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Bicycle wheel

A **bicycle wheel** is a wheel, most commonly a wire wheel, designed for a bicycle. A pair is often called a **wheelset**, especially in the context of ready built "off the shelf" performance-oriented wheels.

Bicycle wheels are typically designed to fit into the frame and fork via dropouts, and hold bicycle tires.

The front wheel from a racing bicycle.

Bicycle wheel with wooden rim

Nipples

Spokes

Cross-section of a rim

Contents

Invention

The first wheel to use the tension in metal spokes was invented by Sir George Cayley to achieve lightness in his 1853 glider.[1]

A Shimano Dura-Ace freehub-style hub

Construction

The first bicycle wheels followed the traditions of carriage building: a wooden hub, a fixed steel axle (the bearings were located in the fork ends), wooden spokes and a shrink fitted iron tire. A typical modern wheel has a metal hub, wire tension spokes and a metal or carbon fiber rim which holds a pneumatic rubber tire.

Hub

A hub is the center part of a bicycle wheel. It consists of an axle, bearings and a hub shell. The hub shell typically has two machined metal flanges to which spokes can be attached. Hub shells can be one-piece with press-in cartridge or free bearings or, in the case of older designs, the flanges may be affixed to a separate hub shell.

Axle

The axle is attached to dropouts on the fork or the frame. The axle can attach using a:

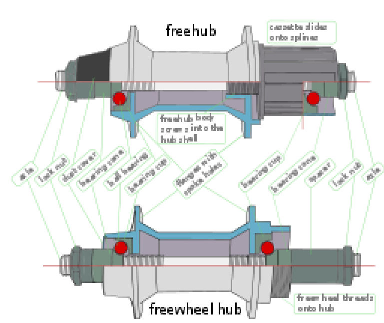
- Quick release - a lever and skewer that pass through a hollow axle designed to allow for installation and removal of the wheel without any tools (found on most modern road bikes and some mountain bikes).
- Nut - the axle is threaded and protrudes past the sides of the fork/frame. (often found on track, fixed gear, single speed, BMX and inexpensive bikes)
- bolt - the axle has a hole with threads cut into it and a bolt can be screwed into those threads. (found on some single speed hubs, Cannondale Lefty hubs)
- Thru axle - a removable axle with a threaded end that is inserted through a hole in one fork leg, through the hub, and then screwed into the other fork leg. Some axles have integrated cam levers that compress axle elements against the fork leg to lock it in place, while others rely on pinch bolts on the fork leg to secure it. Diameters for front thru axles include 20 mm, 15 mm, 12 mm, and 9 mm. Rear axles typically have diameters of 10 or 12 mm. Most thru axles are found on mountain bikes, although increasingly disc-braked cyclocross and road bikes are using them. Thru axles repeatably locate the wheel in the fork or frame, which is important to prevent misalignment of brake rotors when using disc brakes. Unlike other axle systems (except Lefty), the thru axle is specific to the fork or frame, not the hub. Hubs/wheels do not include axles, and the axle is generally supplied with the fork or frame. Adapters are usually available to convert wheels suitable for a larger thru axle to a smaller diameter, and to standard 9mm quick releases. This allows a degree of re-use of wheels between frames with different axle specifications.
- Female axle - hollow center axle, typically 14, 15, 17, or 20 mm in diameter made of chromoly and aluminum, with two bolts thread into on either side.[2] This design can be much stronger than traditional axles, which are commonly only 8 mm, 9 mm, 9.5 mm, or 10 mm in diameter.[3] (found on higher end BMX hubs and some mountain bike hubs)

Since the 1980s, bicycles have adopted standard axle spacing: the hubs of front wheels are generally 100 mm wide fork spacing, road wheels with freehubs generally have a 130 mm wide rear wheel hub. Mountain bikes have adopted a 135 mm rear hub width,[4] which allows clearance to mount a brake disc on the hub or to decrease the wheel dish for a more durable wheel.[4] Freeride and downhill are available with both 142 and 150 mm spacing.[5]

Bearings

The bearings allow the hub shell (and the rest of the wheel parts) to rotate freely about the axle. Most bicycle hubs use steel or ceramic ball bearings. Some hubs use serviceable "cup and cone" bearings, whereas some use pre-assembled replaceable "cartridge" bearings.

A "cup and cone" hub contains loose balls that contact an adjustable 'cone' that is screwed onto the axle and a 'race' that is pressed permanently into the hub shell. Both surfaces are smooth to allow the bearings to roll with little friction. This type of hub can be easily disassembled for lubrication, but it must be adjusted correctly; incorrect adjustment can lead to premature wear or failure.



Freehub vs freewheel hub

In a "cartridge bearing" hub, the bearings are contained in a cartridge that is shaped like a hollow cylinder where the inner surface rotates with respect to the outer surface by the use of ball bearings. The manufacturing tolerances, as well as seal quality, can be significantly superior to loose ball bearings. The cartridge is pressed into the hub shell and the axle rests against the inner race of the cartridge. The cartridge bearing itself is generally not serviceable or adjustable; instead the entire cartridge bearing is replaced in case of wear or failure.

Hub shell and flanges

The hub shell is the part of the hub to which the spokes (or disc structure) attach. The hub shell of a spoked wheel generally has two flanges extending radially outward from the axle. Each flange has holes or slots to which spokes are affixed. Some wheels (like the Full Speed Ahead RD-800) have an additional flange in the center of the hub. Others (like some from Bontrager and Zipp) do not have a noticeable flange. The spokes still attach to the edge of the hub but not through visible holes. Other wheels (like those from Velomax/Easton) have a threaded hub shell that the spokes thread into.

On traditionally spoked wheels, flange spacing affects the lateral stiffness of the wheel, with wider being stiffer, and flange diameter affects the torsional stiffness of the wheel and the number of spoke holes that the hub can accept, with larger diameter being stiffer and accepting more holes.[6] Asymmetrical flange diameters, tried to mitigate the adverse effects of asymmetrical spacing and dish necessary on rear wheels with many sprockets, have also been used with modest benefits.[6]

Hub brakes

Some hubs have attachments for disc brakes or form an integral part of drum brakes.

- Disc brakes – a disc brake comprises a circular plate or disc attached to the hub which is squeezed between brake pads mounted within a caliper that is fixed to one side of the wheel forks. The brake disc can be attached in a variety of ways using bolts or a central locking ring.
- Drum brakes – a drum brake has two brake shoes that expand out into the inside of the hub shell. Rear-mounted drum brakes are often used on tandems to supplement the rear rim brake and give additional stopping power.
- Coaster brake – coaster brakes are a particular type of drum brake which is actuated by a backward pressure applied to the pedals. The mechanism is contained inside the bicycle wheel hub shell.

