Road

Construction, Infrastructure and Technology

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Chapter 1

Introduction to Road Construction

Road construction requires the creation of a continuous right-of-way, overcoming geographic obstacles and having grades low enough to permit vehicle or foot travel and may be required to meet standards set by law or official guidelines. The process is often begun with the removal of earth and rock by digging or blasting, construction of embankments, bridges and tunnels, and removal of vegetation (this may involve deforestation) and followed by the laying of pavement material. A variety of road building equipment is employed in road building.

After design, approval, planning, legal and environmental considerations have been addressed alignment of the road is set out by a surveyor. The Radii and gradient are designed and staked out to best suit the natural ground levels and minimize the amount of cut and fill.

Roadways are designed and built for primary use by vehicular and pedestrian traffic. Storm drainage and environmental considerations are a major concern. Erosion and sediment controls are constructed to prevent detrimental effects. Drainage lines are laid with sealed joints in the road easement with runoff coefficients and characteristics adequate for the land zoning and storm water system. Drainage systems must be capable of carrying the ultimate design flow from the upstream catchment with approval for the outfall from the appropriate authority to a watercourse, creek, river or the sea for drainage discharge.

A road being torn up

Surveyor at work with a leveling instrument

Asphalt layer and roller

Sub-base layer composed of cement-based material being applied during construction of the M8 motorway in Ireland.

A borrow pit (source for obtaining fill, gravel, and rock) and a water source should be located near or in reasonable distance to the road construction site. Approval from local authorities may be required to draw water or for working (crushing and screening) of materials for construction needs. The top soil and vegetation is removed from the borrow pit and stockpiled for subsequent rehabilitation of the extraction area. Side slopes in the excavation area not steeper than one vertical to two horizontal for safety reasons.

Road construction on Marquette Avenue in Minneapolis, Minnesota, United States

Old road surfaces, fences, and buildings may need to be removed before construction can begin. Trees in the road construction area may be marked for retention. These protected trees should not have the topsoil within the area of the tree's drip line removed and the area should be kept clear of construction material and equipment. Compensation or replacement may be required if a protected tree is damaged. Much of the vegetation may be mulched and put aside for use during reinstatement. The topsoil is usually stripped and stockpiled nearby for rehabilitation of newly constructed embankments along the road. Stumps and roots are removed and holes filled as required before the earthwork begins. Final rehabilitation after road construction is completed will include seeding, planting, watering and other activities to reinstate the area to be consistent with the untouched surrounding areas.

Processes during earthwork include excavation, removal of material to spoil, filling, compacting, construction and trimming. If rock or other unsuitable material is discovered it is removed, moisture content is managed and replaced with standard fill compacted to 90% relative compaction. Generally blasting of rock is discouraged in the road bed. When a depression must be filled to come up to the road grade the native bed is compacted after the topsoil has been removed. The fill is made by the "compacted layer method" where a layer of fill is spread then compacted to specifications, the process is repeated until the desired grade is reached.

Typical pavement strata for a heavily traveled road

General fill material should be free of organics, meet minimum California bearing ratio (CBR) results and have a low plasticity index. The lower fill generally comprises sand or

a sand-rich mixture with fine gravel, which acts as an inhibitor to the growth of plants or other vegetable matter. The compacted fill also serves as lower-stratum drainage. Select second fill (sieved) should be composed of gravel, decomposed rock or broken rock below a specified Particle size and be free of large lumps of clay. Sand clay fill may also be used. The road bed must be "proof rolled" after each layer of fill is compacted. If a roller passes over an area without creating visible deformation or spring the section is deemed to comply.

The completed road way is finished by paving or left with a gravel or other natural surface. The type of road surface is dependent on economic factors and expected usage. Safety improvements like Traffic signs, Crash barriers, Raised pavement markers, and other forms of Road surface marking are installed.

According to a May 2009 report by the American Association of State Highway and Transportation Officials (AASHTO) and TRIP—a national transportation research organization—driving on rough roads costs the average American motorist approximately $400 a year in extra vehicle operating costs. Drivers living in urban areas with populations more than 250,000 are paying upwards of $750 more annually because of accelerated vehicle deterioration, increased maintenance, additional fuel consumption, and tire wear caused by poor road conditions.

When a single carriageway road is converted into dual carriageway by building a second separate carriageway alongside the first, it is usually referred to as *duplication*, *twinning* or *doubling*. The original carriageway is changed from two-way to become one-way, while the new carriageway is one-way in the opposite direction. In the same way as converting railway lines from single track to double track, the new carriageway is not always constructed directly alongside the existing carriageway.

