried on flat wagons or modified flat wagons.

Russian Oil Tank Wagon

Tank Wagons carry liquids such as oil or oil products, chemicals, or consumables such as seed oils, milk, beer, or water. Some tank wagons carry gases in their liquid forms, such as liquefied petroleum gas or LPG, or pressurized fluids in a liquid/gaseous state, such as liquefied natural gas (LNG). Tank wagons are often specialized for the type of commodity they carry, for example, chemicals, oils, and oil products use a special tank lining, and milk or beer may be carried in a stainless steel tank. In many countries, tank wagons transporting hazardous materials are required to have safety features, such as shelf couplers that prevent wagons from detaching during a train derailment, or reinforced end shields that prevent couplers from puncturing the tank during derailment. In addition, pressurized tank wagons have pressure relief valves and special venting systems.

These basic freight wagons types have many variations; many railways collaborate with shippers and tailor freight wagons to specific needs.

Freight Bogie



Passenger Bogie

Rolling stock components

Railway rolling stock includes some major common components. Most railway freight and passenger wagons sit on top of **bogies** (or 'trucks' in North America; see photo at left). Most bogies have two **wheel sets** so rollingstock can maneuver around curves while supporting heavy loads. The two **side frames** contain two wheel sets (each wheel set is two wheels and a solid axle mounted together as one piece). **Roller bearings** are used between the axles and the side frames to permit the wheel sets to turn freely. Usually, wagons bodies are not fastened to the bogies but rest on and pivot around a center support. Generally, bogies on passenger rolling stock support a **suspension system** that isolates them from the wheels and infrastructure. Bogies also support the **braking systems**. Most passenger and freight rail cars use brakes operated by air pressure. Freight braking systems use air pressure to press brake pads to each wheel tread. Some passenger systems use the same type of braking system, but most high speed trains are equipped with disk brakes attached directly to wheelset axles in addition to tread brake systems.

Couplers are designed to allow railway cars to be joined together quickly and easily while draft gears provide the mechanism to transmit the longitudinal forces that propel the train through the car body to the next car, without interfering with the workings of the bogies. Some couplers, like those shown at left, have top and bottom extensions (**shelf couplers**) to ensure that cars stay coupled even if one car

Shelf Couplers and Air Hoses

Spring Loaded Freight Car Buffers

leaves the tracks. Draft gear and coupler system strength determine the safe weight at which a train can operate on a railway. Many rail systems use **buffer pads** alongside coupler mechanisms to reduce 'slack action', the tendency of a group of wagons to elongate or contract when in motion.