Rear wheel of 1960s Bootie Folding Cycle with Sturmey-Archer drum brake

For information on other types of bicycle brakes see the full article on bicycle brake systems.

Gears

The rear hub has one or more methods for attaching a gear to it.

- Freehub–- The mechanism that allows the rider to coast is built into the hub. Splines on the freehub body allow a single sprocket or, more commonly, a cassette containing several sprockets to be slid on. A lock ring then holds the cog(s) in place. This is the case for most modern bicycles.
- Freewheel – The mechanism that allows the rider to coast is not part of the hub, it is contained in a separate freewheel body. The hub has threads that allow the freewheel body to be screwed on, and the freewheel body has threads or splines for fitting sprockets, or in the case of most single speed freewheels an integral sprocket. This style of hub was used before the freehub became practical.
- Track sprocket – There is no mechanism that allows the rider to coast. There are two sets of threads on the hub shell. The threads are in opposite directions. The inner (clockwise) set of threads is for a track sprocket and the outer (counter-clockwise) set is for a reverse threaded lock ring. The reverse threads on the lock ring keep the sprocket from unscrewing from the hub, which is otherwise possible when slowing down.
- Flip-flop hub – Both sides of the hub are threaded, allowing the wheel to be removed and reversed in order to change which gear is used. Depending on the style of threads, may be used with either a single-speed freewheel or a track sprocket.
- Internal geared hub – the mechanism to provide multiple gear-ratios is contained inside the shell of the hub. Many bicycles with three-speed internally geared hubs were built in the last century. This is an extremely robust design, although for a larger number of gear ratios, it becomes heavier than more modern designs of multi-gear-ratio arrangements. Modern hubs are available from three-speed to 14 speeds[7] or a continuously variable transmission hub,[8] in the case of the NuVinci.

Rim

The rim is commonly a metal extrusion that is butted into itself to form a hoop, though may also be a structure of carbon fiber composite, and was historically made of wood. Some wheels use both an aerodynamic carbon hoop bonded to an aluminum rim on which to mount conventional bicycle tires.

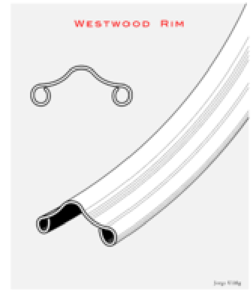
Metallic bicycle rims are now normally made of aluminium alloy, although until the 1980s most bicycle rims - with the exception of those used on racing bicycles - were made of steel[9] and thermoplastic.

Rims designed for use with rim brakes provide a smooth parallel braking surface, while rims meant for use with disc brakes or hub brakes sometimes lack this surface.

The Westwood pattern rim was one of the first rim designs, and rod-actuated brakes, which press against the inside surface of the rim were designed for this rim. These rims cannot be used with caliper rim brakes.

The cross-section of a rim can have a wide range of geometry, each optimized for particular performance goals. Aerodynamics, mass and inertia, stiffness, durability, tubeless tire compatibility, brake compatibility, and cost are all considerations. If the part of the cross-section of the rim is hollow where the spokes attached, as in the Sprint rim pictured, it is described as **box-section** or **double-wall** to distinguish it from **single-wall** rims such as the Westwood rim pictured.[10] The double wall can make the rim stiffer. **Triple-wall** rims have additional reinforcement inside the box-section.

Aluminum rims are often reinforced with either single eyelets or double eyelets to distribute the stress of the spoke. A single eyelet reinforces the spoke hole much like a hollow rivet. A double eyelet is a cup that is riveted into both walls of a double-walled rim.



Westwood rim as fitted to vintage roadster bicycles with rod/ stirrup brakes, today being used in contemporary “drum brake” traditional utility bicycles

Clincher rims

Most bicycle rims are "clincher" rims for use with **clincher** tires. These tires have a wire or aramid (Kevlar or Twaron) fiber bead that interlocks with flanges in the rim. A separate airtight inner tube enclosed by the rim supports the tire carcass and maintains the bead lock. If the inner part of the rim where the inner tube fits has spoke holes, they must be covered by a rim tape or strip, usually rubber, cloth, or tough plastic, to protect the inner tube.

An advantage of this system is that the inner tube can be easily accessed in the case of a leak to be patched or replaced.

The ISO 5775-2 standard defines designations for bicycle rims. It distinguishes between

1. Straight-side (SS) rims
2. Crochet-type (C) rims
3. Hooked-bead (HB) rims

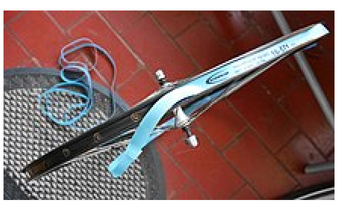
Endrick Rim as fitted to sports bicycles from the 1930s, 40s and 50s, forerunner of modern-day rim brakes

Traditional clincher rims were straight-sided. Various "hook" (also called "crochet") designs emerged in the 1970s to hold the **bead** of the tire in place,[11][12] allowing high (6–10 bar, 80–150 psi) air pressure.

Tubular or sew-up rims

Some rims are designed for tubular tires which are torus shaped and attached to the rim with adhesive. The rim provides a shallow circular outer cross section in which the tire lies instead of flanges on which tire beads seat.

Tubeless



Fitting rim tape around 26 inch wheel (MTB). Rim tape protects the bicycle wheel's inner tube from spoke holes, which will puncture the tube if exposed inside the rim.

A tubeless tire system requires an airtight rim — capable of being sealed at the valve stem, spoke holes (if they go all the way through the rim) and the tire bead seat — and a compatible tire. Universal System Tubeless (UST), originally developed by Mavic, Michelin and Hutchinson[13] for mountain bikes is the most common system of tubeless tires/rims for bicycles.[14] The main benefit of tubeless tires is the ability to use low air pressure for better traction without getting pinch flats because there is no tube to pinch between the rim and an obstacle.[13]

Rims for tubular tires, referred to as "sprint rims" in Britain and Ireland.