Maintenance

Like all structures, roads deteriorate over time. Deterioration is primarily due to accumulated damage from vehicles, however environmental effects such as frost heaves, thermal cracking and oxidation often contribute. According to a series of experiments carried out in the late 1950s, called the AASHO Road Test, it was empirically determined that the effective damage done to the road is roughly proportional to the 4th power of axle weight. A typical tractor-trailer weighing 80,000 pounds (36.287 t) with 8,000 pounds (3.6287 t) on the steer axle and 36,000 pounds (16.329 t) on both of the tandem axle groups is expected to do 7,800 times more damage than a passenger vehicle with 2,000 pounds (0.907 t) on each axle. Potholes on roads are caused by rain damage and vehicle braking or related construction works.

Pavements are designed for an expected service life or design life. In some UK countries the standard design life is 40 years for new bitumen and concrete pavement. Maintenance is considered in the whole life cost of the road with service at 10, 20 and 30 year milestones. Roads can be and are designed for a variety of lives (8-, 15-, 30-, and 60-year designs). When pavement lasts longer than its intended life, it may have been overbuilt, and the original costs may have been too high. When a pavement fails before its intended design life, the owner may have excessive repair and rehabilitation costs. Many concrete pavements built since the 1950s have significantly outlived their intended design lives. Some roads like Chicago, Illinois's "Wacker Drive", a major two-level viaduct in downtown area are being rebuilt with a designed service life of 100 years.

Virtually all roads require some form of maintenance before they come to the end of their service life. Pro-active agencies continually monitor road conditions and apply preventive maintenance treatments as needed to prolong the lifespan of their roads. Technically advanced agencies monitior the road network surface condition with sophisticated

equipment such as laser/inertial Profilometers. These measurements include road curvature, cross slope, asperity, roughness, rutting and texture (roads). This data is fed into a pavement management system, which recommends the best maintenance or construction treatment to correct the damage that has occurred.

Maintenance treatments for asphalt concrete generally include crack sealing, surface rejuvenating, fog sealing, micro-milling and surface treatments. Thin surfacing preserves, protects and improves the functional condition of the road while reducing the need for routing maintenance, leading to extended service life without increasing structural capacity.

Failure to maintain roads properly can create significant costs to society, in a 2009 report released by the American Association of State Highway and Transportation Officials (USA) about 50% of the roads in the USA are in bad condition with urban areas worse. The report estimates that urban drivers pay an average of $746/year on vehicle repairs while the average US motorist pays about $335/year. In contrast, the average motorist pays about $171/year in road maintenance taxes (based on 600 gallons/year and $0.285/gallon tax).

Slab Stabilization

Distress and serviceability loss on concrete roads can be caused by loss of support due to voids beneath the concrete pavement slabs. The voids usually occur near cracks or joints due to surface water infiltration. The most common causes of voids are pumping, consolidation, subgrade failure and bridge approach failure. Slab stabilization is a non-destructive method of solving this problem and is usually employed with other Concrete Pavement Restoration (CPR) methods including patching and diamond grinding. The technique restores support to concrete slabs by filing small voids that develop underneath the concrete slab at joints, cracks or the pavement edge. The process consists of pumping a cementitous grout or polyurethane mixture through holes drilled through the slab. The grout can fill small voids beneath the slab and/or sub-base. The grout also displaces free water and helps keep water from saturating and weakening support under the joints and slab edge after stabilization is complete. The three steps for this method after finding the voids are locating and drilling holes, grout injection and post-testing the stabilized slabs.

Slab stabilization does not correct depressions, increase the design structural capacity, stop erosion or eliminate faulting. It does, however, restore the slab support, therefore, decreasing deflections under the load. Stabilization should only be performed at joints and cracks where loss of support exists. Visual inspection is the simplest manner to find voids. Signs that repair is needed are transverse joint faulting, corner breaks and shoulder drop off and lines at or near joints and cracks. Deflection testing is another common procedure utilized to locate voids. It is recommended to do this testing at night as during cooler temperatures, joints open, aggregate interlock diminishes and load deflections are at their highest.

Another testing method is ground penetrating radar. It pulses electromagnetic wave technology into the pavement and then ceases the transmission during which the transmitter-receiver detects signals that are deflected from the pavement. Yet another method is the epoxy/core test, which confirms void presence by visual and mechanical methods. It consists of drilling a 25 to 50 millimeter hole through the pavement and into the sub-base with a dry-bit roto-hammer. Next, a two-part epoxy is poured into the hole that is dyed for visual clarity. Once the epoxy is hardened, the technicians drill through the hole. If a void is present, the epoxy will stick to the core and provide physical evidence.

Common stabilization materials are pozzolan-cement grout and polyurethane. The requirements for slab stabilization are strength and the ability to flow into or expand to fill small voids. Colloidal mixing equipment is necessary to use the pozzolan-cement grouts. The contractor should place the grout using a positive-displacement injection pump or a non-pulsing progressive cavity pump. A drill is also necessary but it must produce a clean hole with no surface spalling or breakouts. The injection devices must include a grout packer that is capable of sealing a hole. The injection device must also have a return hose or a fast-control reverse switch in case workers detect slab movement on the uplift gauge. The uplift beam helps to monitor the slab deflection and has to have sensitive dial gauges.