Some cyclists have avoided the price premium for a tubeless system by sealing the spoke holes with a special rim strip and then sealing the valve stem and bead seat with a latex sealer.[13] However, tires not designed for tubeless application do not have as robust a sidewall as those that are.[13]

The drawbacks to tubeless tires are that they are notorious for being harder to mount on the rim than clincher tires,[13] and that the cyclist must still carry a spare tube to insert in case of a flat tire due to a puncture.[13]

French tire manufacturer Hutchinson has introduced a tubeless wheel system, Road Tubeless, that shares many similarities to the UST (Universal System Tubeless) that was developed in conjunction with Mavic and Michelin. Road Tubeless rims, like UST rims, have no spoke holes protruding to the air chamber of the rim. The flange of the Road Tubeless rim is similar to the hook bead of a standard clincher rim but is contoured to very close tolerances to interlock with a Road Tubeless tire, creating an airtight seal between tire and rim. This system eliminates the need for a rim strip and inner tube.

Increasingly common are tubeless tires conforming to the UST (Universal System Tubeless) standard pioneered by French wheel manufacturer Mavic in conjunction with tire manufacturers Hutchinson and Michelin.

In 2006, Shimano and Hutchinson introduced a tubeless system for road bikes.[15]

Spokes

The rim is connected to the hub by several spokes under tension. Original bicycle wheels used wooden spokes that could be loaded only in compression, modern bicycle wheels almost exclusively use spokes that can only be loaded in tension.

The rear wheel is subjected to greater stress because more weight is carried on the rear wheel. The rear wheel spokes on the right are more likely to fail. The rear wheels are asymmetrical to make room for multisprocket gear clusters. This asymmetry means that the spokes on the right are twice as tight as those on the left. The spokes break due to fatigue and not excessive force.[16]

There are a few companies making wheels with spokes that are used in both compression and tension.[17]

One end of each spoke is threaded for a specialized nut, called a nipple, which is used to connect the spoke to the rim and adjust the tension in the spoke. This is normally at the rim end. The hub end normally has a 90 degree bend to pass through the spoke hole in the hub, and a head so it does not slip through the hole.

Double-butted spokes have reduced thickness over the center section and are lighter, more elastic, and more aerodynamic than spokes of uniform thickness. *Single-butted* spokes are thicker at the hub and then taper to a thinner section all the way to the threads at the rim.[18] *Triple-butted* spokes also exist and are thickest at the hub, thinner at the threaded end, and thinnest in the middle.[19]

Apart from tubeless wheels, which do not need them, tubed bicycle wheels require rim tapes or strips, a flexible but tough liner strip (usually rubber or woven nylon or similar material) attached to the inner circumference of the wheel to cover the ends of the nipples. Otherwise, the nipple ends wear a hole in the tube causing a flat tire.

In 2007, Mavic introduced their R-Sys, a new bicycle spoke technology that allows the spokes to be loaded in both tension and compression. This technology is promised to allow for fewer spokes, lower wheel weight and inertia, increased wheel stiffness, with no loss of durability. However, in 2009 Mavic recalled R-Sys front wheels due to spoke failures leading to collapse of the entire wheel.[20]

Cross section

Spokes are usually circular in cross-section, but high-performance wheels may use spokes of flat or oval cross-section, also known as bladed, to reduce aerodynamic drag. Some spokes are hollow tubes.[18]

Material

The spokes on the vast majority of modern bicycle wheels are steel or stainless steel. Stainless steel spokes are favored by most manufacturers and riders for their durability, stiffness, damage tolerance, and ease of maintenance.[21] Spokes are also available in titanium,[21] aluminum,[22] or carbon fiber.[21]

Number of spokes

Conventional metallic bicycle wheels for single rider bikes commonly have 28, 32 or 36 spokes, while wheels on tandems have as many as 40 or 48 spokes to support the weight of an additional rider. BMX bikes commonly have 36 or 48 spoke wheels. Lowrider bicycles may have as many as 144 spokes per wheel.[23][24][25] Wheels with fewer spokes have an aerodynamic advantage, as the aerodynamic drag from the spokes is reduced. On the other hand, the reduced number of spokes results in a larger section of the rim being unsupported, necessitating stronger and often heavier rims. Some wheel designs also locate the spokes unequally into the rim, which requires a stiff rim hoop and correct tension of the spokes. Conventional wheels with spokes distributed evenly across the circumference of the rim are considered more durable and forgiving to poor maintenance. The more general trend in wheel design suggests technological advancement in rim materials may result in further reduction in the number of spokes per wheel.

Broken rim after a bicycle/car-door collision

Lacing

Lacing is the process of threading spokes through holes in the hub and rim[26] so that they form a spoke pattern.[27] While most manufacturers use the same lacing pattern on both left and right sides of a wheel, it is becoming increasingly common to find specialty wheels with different lacing patterns on each side. A spoke can connect the hub to the rim in a radial fashion, which creates the lightest and most aerodynamic wheel.[27] However, to efficiently transfer torque from the hub to the rim, as with driven wheels or wheels with drum or disc brakes, durability dictates that spokes be mounted at an angle to the hub flange up to a "tangential lacing pattern" to achieve maximum torque capability (but minimum vertical wheel stiffness).[27] Names for various lacing patterns are commonly referenced to the number of spokes that any one spoke crosses. Conventionally laced 36- or 32-spoke wheels are most commonly built as a cross-3 or a cross-2, however other cross-numbers are also possible. The angle at which the spoke interfaces the hub is not solely determined by the cross-number; as spoke count and hub diameter will lead to significantly different spoke angles. For all common tension-spoke wheels with crossed spokes, a torque applied to the hub will result in one half of the spokes - called "leading spokes" tensioned to drive the rim, while other half - "trailing spokes" are tensioned only to counteract the leading spokes. When forward torque is applied (i.e., during acceleration), the trailing spokes experience a higher tension, while leading spokes are relieved, thus forcing the rim to rotate. While braking, leading spokes tighten and trailing spokes are relieved. The wheel can thus transfer the hub torque in either direction with the least amount of change in spoke tension, allowing the wheel to stay true while torque is applied.

Wheels that are not required to transfer any significant amount of torque from the hub to the rim are often laced radially.[27] Here, the spokes leave the hub at perpendicular to the axle and go straight to the rim, without crossing any other spokes - e.g., "cross-0". This lacing pattern can not transfer torque as efficiently as tangential lacing. Thus it is generally preferred to build a crossed-spoke wheel where torque forces, whether driving or braking, issue from the hub. Where braking is concerned, the older-style caliper devices that contact the rims to apply braking force are not affected by lacing patterns in this way because braking forces are transferred from the calipers directly to the rim, then to the tires and then to the roadway. Disc brakes, however, transfer their force to the roadway via the spokes from the disc's mounting point on the hub and are therefore affected by the lacing pattern in a manner similar to that of the drive system.

Hubs that have previously been laced in any other pattern should not be used for radial lacing, as the pits and dents created by the spokes can be the weak points along which the hub flange may break. This is not always the case: for example if the hub used has harder, steel flanges like those on a vintage bicycle.