Joint Sealing

Also called joint and crack repair, this method's purpose is to minimize infiltration of surface water and incompressible material into the joint system. Joint sealants are also used to reduce dowel bar corrosion in Concrete Pavement Restoration (CPR) techniques. Successful resealing consists of old sealant removal, shaping and cleaning the reservoir, installing the backer rod and installing the sealant. Sawing, manual removal, plowing and cutting are methods used to remove the old sealant. Saws are used to shape the reservoir. When cleaning the reservoir, no dust, dirt or traces of old sealant should remain. Thus, it is recommended to water wash, sand-blast and then air blow to remove any sand, dirt or dust. The backer rod installation requires a double-wheeled, steel roller to insert the rod to the desired depth. After inserting the backer rod, the sealant is placed into the joint. There are various materials to choose for this method including hot pour bituminous liquid, silicone and preformed compression seals.

Safety considerations

Pedestrian crossing, line markings and street furniture

Careful design and construction of roads can increase Road traffic safety and reduce the harm (deaths, injuries, and property damage) on the highway system from traffic collisions.

On neighborhood roads traffic calming, safety barriers, pedestrian crossings and cycle lanes can all protect pedestrians and cyclists.

Lane markers in some countries and states are marked with Cat's eyes or Botts dots, bright reflectors that do not fade like paint. Botts dots are not used where it is icy in the winter, because frost and snowplows can break the glue that holds them to the road, although they can be embedded in short, shallow trenches carved in the roadway, as is done in the mountainous regions of California.

For major roads risk can be reduced by providing limited access from properties and local roads, grade separated junctions and median dividers between opposite-direction traffic to reduce likelihood of head-on collisions.

The placement of energy attenuation devices (e.g. guardrails, wide grassy areas, sand barrels) is also common. Some road fixtures such as road signs and fire hydrants are designed to collapse on impact. Light poles are designed to break at the base rather than violently stop a car that hits them. Highway authorities may also remove larger trees from the immediate vicinity of the road.

Environmental performance

Air pollution along Pasadena Highway in Los Angeles, United States

Careful design and construction of a road can reduce any negative environmental impacts.

Water management systems can be used to reduce the effect of pollutants from roads. Rainwater and snowmelt running off of roads tends to pick up gasoline, motor oil, heavy metals, trash and other pollutants and result in Water pollution. Road runoff is a major source of nickel, copper, zinc, cadmium, lead and polycyclic aromatic hydrocarbons (PAHs), which are created as combustion byproducts of gasoline and other fossil fuels. De-icing chemicals and sand can run off into roadsides, contaminate groundwater and pollute surface waters; and road salts can be toxic to sensitive plants and animals. Sand applied to icy roads can be ground up by traffic into fine particulates and contribute to air

pollution. Sand can alter stream bed environments, causing stress for the plants and animals that live there.

Roadways are a chief source of environmental noise generation. In the early 1970s it was recognized that design of roads can be conducted to influence and minimize noise generation. Noise barriers are used to reduce Noise pollution, in particular where roads are located close to built-up areas. Regulations can restrict the use of Engine braking.

Motor vehicle emissionss contribute air pollution. Concentrations of air pollutants and adverse respiratory health effects are greater near the road than at some distance away from the road. Road dust kicked up by vehicles may trigger allergic reactions.

Regulation

Right- and left-hand traffic

Traffic flows on the right or on the left side of the road depending on the country. In countries where traffic flows on the right, traffic signs are mostly on the right side of the road, roundabouts and traffic circles go counter-clockwise/anti-clockwise, and pedestrians crossing a two-way road should watch out for traffic from the left first. In countries where traffic flows on the left, the reverse is true.

About 33% of the world by population drive on the left, and 67% keep right. By roadway distances, about 28% drive on the left, and 72% on the right, even though originally most traffic drove on the left worldwide.

Economics

A city street in Mumbai, India with left-hand traffic

Transport economics is used to understand both the relationship between the transport system and the wider economy and the complex network effects when there are multiple paths and competing modes for both personal and freight (road/rail/air/ferry) and where Induced demand can result in increased on decreased transport levels when road provision is increased by building new roads or decreased (for example California State Route 480). Roads are generally built and maintained by the public sector using taxation although implementation may be through private contractors). or occasionally using road tolls.

Economics and society depend heavily on efficient roads. In the European Union (EU) 44% of all goods are moved by trucks over roads and 85% of all persons are transported by cars, buses or coaches on roads. The term was also commonly used to refer to roadsteads, waterways that lent themselves to use by shipping.