Wheel builders also employ other exotic spoke lacing patterns (such as "crow's foot", which is essentially a mix of radial and tangential lacing) as well as innovative hub geometries. Most of these designs take advantage of new high-strength materials or manufacturing methods to improve wheel performance. As with any structure, however, practical usefulness is not always agreed, and often nonstandard wheel designs may be opted for solely aesthetic reasons.

Adjustment ("truing")

There are three aspects of wheel geometry which must be brought into adjustment in order to true a wheel. "Lateral truing" refers to elimination of local deviations of the rim to the left or right of center. "Vertical truing" refers to adjustments of local deviations (known as hop) of the radius, the distance from the rim to the center of the hub. "Dish" refers to the left-right centering of the plane of the rim between the lock nuts on the outside ends of the axle. This plane is itself determined as an average of local deviations in the lateral truing.[28] For most rim-brake bicycles, the dish will be symmetrical on the front wheel. However, on the rear wheel, because most bicycles accommodate a rear sprocket (or group of them), the dishing will often be asymmetrical: it will be dished at a deeper angle on the non-drive side than on the drive side.

In addition to the three geometrical aspects of truing, the overall tension of the spokes is significant to the wheel's fatigue durability, stiffness, and ability to absorb shock. Too little tension leads to a rim that is easily deformed by impact with rough terrain. Too much tension can deform the rim, making it impossible to true, and can decrease spoke life. Spoke tensiometers are tools which measure the tension in a spoke. Another common method for making rough estimates of spoke tension involves plucking the spokes and listening to the audible tone of the vibrating spoke. The optimum tension depends on the spoke length and spoke gauge (diameter). Tables are available online which list tensions for each spoke length, either in terms of absolute physical tension, or notes on the musical scale which coincide with the approximate tension to which the spoke should be tuned. In the real world, a properly trued wheel will not, in general, have a uniform tension across all spokes, due to variation among the parts from which the wheel is made.

Finally, for best, long-lasting results, spoke wind-up should be minimized. When a nipple turns, it twists the spoke at first, until there is enough torsional stress in the spoke to overcome the friction in the threads between the spoke and the nipple. This is easiest to see with bladed or ovalized spokes, but occurs in round spokes as well. If a wheel is ridden with this torsional stress left in the spokes, they may untwist and cause the wheel to become out of true. Bladed and ovalized spokes may be held straight with an appropriate tool as the nipple is turned. The common practice for minimizing wind-up in round spokes is to turn the nipple past the desired orientation by about a quarter turn, and then turn it back that quarter turn.[29]

In wheel truing, all these factors must be incrementally brought into balance against each other. A commonly recommended practice is to find the worst spot on the wheel, and bring it slightly more into true before moving on to the next worst spot on the wheel.

"Truing stands" are mechanical devices for mounting wheels and truing them. It is also possible to true a wheel while it is mounted on the bike: brake pads or some other fixed point may be used as a reference mark, however this is less accurate.

Nipples

At one end of each spoke is a specialized nut, called a nipple, which is used to connect the spoke to the rim and adjust the tension in the spoke. The nipple is usually located at the rim end of the spoke but on some wheels is at the hub end to move its weight closer to the axis of the wheel, reducing the moment of inertia. A variant of this is integrating nipples into the hub, its flange containing the threads for usually bladed spokes.[30]

Until recently there were only two types of nipples: brass and aluminum (often referred to as "alloy"). Brass nipples are heavier than aluminum, but they are more durable. Aluminium nipples save weight, but they are less durable than brass and more likely to corrode.

A nipple at the rim of a wheel usually protrudes from the rim towards the center of the wheel, but in racing wheels may be internal to the rim, offering a slight aerodynamic advantage.[31]

Alternatives

A wheel can be formed in one piece from a material such as thermoplastic (glass-filled nylon in this case), carbon fiber or aluminium alloy. Thermoplastic is commonly used for inexpensive BMX wheels. They have a low maximum tire pressure of 45 psi (3bars or atmospheres).[32] Carbon fiber is typically used for high-end aerodynamic racing wheels.

Disc wheels

A sectioned, carbon–composite, rear wheel for mountain bikes.

Disc wheels are designed to minimize aerodynamic drag. A full disc is usually heavier than traditional spoke wheels, and can be difficult to handle when ridden with a cross wind. For this reason, international cycling organizations often ban disc wheels or limit their use to the rear wheel of a bicycle. However, international triathlon federations were (and are still) less restrictive and is what led to the wheels' initial usage growth in popularity in the 1980s.

A disc wheel may simply be a fairing that clips onto a traditional, spoke wheel, addressing the drag that the spokes generate by covering them; or the disc can be integral to the wheel with no spokes inside. In the latter case carbon fiber is the material of choice. A spoke wheel with a disc cover may not be legal under UCI Union Cycliste Internationale rules because it is a non-structural fairing but are again acceptable under ITU International Triathlon Union rules.

A compromise that reduces weight and improves cross wind performance has a small number (three or four) tension-compression spokes molded integral to the rim – also typically carbon fiber.

Types

Bicycle wheels can be categorized by their primary use.

Road/racing bicycle wheels

For road bicycle racing performance there are several factors which are generally considered the most important:

- aerodynamics
- weight
- rotational inertia
- hub/bearing smoothness
- stiffness


A Campagnolo rear wheel with "G3" triplet spoke lacing. There are 18 tangential spokes on the right side, but only 9 radial on the left. Picture also shows a 10-speed cassette

Semi-aerodynamic and aerodynamic wheelsets are now commonplace for road bicycles. Aluminum rims are still the most common, but carbon fiber is also becoming popular. Carbon fiber is also finding use in hub shells to reduce weight; however, because of the hub's proximity to the center of rotation reducing the hub's weight has less inertial effect than reducing the rim's weight.

Semi-aerodynamic and aerodynamic wheelsets are characterized by greater **rim depth**, which is the radial distance between the outermost and the innermost surfaces of the rim; a triangular or pyramidal cross-section; and by fewer numbers of spokes, or no spokes at all—with blades molded of composite material supporting the rim. The spokes are also often flattened in the rotational direction to reduce wind drag. These are called *bladed spokes*. However, semi-aerodynamic and aerodynamic wheelsets tend to be heavier than more traditional spoked wheelsets due to the extra shapings of the rims and spokes. More importantly, the rims must be heavier when there are fewer spokes, as the unsupported span between spokes is greater. A number of wheel manufacturers are now producing wheels with roughly half the spokes of the highest performance traditional wheel from the 1980s, with approximately the same rotational inertia and less total weight. These improvements have been made possible primarily through improved aluminium alloys for the rims.