Construction costs

According to www.nysthruway.gov, some typical costs to construct roads in several USA states include: CONSTRUCTION COST Expressway Section Per-Mile Cost Connecticut Turnpike $3,449,000 New Jersey Turnpike $2,200,000 Pennsylvania Turnpike (Delaware Extension) $1,970,000 Northern Indiana Toll Road $1,790,000 Garden State Parkway $1,720,000 Massachusetts Turnpike $1,600,000 Thruway, New York to Pennsylvania Line $1,547,000 Ohio Turnpike $1,352,000 Pennsylvania Turnpike (early construction) $736,000

Statistics

The United States has the largest network of roadways of any country with 6,430,366 kilometres (3,995,644 mi) (2005). The People's Republic of China is second with 3,583,715 kilometres (2,226,817 mi) of roadway (2007). The Republic of India has the third largest road system in the world with 3,383,344 kilometres (2,102,312 mi) (2002). When looking only at expressways the National Trunk Highway System (NTHS) in People's Republic of China has a total length of 45,000 kilometres (28,000 mi) at the end of 2006, and 60,300 km at the end of 2008, second only to the United States with 90,000 kilometres (56,000 mi) in 2005.

Chapter 2

Asphalt Concrete

Asphalt concrete.

As shown in this cross-section, many older roadways are smoothed by applying a thin layer of **asphalt concrete** to the existing portland cement concrete.

A layer of asphalt concrete. In road construction, a base layer of crushed rock is usually laid down first to increase durability

Machine laying asphalt concrete, fed from a dump truck

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of asphalt (used as a binder) and mineral aggregate mixed together, then laid down in layers and compacted.

The terms "asphalt (or asphaltic) concrete", "bituminous asphalt concrete" and the abbreviation "AC" are typically used only in engineering and construction documents and literature. Asphalt concrete pavements are often called just "asphalt" by laypersons who tend to associate the term concrete with Portland cement concrete only. The engineering definition of concrete is any composite material composed of mineral aggregate glued together with a binder, whether that binder is Portland cement, asphalt or even epoxy. Informally, asphalt concrete is also referred to as "blacktop", particularly in North America.

Mixture formulations

Mixing of asphalt and aggregate is accomplished in one of several ways:

- **Hot mix asphalt concrete** (commonly abbreviated as HMAC or HMA) is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at about 300 °F (roughly 150 °C) for virgin asphalt and 330 °F (166 °C) for polymer modified asphalt, and the asphalt cement at 200 °F (95 °C). Paving and compaction must be performed while the asphalt is

sufficiently hot. In many countries paving is restricted to summer months because in winter the compacted base will cool the asphalt too much before it is packed to the optimal air content. HMAC is the form of asphalt concrete most commonly used on highly trafficked pavements such as those on major highways, racetracks and airfields.

- **Warm mix asphalt concrete** (commonly abbreviated as WMA or WAM) is produced by adding either zeolites, waxes, or asphalt emulsions to the mix. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols and vapours. Not only are working conditions improved, but the lower laying-temperature also leads to more rapid availability of the surface for use, which is important for construction sites with critical time schedules. The usage of these additives in hot mixed asphalt (above) may afford easier compaction and allow cold weather paving or longer hauls.
- **Cold mix asphalt concrete** is produced by emulsifying the asphalt in water with (essentially) soap prior to mixing with the aggregate. While in its emulsified state the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of cold HMAC. Cold mix is commonly used as a patching material and on lesser trafficked service roads.
- **Cut-back asphalt concrete** is produced by dissolving the binder in kerosene or another lighter fraction of petroleum prior to mixing with the aggregate. While in its dissolved state the asphalt is less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates.
- **Mastic asphalt concrete** or sheet asphalt is produced by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid after which the aggregate mix is then added.

  The bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the mastic asphalt mixer is transported to the work site where experienced layers empty the mixer and either machine or hand lay the mastic asphalt contents on to the road. Mastic asphalt concrete is generally laid to a thickness of around ¾–1 3⁄16 inches (20-30 mm) for footpath and road applications and around ⅜ of an inch (10 mm) for flooring or roof applications.
  In addition to the asphalt and aggregate, additives, such as polymers, and antistripping agents may be added to improve the properties of the final product.

- **Natural asphalt concrete** can be produced from bituminous rock, found in some parts of the world, where porous sedimentary rock near the surface has been impregnated with upwelling bitumen.

A landing strip, one of the uses of asphalt concrete

Asphalt concrete is often touted as being *100% recyclable*. Several in-place recycling techniques have been developed to rejuvenate oxidized binders and remove cracking, although the recycled material is generally not very water-tight or smooth and should be overlaid with a new layer of asphalt concrete. Asphalt concrete that is removed from a pavement is usually stockpiled for later use as a base course material. This reclaimed material, commonly known by the acronym 'RAP' for recycled or reclaimed asphalt pavement, is crushed to a consistent gradation and added to the HMA mixing process. Very little asphalt concrete is actually disposed of in landfills. Sometimes waste materials, such as rubber from old tires, are added to asphalt concrete as is the case with rubberized asphalt, but there is a concern that the hybrid material may not be recyclable.

Asphalt damaged by cryoturbation, or freezing of groundwater

Asphalt deterioration can include alligator cracks, potholes, upheaval, raveling, rutting, shoving, stripping, and grade depressions. In cold climates, freezing of the groundwater underneath can crack asphalt even in one winter (by cryoturbation). Filling the cracks with bitumen can temporarily fix the cracks, but only proper construction, i.e. allowing water to drain away from under the road, can slow this process.

Asphalt concrete pavements—especially those at airfields—are sometimes called tarmac for historical reasons, although they do not contain tar and are not constructed using the macadam process.

Performance characteristics

Asphalt concrete has different performance characteristics in terms of surface durability, tire wear, braking efficiency and roadway noise. The appropriate asphalt performance characteristic is obtained by the traffic level amount in categories A,B,C,D,E, and friction coarse (FC-5). Asphalt concrete generates less roadway noise than Portland cement concrete surfacing, and is typically less noisy than chip seal surfaces. Tire noise effects are amplified at higher operating speeds. The sound energy is generated through rolling friction converting kinetic energy to sound waves. The idea that highway design could be

influenced by acoustical engineering considerations including selection of surface paving types arose in the very early 1970s

Asphalt

A layer of asphalt concrete paving

The primary use of asphalt is in road construction, where it is used as the glue or binder for the aggregate particles.

Asphalt (or Bitumen) is a sticky, black and highly viscous liquid or semi-solid that is present in most crude petroleums and in some natural deposits. Until the 20th century, the term **asphaltum** was also used. It is most commonly modelled as a colloid, with *asphaltenes* as the dispersed phase and *maltenes* as the continuous phase (though there is some disagreement amongst chemists regarding its structure). One writer states that although a "considerable amount of work has been done on the composition of asphalt, it is exceedingly difficult to separate individual hydrocarbon in pure form", and "it is

almost impossible to separate and identify all the different molecules of asphalt, because the number of molecules with different chemical structure is extremely large".

In American English, asphalt (or asphalt cement) is the carefully refined residue from the distillation process of selected crude oils. Outside the U.S., the product is often called bitumen. Natural deposits terminology also sometimes uses the word bitumen, such as at the La Brea Tar Pits.

Etymology

The word *asphalt* is derived from the late Middle English : from French *asphalte*, based on Late Latin *asphalton*, *asphaltum*, which is the romanization of the Greek *ásphalton*, *ásphaltos* (*ἄσφαλτος*), a word meaning "asphalt/bitumen/pitch" which some derive from α- "without" and σφάλλω, (*sfallō*), "to make fall". Note that in French, the term *asphalte* is used for naturally occurring bitumen-soaked limestone deposits, and for specialised manufactured products with fewer voids or greater bitumen content than the "asphaltic concrete" used to pave roads. Another description has it that the term derives from the Accadian term "asphaltu" or "sphallo," meaning "to split." It was later adopted from the Homeric Greeks as a verb meaning "to make firm or stable," "to secure". It is a significant fact that the first use of asphalt by the ancients was in the nature of a cement for securing or joining together various objects, and it thus seems likely that the name itself was expressive of this application. From the Greek, the word passed into late Latin, and thence into French ("asphalte") and English ("asphaltum" and "asphalt"). The expression "bitumen" originated in the Sanskrit, where we find the words "jatu," meaning "pitch," and "jatu-krit," meaning "pitch creating," "pitch producing" (referring to coniferous or resinous trees). The Latin equivalent is claimed by some to be originally 'gwitu-men' (pertaining to pitch), and by others, "pixtumens" (exuding or bubbling pitch), which was subsequently shortened to "bitumen," thence passing via French into English. From the same root is derived the Anglo Saxon word "cwidu" (Mastix), the German word "Kitt" (cement or mastic) and the old Norse word "kvada".

Modern usage

In British English, the word 'asphalt' refers to a mixture of mineral aggregate and bitumen (or tarmac in common parlance). The earlier word 'asphaltum' is now archaic and not commonly used. In American English, 'asphalt' is equivalent to the British 'bitumen'. However, 'asphalt' is also commonly used as a shortened form of 'asphalt concrete' (therefore equivalent to the British 'tarmac'). In Australian English, bitumen is sometimes used as the generic term for road surfaces. In Canadian English, the word bitumen is used to refer to the vast Canadian deposits of extremely heavy crude oil, while asphalt is used for the oil refinery product used to pave roads and manufacture roof shingles. Diluted bitumen (diluted with naphtha to make it flow in pipelines) is known as dilbit in the Canadian petroleum industry, while bitumen "upgraded" to synthetic crude oil is known as syncrude and syncrude blended with bitumen as *synbit*.