Most clincher carbon fiber wheelsets, such as those made by Zipp and Mavic, still use aluminum parts at the clinching part of the rim. An increased number of all-carbon rims, such as Campagnolo Hyperon Ultra Clincher, Viva v8 wheels, Bontrager's Carbon Clincher wheels, DT Swiss RRC1250, Corima Winium and Aero (also tubeless, see below) and Lightweight Standard C wheelsets are now available.

700C road bicycle wheels / ISO 622 mm


700C front wheel

Touring, race, and cyclo-cross bicycles may have vastly different design goals for their wheels. Aerodynamic performance and low weight are beneficial for road bicycles, while for cyclo-cross strength gains importance, and for touring bicycles, strength becomes more important again. However, this diameter of rim, identical in diameter to the "29er" rim, is by far the most common on these styles of bicycles. Road wheels may be designed for tubular or clincher tires, commonly referred to as "700C" tires.

650C triathlon bicycle wheels / ISO 571 mm

These wheels experienced a brief popularity in the 1990s on triathlon bikes.[33]

650B gravel bicycle wheels / ISO 584 mm

In the late 2010s, 650B wheels began appearing on gravel bikes.[33]

Plastic BMX wheel

Mountain bike wheels

Mountain bike wheels are described by the approximate outer diameter of the rim plus a wide, ~2+ inch tire.

24 inch / ISO 507 mm

24-inch clincher tires (with inner tubes) are the most common wheel size for junior mountain bikes. The typical 24-inch rim has a diameter of 507 millimetres (20.0 in) and an outside tire diameter of about 24 inches (610 mm).

A 29" and 26" mountain bike wheel

26 inch / ISO 559 mm

26-inch clincher tires (with inner tubes) were the most common wheel size for new mountain bikes until the early 2010s.[34] This tradition was started initially because the early mountain bike pioneers procured the wheels for their early bikes from American-made bicycles rather than the larger European standards in use. The typical 26-inch rim has a diameter of 559 millimetres (22.0 in) and an outside tire diameter of about 26.2 inches (670 mm).

27.5 inch / ISO 584 mm

27.5-inch mountain bike wheels[35][36][37][38][39] (which some also refer to as 650B[40][41] use a rim that has a diameter of 584 mm (23.0") with wide, knobby tires (~27.5 x 2.3 / ISO 58-584) are approximately the midway point between the 26-inch (ISO-559mm) and the 29-inch (ISO-622mm) standards. They carry some of the advantages of both formats, with a smoother ride than a 26-inch wheel and more stiffness and durability than a 29" wheel.

29 inch / ISO 622 mm

"29-inch wheels", which also conform to the popular 700C (622 mm diameter clincher) wheel standard are becoming more popular for not only cyclocross bikes but also cross-country mountain bikes. Their rim diameter of 622 millimetres (24½ in) is identical to most road, hybrid, and touring bicycle wheels, but they are typically reinforced for greater durability in off-road riding. The average 29-inch mountain bike tire is ISO 59-622 - corresponding to an outside diameter of about 29.15 inches (740 mm).

BMX wheels

There are two distinct wheel sizes that get described as 20 in., and both get used in the BMX sport.

20 inch / ISO 406 mm

Usually 20 inches in diameter (rim diameter of 406 mm), BMX wheels are small for several reasons: they are suitable for young and small riders; their lower cost is compatible with inexpensive bicycles; the size makes them stronger to withstand the additional loads generated by BMX jumps and stunts; and to reduce rotational inertia for easier wheel acceleration.

20 inch / ISO 451 mm

Nominally 20 x 1-1/8" or 20 x 1-3/8", with rim diameter 451 mm. These are intended for racing by lightweight BMX riders, and sometimes referred to as "skinnies". The size is also used on classic British folding or shopping bikes.

Technical aspects

Sizes

Bicycle rims and tires came in many different types and sizes before efforts were made to standardize and improve wheel/tire compatibility. The International Organization for Standardization (ISO) and the European Tyre and Rim Technical Organisation (ETRTO) define a modern, unambiguous system of sizing designations and measurement procedures for different types of tires and rims in international standard ISO 5775. For example:

- **For wired-edge tires** the ISO designation lists the width of the inflated tire and the "bead-seat diameter", both in millimeters and separated by a hyphen: **37-622**. The bead seat diameter (BSD) is the diameter of the surface of the rim upon which the tire bead sits.

- **For rims** the ISO designation lists the rim's bead seat diameter and the rim's inner width, both in millimeters and separated by a cross, along with a letter code for the rim type (e.g., "C" = Crochet-type): **622x19C**

In practice, most tires (and inner tubes) sold today carry, in addition to the modern ISO 5775-1 designation, some historic size markings, for which no officially maintained definition currently exists, but which are still widely used:

- an old French tire designation that was based on the approximate outer diameter of the inflated tire in millimeters: **700×35 C**.
- an old British inch-based designation: **597 mm (26 × 1¼), 590 mm (26 × 1⅜)**, **630 mm (27 × 1¼)**, and **635 mm (28 × 1½)**

Which designation is most popular varies with region and type of bicycle. For a comprehensive equivalence table between old and new markings, see the ISO 5775 article, the table in Annex A of the ISO 5772 standard, as well as Tire Sizing (http://www.sheldonbrown.com/tire_sizing.html) by Sheldon Brown.

Most road and racing bicycles today use 622 mm diameter (700C) rims, though 650C rims are popular with smaller riders and triathletes. The 650C size has the ISO diameter size of 571 mm. Size 650B is 584 mm and 650A is 590 mm. 650B is being promoted as a 'best of both worlds' size for mountain biking.[42] Most adult mountain bikes use 26 inch wheels. Smaller youth mountain bikes use 24 inch wheels. The larger 700C (29 inch) wheels have enjoyed some recent popularity among off-road bicycle manufacturers. These rims are the same bead seat diameter as 700C wheels and are generally compatible with bicycle frames and tires designed for the 700C standard, however, rims designated as 29 inch are designed for wider tires than rims designated 700C, so frame clearance may be an issue. The formerly popular 27 inch (630 mm) wheel size is now rare.

Children's bicycles are commonly sized primarily based on wheel diameter rather than seat tube length (along the rider's inseam) dimension. Thus, a wide range of small bike wheels are still found, ranging from 239 mm (9.4 in) diameter to 400 mm (16 in).

Smaller wheel sizes are also found on folding bicycles to minimise the folded size. These range from 16-inch diameter (e.g. Brompton) through 20 inches (e.g. Bike Friday) up to even 26 inches.