Background

Asphalt in use for resurfacing of Francisco Delandes Avenue, in Belo Horizonte, Brazil.

Asphalt being used to pave a street in Poá - SP - Brazil.

Asphalt or bitumen can sometimes be confused with tar, which is a similar black thermo-plastic material produced by the destructive distillation of coal. During the early- and mid-20th century when town gas was produced, tar was a readily available product and extensively used as the binder for road aggregates. The addition of tar to macadam roads led to the word tarmac, which is now used in common parlance to refer to road making materials. However, since the 1970s, when natural gas succeeded town gas, asphalt (bitumen) has completely overtaken the use of tar in these applications.

Asphalt can be separated from the other components in crude oil (such as naphtha, gasoline and diesel) by the process of fractional distillation, usually under vacuum conditions. A better separation can be achieved by further processing of the heavier fractions of the crude oil in a de-asphalting unit, which uses either propane or butane in a supercritical phase to dissolve the lighter molecules which are then separated. Further processing is possible by "blowing" the product: namely reacting it with oxygen. This makes the product harder and more viscous.

Natural deposits of asphalt include lake asphalts (primarily from the Pitch Lake in Trinidad and Tobago and Lake Bermudez in Venezuela), Gilsonite, the Dead Sea, and Tar Sands. Asphalt was mined at Ritchie Mines in Macfarlan in Ritchie County, West Virginia in the United States from 1852 to 1873.

Asphalt is typically stored and transported at temperatures around 150 degrees Celsius (300 °F). Sometimes diesel oil or kerosene are mixed in before shipping to retain

liquidity; upon delivery, these lighter materials are separated out of the mixture. This mixture is often called **bitumen feedstock**, or BFS. Some dump trucks route the hot engine exhaust through pipes in the dump body to keep the material warm. The backs of tippers carrying asphalt, as well as some handling equipment, are also commonly sprayed with a releasing agent before filling to aid release. Diesel oil is sometimes used as a release agent, although it can mix with and thereby reduce the quality of the asphalt.

Known uses

Ancient times

In the ancient Middle East, natural asphalt deposits were used for mortar between bricks and stones, to cement parts of carvings, such as eyes, into place, for ship caulking, and for waterproofing. The Persian word for asphalt is *moom*, which is related to the English word mummy. Asphalt was also used by ancient Egyptians to embalm mummies. In the ancient Far East, natural asphalt was slowly boiled to get rid of the higher fractions, leaving a material of higher molecular weight which is thermoplastic and when layered on objects, became quite hard upon cooling. This was used to cover objects that needed waterproofing, such as scabbards and other items. Statuettes of household deities were also cast with this type of material in Japan, and probably also in China.

In North America, archaeological recovery has indicated that asphaltum was sometimes used to apply stone projectile points to a wooden shaft.

Early use in Europe

Bituminous outcrop of the Puy de la Poix, Clermont-Ferrand, France

An 1838 edition of *Mechanics Magazine* cites an early use of asphalt in France. A pamphlet dated 1621, by "a certain Monsieur d'Eyrinys, states that he had discovered the existence (of asphaltum) in large quantities in the vicinity of Neufchatel", and that he proposed to use it in a variety of ways - "principally in the construction of air-proof granaries, and in protecting, by means of the arches, the water-courses in the city of Paris from the intrusin of dirt and filth", which at that time made the water unusable. "He expatiates also on the excellence of this material for forming level and durable terraces" in palaces, "the notion of forming such terraces in the streets not one likely to cross the brain of a Parisian of that generation". But it was generally neglected in France until the

revolution of 1830. Then, in the 1830s, there was a surge of interest, and asphalt became widely used "for pavements, flat roofs, and the lining of cisterns, and in England, some use of it had been made of it for similar purposes". Its rise in Europe was "a sudden phenomenon", after natural deposits were found "in France at Osbann (BasRhin), the Parc (l'Ain) and the Puy-de-la-Poix (Puy-de-Dome)", although it could also be made artificially. One of the earliest uses in France was the laying of about 24,000 square yards of Seyssel asphalt at the Place de la Concorde in 1835.

Early use in the United Kingdom

Among the earlier uses of asphalt in the United Kingdom, was for etching. William Salmon's *Polygraphice* (1673) provides a recipe for varnish used in etching, consisting of three ounces of virgin wax, two ounces of mastic, and one ounce of asphaltum. By the fifth edition in 1685, he had included more asphaltum recipes from other sources.

The first British patent for the use of asphalt was 'Cassell's patent asphalte or bitumen' in 1834. Then on 25 November 1837, Richard Tappin Claridge patented the use of Seyssel asphalt (patent #7849), for use in asphalte pavement, having seen it employed in France and Belgium when visiting with Frederick Walter Simms, who worked with him on the introduction of asphalt to Britain. Dr T. Lamb Phipson claims that his father, Samuel Ryland Phipson, a friend of Claridge, was also "instrumental in introducing the asphalte pavement (in 1836)". Indeed, mastic pavements had been previously employed at Vauxhall by a competitor of Claridge, but without success.