Wheel rims also come in a variety of widths to provide optimum performance for different uses. High performance road racing rims are narrow, 18 mm or so. Wider touring or durable off-road tires require rims of 24 mm wide or more.[43]

26 inch

The common "26-inch" wheel used on mountain bikes and beach cruisers is an American size using a 559 mm rim, traditionally with hooked edges.

Other sizes 26"

There are four other "26-inch" (British designation) or "650" (French) sizes, from the narrow tires to the widest, which traditionally all measured the same outside diameter.[40][44]

- **650** - ISO 32-597 (26 x 1¼) - Older British sport bikes. Schwinns with narrow tires.[45]
- **650A** - ISO 37-590 (26 x 1⅜) - Common on many vintage frames ranging from American-made Murray and Huffy as well as English and French manufactures like Raleigh and Peugeot.
- **650B** - ISO 40-584 (26 x 1½) - Also 650B demi-ballon. French tandems, Porteurs, touring bicycles; enjoying a revival.[41] (584 mm rims with large volume ISO 56-584 knobby tires, aka; balloon, are also known as 27.5 inch mountain bike wheels)
- **650C** - ISO 44-571 (26 x 1¾) - Formerly 47mm wide on Schwinn cruisers and for British trade/delivery bikes. Currently ISO 28-571, size is the same, but the narrower and less overall wheel diameter are built for triathlon, time trial and small road bikes.[46]

Widths of tires and corresponding ISO width designations may vary, though the wheel outside diameter remains approximately the same.[47]

28 inch

Traditionally, there were four different sizes of 28-inch diameter wheels, from the narrow tires to the widest, they all measured the same outside diameter, which coincide with four different families of 700 tire sizes, these are 700, 700A, 700B and 700C. The largest of these rims (ISO 647mm/642mm) with the narrower tires are no longer available.[40][48][49]

28 Inches
Obsolete sizes in grey

Size (in fraction)	French Code	ISO	Application
28 x $1\frac{1}{4}$	700	647mm	Old English and Dutch Bicycles / Old track bicycles
28 x $1\frac{3}{8}$	700A	642mm	Most old English sports bikes, almost extinct, now available in the Asia Pacific and the Middle East regions
28 x $1\frac{1}{2}$	700B	635mm	Roadster type bicycles of English, Dutch, Chinese, Indian and Ukrainian origin / Classic Path Racer type bicycle of English origin / Maintaining in popularity throughout the world
28 x $\frac{3}{4}$ 28 x $1\frac{1}{8}$ 28 x $1\frac{1}{4}$ 28 x $1\frac{5}{8}$ 28 x $1\frac{3}{4}$ 29 x $2\frac{3}{8}$	700C	622mm	ISO 18-622 through ISO 28-622, for racing bicycles, narrow wheels and the diameter of the wheel is less than 28 inches. ISO 32-622 through ISO 42-622, traditional urban bicycle size. ISO 47-622 (28 x $1\frac{3}{4}$) through ISO 60-622 (29 × 2.35). The 28 x 2.00, ISO 50-622 onwards, as a marketing term for wide tires for mountain bikes, are known as 29 inch for their larger wheel diameter and measured in decimal sizes.

Rolling resistance

There are a number of variables that determine rolling resistance: tire tread, width, diameter, tire construction, tube type (if applicable), and pressure are all important.

Smaller diameter wheels, all else being equal, have higher rolling resistance than larger wheels.[50] "Rolling resistance increases in near proportion as wheel diameter is decreased for a given constant inflation pressure."[51]

Rotating mass

Due to the fact that wheels rotate as well as translate (move in a straight line) when a bicycle moves, more force is required to accelerate a unit of mass on the wheel than on the frame. In wheel design, reducing the rotational inertia has the benefit of more responsive, faster-accelerating wheels. To accomplish this, wheel designs are employing lighter rim materials, moving the spoke nipples to the hub or using lighter nipples such as aluminum. Note however that rotational inertia is a factor only during acceleration (and deceleration/braking). At constant speed, aerodynamics are a significant factor. For climbing, total mass remains important. See Bicycle performance for more detail.

Dish

The hub flanges of modern tension-spoked bicycle wheels are always spaced wider than where the spokes attach to the rim. When viewed in cross section, the spokes and hub form a triangle, a structure that is stiff both vertically and laterally. In three dimensions, if the spokes were covered, they would form two cones or "dishes". The greater the separation between the hub flanges, the deeper the dishes, and the stiffer and stronger the wheel can be laterally. The more vertical the spokes, the shallower the dish, and the less stiff the wheel will be laterally.

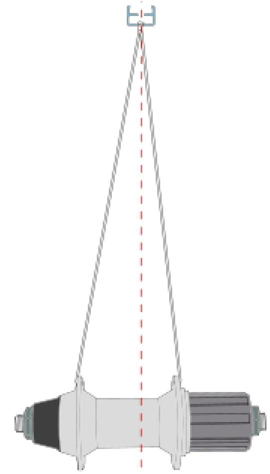


Diagram showing the difference in length and angle of spokes.

The dishes on each side of a wheel are not always equal. The cogset (freewheel or cassette) of a rear wheel and disc brake rotors, if installed, takes up width on the hub, and so the flanges may not be located symmetrically about the center plane of the hub or the bike. Since the rim must be centered, but the hub flanges are not, there is a difference in dish between the two sides. Such an asymmetrical wheel is called a "dished" wheel. The side of the wheel with less dish has slightly shorter but significantly higher-tensioned spokes than the side with more dish. Several different techniques have been tried to minimize this spoke asymmetry. In addition to modified hub geometry, some rims have off-center spoke holes, and the mounting of common J-bend spokes at the hub flange can be altered "inboard" or "outboard".[52]

A truing stand or a dishing gauge, can be used to measure the position of the rim relative to the hub. Thus "dishing" is also used to describe the process of centering the rim on the hub, even in the case of symmetrical wheels.[53]

Stiffness

The stiffness of a bicycle wheel can be measured in three primary directions: radial, lateral, and torsional. The radial stiffness is primarily a measure of how well the wheel absorbs bumps from the surface on which it rolls. Lateral stiffness, especially of the front wheel influences the handling of the bicycle. Torsional, or tangential stiffness is a measure of how well the wheel transmits propulsive and braking forces, if applied at the hub, as in the case of hub or disc brakes.