In 1838, Claridge obtained patents in Scotland on 27 March, and Ireland on 23 April, and in 1851 extensions were sought for all three patents, by the trustees of a company previously formed by Claridge. This was *Claridge's Patent Asphalte Company*, formed in 1838 for the purpose of introducing to Britain "Asphalte in its natural state from the mine at Pyrimont Seysell in France", and "laid one of the first asphalt pavements in Whitehall". Trials were made of the pavement in 1838 on the footway in Whitehall, the stable at Knightsbridge Barracks, "and subsequently on the space at the bottom of the steps leading from Waterloo Place to St. James Park". "The formation in 1838 of Claridge's Patent Asphalte Company (with a distinguished list of aristocratic patrons, and Marc and Isambard Brunel as, respectively, a trustee and consulting engineer), gave an enormous impetus to the development of a British asphalt industry". "By the end of 1838, at least two other companies, Robinson's and the Bastenne company, were in production", with asphalt being laid as paving at Brighton, Herne Bay, Canterbury, Kensington, the Strand, and a large floor area in Bunhill-row, while meantime Claridge's Whitehall paving "continue(d) in good order".

Indeed in 1838, there was a flurry of entrepreneurial activity over asphalt, which had uses beyond paving. For example, asphalt could also used for flooring, damp proofing in buildings, and for waterproofing of various types of pools and baths, with these latter themselves proliferating in the 19th century. On the London stockmarket, there were various claims as to the exclusivity of asphalt quality from France, Germany and England. And numerous patents were granted in France, with similar numbers of patent

applications being denied in England due to their similarity to each other. In England, "Claridge's was the type most used in the 1840s and 50s"

In 1914, Claridge's Company entered into a joint venture to produce tar-bound macadam, with materials manufactured through a subsidiary company called Clarmac Roads Ltd. Two products resulted, namely *Clarmac*, and *Clarphalte*, with the former being manufactured by Clarmac Roads and the latter by Claridge's Patent Asphalte Co., although *Clarmac* was more widely used. However, the First World War impacted financially on the Clarmac Company, which entered into liquidation in 1915. The failure of Clarmac Roads Ltd had a flow-on effect to Claridge's Company, which was itself compulsorily wound up, ceasing operations in 1917, having invested a substantial amount of funds into the new venture, both at the outset, and in a subsequent attempt to save the Clarmac Company.

Early use in the United States

The first use of asphaltum in the New World was by indigenous tribes. On the west coast, as early as the 13th century, the Tongva and Chumash Nations collected the naturally occurring asphaltum that seeped to the surface above underlying petroleum deposits. Both tribes used the substance as an adhesive. It is found on many different artifacts of tools and ceremonial items. For example, it was used on rattles to adhere gourds or turtle shells to rattle handles. It was also used in decorations. Small round shell beads were often set in asphaltum to provide decorations. It was used as a sealant on baskets to make them water tight for carrying water. Asphaltum was used also to seal the planks on ocean-going canoes.

Roads in the US have been paved with asphalt since at least 1870, when a street in front of Newark, NJ's City Hall was paved. In 1876, asphalt was used to pave Pennsylvania Avenue in Washington, DC, in time for the celebration of the national centennial. Asphalt was also used for flooring, paving and waterproofing of baths and swimming pools during the early 20th century, following similar trends in Europe.

Rolled asphalt concrete

The largest use of asphalt is for making asphalt concrete for road surfaces and accounts for approximately 85% of the asphalt consumed in the United States. Asphalt pavement material is commonly composed of 5 percent asphalt cement and 95 percent aggregates (stone, sand, and gravel). Due to its highly viscous nature, asphalt cement must be heated so that it can be mixed with the aggregates at the asphalt mixing plant. There are about 4,000 asphalt mixing plants in the U.S.

Asphalt road surface is the most widely recycled material in the US, both by gross tonnage and by percentage. According to a report issued by the Federal Highway Administration and the United States Environmental Protection Agency, 80% of the asphalt removed each year from road surfaces during widening and resurfacing projects is reused as part of new roads, roadbeds, shoulders and embankments.

Roofing shingles account for most of the remaining asphalt consumption. Other uses include cattle sprays, fence post treatments, and waterproofing for fabrics.

Asphalt is widely used in airports around the world. Due to the sturdiness, it is widely used for runways dedicated to aircraft landing and taking off.