Several factors affect these stiffnesses to varying degrees. These include wheel radius, rim bending and torsional stiffness, number of spokes, spoke gauge, lacing pattern, hub stiffness, hub flange spacing, hub radius.[54] In general lateral and radial stiffness decreases with the number of spoke crossings and torsional stiffness increases with the number of spoke crossings. One factor that has little influence on these stiffnesses is spoke tension.[55]

Too much spoke tension, however, can lead to catastrophic failure in the form of buckling.[56] The "most significant factor affecting the lateral spoke system stiffness" is the angle between the spokes and the wheel midplane. Thus any change that increases this angle, such as increasing the width of the hub, while keeping all other parameters constant, increases the resistance to buckling.[57]

See also

- Spoke wrench
- Wheelbuilding
- Wire wheel
- Bicycle
- Mountain bike
- Downhill bike
- Glossary of cycling
- *Bicycle Wheel*, 1916-17 Marcel Duchamp sculpture
- *The Bicycle Wheel* (book)

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External links

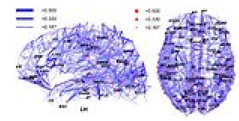
- Building Bicycle Wheels by Sheldon Brown (http://www.sheldonbrown.com/wheelbuild.html)
- Tire Sizing Systems by Sheldon Brown (http://sheldonbrown.com/tire-sizing.html)

WIKIPEDIA

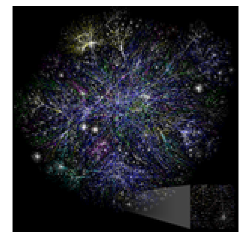
Hub (network science)

In network science, a **hub** is a node with a number of links that greatly exceeds the average. Emergence of hubs is a consequence of a scale-free property of networks.[1] While hubs cannot be observed in a random network, they are expected to emerge in scale-free networks. The uprise of hubs in scale-free networks is associated with power-law distribution. Hubs have a significant impact on the network topology. Hubs can be found in many real networks, such as the brain or the Internet.

A hub is a component of a network with a high-degree node. Hubs have a significantly larger number of links in comparison with other nodes in the network. The number of links (degrees) for a hub in a scale-free network is much higher than for the biggest node in a random network, keeping the size N of the network and average degree $<k>$ constant. The existence of hubs is the biggest difference between random networks and scale-free networks. In random networks, the degree k is comparable for every node; it is therefore not possible for hubs to emerge. In scale-free networks, a few nodes (hubs) have a high degree k while the other nodes have a small number of links.



Network representation of brain connectivity. Hubs are highlighted

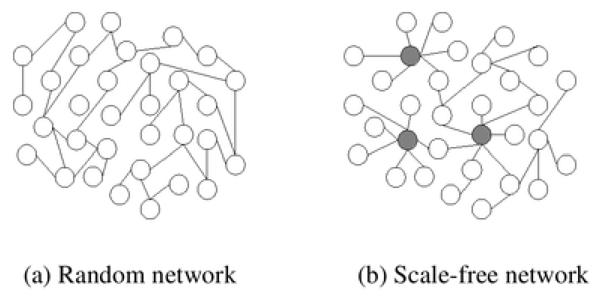


Partial map of the Internet based on the January 15, 2005. Hubs are highlighted

Contents

Emergence

Emergence of hubs can be explained by the difference between scale-free networks and random networks. Scale-free networks (Barabási–Albert model) are different from random networks (Erdős–Rényi model) in two aspects: (a) growth, (b) preferential attachment.[2]



Random network (a) and scale-free network (b). In the scale-free network, the larger hubs are highlighted.

- (a) Scale-free networks assume a continuous growth of the number of nodes N, compared to random networks which assume a fixed number of nodes. In scale-free networks the degree of the largest hub rises polynomially with the size of the network. Therefore, the degree of a hub can be high in a scale-free network. In random networks the degree of the largest node rises logaritmically (or slower) with N, thus the hub number will be small even in a very large network.
- (b) A new node in a scale-free network has a tendency to link to a node with a higher degree, compared to a new node in a random network which links itself to a random node. This process is called preferential attachment. The tendency of a new node to link to a node with a high degree k is characterized by power-law distribution (also known as rich-gets-richer process). This idea was introduced by Vilfredo Pareto and it explained why a small percentage of the population earns most of the money. This process is present in networks as well, for example 80 percent of web links point to 15 percent of webpages. The emergence of scale-free networks is not typical only of networks created by human action, but also of such networks as metabolic networks or illness networks.[3] This phenomenon may be explained by the example of hubs on the World Wide Web such as Facebook or Google. These webpages are very well known and therefore the tendency of other webpages pointing to them is much higher than linking to random small webpages.

The mathematical explanation for Barabási–Albert model:

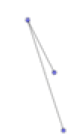
The network begins with an initial connected network of m_0 nodes.

New nodes are added to the network one at a time. Each new node is connected to $m \leq m_0$ existing nodes with a probability that is proportional to the number of links that the existing nodes already have. Formally, the probability p_i that the new node is connected to node i is[2]

$$p_i = \frac{k_i}{\sum_j k_j},$$

where k_i is the degree of the node i and the sum is taken over all pre-existing nodes j (i.e. the denominator results in twice the current number of edges in the network).

Emergence of hubs in networks is also related to time. In scale-free networks, nodes which emerged earlier have a higher chance of becoming a hub than latecomers. This phenomenon is called first-mover advantage and it explains why some nodes become hubs and some do not. However, in a real network, the time of emergence is not the only factor that influences the size of the hub. For example, Facebook emerged 8 years later after Google became the largest hub on the World Wide Web and yet in 2011 Facebook became the largest hub of WWW. Therefore, in real networks the growth and the size of a hub depends also on various attributes such as popularity, quality or the aging of a node.



The steps of the growth of the network according to the Barabasi–Albert model ($m_0 = m = 2$)

Attributes

There are several attributes of Hubs in a Scale-Free Network

Shortening the path lengths in a network

The more observable hubs are in a network, the more they shrink distances between nodes.
In a scale-free network, hubs serve as bridges between the small degree nodes.[4] Since the distance of two random nodes in a scale-free network is small, we refer to scale-free networks as "small" or "ultra small". While the difference between path distance in a very small network may not be noticeable, the difference in the path distance between a large random network and a scale-free network is remarkable.

Average path length in scale-free networks: $\ell \sim \frac{\ln N}{\ln \ln N}$.

Aging of hubs (nodes)

The phenomenon present in real networks, when older hubs are shadowed in a network. This phenomenon is responsible for changes in evolution and topology of networks.[5] The example of aging phenomenon may be the case of Facebook overtaking the position of the largest hub on the Web, Google(which was the largest node since 2000).

Robustness and Attack Tolerance

During the random failure of nodes or targeted attack hubs are key components of the network. During the random failure of nodes in network hubs are responsible for exceptional robustness of network.[6] The chance that a random failure would delete the hub is very small, because hubs coexists with a large number of small degree nodes. The removal of small degree nodes does not have a large effect on integrity of network. Even though the random removal would hit the hub, the chance of fragmantation of network is very small because the remaining hubs would hold the network together. In this case, hubs are the strength of a scale-free networks.

During a targeted attack on hubs, the integrity of a network will fall apart relatively fast. Since small nodes are predominantly linked to hubs, the targeted attack on the largest hubs results in destroys the network in a short period of time. The financial market meltdown in 2008 is an example of such a network failure, when bankruptcy of the largest players (hubs) led to a continuous breakdown of the whole system.[7] On the other hand, it may have a positive effect when removing hubs in a terrorist network; targeted node deletion may destroy the whole terrorist group. The attack tolerance of a network may be increased by connecting its peripheral nodes, however it requires to double the number of links.

Degree correlation

The perfect degree correlation means that each degree-k node is connected only to the same degree-k nodes. Such connectivity of nodes decide the topology of networks, which has an effect on robustness of network, the attribute discussed above. If the number of links between the hubs is the same as would be expected by chance, we refer to this network as Neutral Network. If hubs tend to connected to each other while avoiding linking to small-degree nodes we refer to this network as Assortative Network. This network is relatively resistant against attacks, because hubs form a core group, which is more reduntant against hub removal. If hubs avoid connecting to each other while linking to small-degree nodes, we refer to this network as Disassortative Network. This network has a hub-and-spoke character. Therefore, if we remove the hub in this type of network, it may damage or destroy the whole network.

Spreading phenomenon

The hubs are also responsible for effective spreading of material on network. In an analysis of disease spreading or information flow, hubs are referred to as super-spreaders. Super-spreaders may have a positive impact, such as effective information flow, but also devastating in a case of epidemic spreading such as H1N1 or AIDS. The mathematical models such as model of H1H1 Epidemic prediction [8] may allow us to predict the spread of diseases based on human mobility networks, infectiousness, or social interactions among humans. Hubs are also important in the eradication of disease. In a scale-free network hubs are most likely to be infected, because of the large number of connections they have. After the hub is infected, it broadcasts the disease to the nodes it is linked to. Therefore, the selective immunization of hubs may be the cost-effective strategy in eradication of spreading disease.

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Transport hub

A **transport hub** (also **transport interchange**) is a place where passengers and cargo are exchanged between vehicles and/or between transport modes. Public transport hubs include train stations, rapid transit stations, bus stops, tram stops, airports and ferry slips. Freight hubs include classification yards, airports, seaports and truck terminals, or combinations of these. For private transport, the parking lot functions as a hub.

Penn Station in Midtown Manhattan, New York City, the busiest transportation hub in the Western Hemisphere.

Historically, an **interchange service** in the scheduled passenger air transport industry involved a "through plane" flight operated by two or more airlines where a single aircraft was used with the individual airlines operating it with their own flight crews on their respective portions of a direct, no-change-of-plane multi-stop flight. In the U.S., a number of air carriers including Alaska Airlines, American Airlines, Braniff International Airways, Continental Airlines, Delta Air Lines, Eastern Airlines, Frontier Airlines (1950-1986), Hughes Airwest, National Airlines (1934-1980), Pan Am, Trans World Airlines (TWA), United Airlines and Western Airlines previously operated such cooperative "through plane" interchange flights on both domestic and/or international services with these schedules appearing in their respective system timetables.[1][2]

Delta Air Lines pioneered the hub and spoke system for aviation in 1955 from its hub in Atlanta, Georgia, United States,[3] in an effort to compete with Eastern Air Lines. FedEx adopted the hub and spoke model for overnight package delivery during the 1970s. When the United States airline industry was deregulated in 1978, Delta's hub and spoke paradigm was adopted by several airlines. Many airlines around the world operate hub-and-spoke systems facilitating passenger connections between their respective flights.


Underground bus and coach terminal and metro station are located underneath the Kamppi Center in Helsinki, Finland

Contents

Public transport

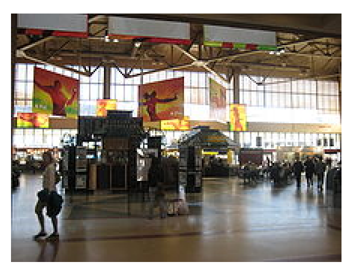
Intermodal passenger transport hubs in public transport include bus stations, railway stations and metro stations, while a major transport hub, often multimodal (bus and rail), may be referred to as a **transport centre** or, in American English, as a **transit center**.[4] Sections of city streets that are devoted to functioning as transit hubs are referred to as transit malls. In cities with a central station, that station often also functions as a transport hub in addition to being a railway station.


Szczecin: Port of Szczecin, motorway, expressway and railway connections, an inter-city public transport, a city bus and electric trams network and "Solidarity" Szczecin–Goleniów Airport, Poland

Journey planning involving transport hubs is more complicated than direct trips, as journeys will typically require a transfer at the hub. Modern electronic journey planners for public transport have a digital representation of both the stops and transport hubs in a network, to allow them to calculate journeys that include transfers at hubs.

Airports

Airports have a twofold hub function. First they concentrate passenger traffic into one place for onward transportation. This makes it important for airports to be connected to the surrounding transport infrastructure, including roads, bus services, and railway and rapid transit systems. Secondly some airports function as intra-modular hubs for the airlines, or airline hubs. This is a common strategy among network airlines who fly only from limited number of airports and usually will make their customers change planes at one of their hubs if they want to get between two cities the airline doesn't fly directly between.


South Station, a MBTA, Amtrak and Greyhound transportation hub in Boston, Massachusetts, United States

Airlines have extended the hub-and-spoke model in various ways. One method is to create additional hubs on a regional basis, and to create major routes between the hubs. This reduces the need to travel long distances between nodes that are close together. Another method is to use focus cities to implement point-to-point service for high traffic routes, bypassing the hub entirely.

Freight

DHL hub Leipzig/Halle Airport, Germany

There are usually three kinds of freight hubs: sea-road, sea-rail and road-rail, though they can also be sea-road-rail. With the growth of containerization, intermodal freight transport has become more efficient, often making multiple legs cheaper than through services—increasing the use of hubs.

In suburban Toronto, Finch Station connects underground train, local, regional, and interregional bus services.

See also

- Central station
- Infrastructure security
- Intermodal journey planner
- Junction (traffic)
- Layover
- Spoke-hub distribution paradigm

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