Mastic asphalt

Mastic asphalt is a type of asphalt which differs from dense graded asphalt (asphalt concrete) in that it has a higher bitumen (binder) content, usually around 7–10% of the whole aggregate mix, as opposed to rolled asphalt, which has only around 5% added bitumen. This thermoplastic substance is widely used in the building industry for waterproofing flat roofs and tanking underground. Mastic asphalt is heated to a temperature of 210 °C (410 °F) and is spread in layers to form an impervious barrier about 20 millimeters (0.8 in) thick.

Asphalt emulsion

A number of technologies allow asphalt to be mixed at much lower temperatures. These involve mixing the asphalt with petroleum solvents to form "cutbacks" with reduced melting point or mixtures with water to turn the asphalt into an emulsion. Asphalt emulsions contain up to 70% asphalt and typically less than 1.5% chemical additives. There are two main types of emulsions with different affinity for aggregates, cationic and anionic. Asphalt emulsions are used in a wide variety of applications. Chipseal involves spraying the road surface with asphalt emulsion followed by a layer of crushed rock, gravel or crushed slag. Slurry Seal involves the creation of a mixture of asphalt emulsion and fine crushed aggregate that is spread on the surface of a road. Cold mixed asphalt can also be made from asphalt emulsion to create pavements similar to hot-mixed asphalt, several inches in depth and asphalt emulsions are also blended into recycled hot-mix asphalt to create low cost pavements.

Alternatives and bioasphalt

Certain activist groups have become increasingly concerned about the global peak oil and climate change problem in recent years due to by-products that are released into the atmosphere. Most of the emissions are derived primarily from burning fossil fuels. This has led to the introduction of petroleum bitumen alternatives that are more environmentally friendly and non-toxic.

Chapter 3

Road Roller

John Deere roller being used to compact the ground before placing concrete

An old diesel road roller

A **road roller** (sometimes called a *roller-compactor*, or just *roller*) is a compactor type engineering vehicle used to compact soil, gravel, concrete, or asphalt in the construction of roads and foundations, similar rollers are used also at landfills or in agriculture.

In some parts of the world, road rollers are still known colloquially as steam rollers, regardless of their method of propulsion. This typically only applies to the largest examples (used for road-making).

History

Horse-drawn road roller from 1800

Steam-powered roller

Zettelmeyer diesel road roller

The first road rollers were horse-drawn, and were probably just borrowed farm implements.

Since the effectiveness of a roller depends to a large extent on its weight, self-powered vehicles replaced horse-drawn rollers from the mid-19th century. The first such vehicles were steam rollers. Double-cylinder designs were preferred. Single-cylinder steam rollers were uncommon and unpopular, as the power impulses from the steam engine would produce slight waves in the road. Some road companies in the United States used steamrollers through the 1950s, and in the UK, some remained in commercial service until the early 1970s.


Horst Gedmann
60 Jahre
Limburg-Lahn.


RUTHEMEYER


RUTHEMEYER

As internal combustion engine technology improved during the 20th century, kerosene-, gasoline- (petrol), and diesel-powered rollers gradually replaced their steam-powered counterparts. The first internal-combustion powered road rollers were very similar to the steam rollers they replaced. They used similar mechanisms to transmit power from the engine to the wheels, typically large, exposed spur gears. Some companies did not like them in their infancy, as the engines of the era were typically difficult to start, particularly the kerosene-powered ones.

Virtually all road rollers in commercial use now use diesel power.

Uses

Road rollers use the weight of the vehicle to compress the surface being rolled. Initial compaction of the substrate is done using a **pneumatic-tyred roller**, with two rows (front and back) of pneumatic tyres. The flexibility of the tyres, with a certain amount of vertical movement of the wheels, enables the roller to operate effectively on uneven ground. The finish is done using metal-drum rollers to ensure a smooth, even result.

Rollers are also used in landfill compaction. Such compactors typically have knobbed ("sheeps-foot") wheels, and do not achieve a smooth surface. The knobs aid in compression due to the smaller area contacting the ground.


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Configurations

The roller can be a simple drum with a handle that is operated by one person, and weighs 100 pounds, or as large as a ride-on road roller weighing 21 short tons (44,000 lb or 20 tonnes) and costing more than US$150,000. A landfill unit can weigh 59 short tons (54 tonnes). On some machines the drums may be filled with water.

Roller Types

- Manual walk-behind
- Powered walk-behind (electric or diesel/gas powered)
- Trench roller (manual units or radio-frequency remote control)
- Ride-on
- Ride-on with knock-down bar
- Ride-on articulating-swivel
- Vibratory
- Pneumatic-tyre
- Tandem roller
- Tractor-mounted and -powered

Powered, vibrating walk-behind

Ride-on with articulating-swivel (small machine)

Ride-on with articulating-swivel (large machine)

Vibrating Dynapac CC232

A Caterpillar CS-533E vibratory roller.

Pneumatic roller

A road-roller powered by a tractor mounted on it from rural India

Road roller, museum, Tenterfield, NSW

Drum types

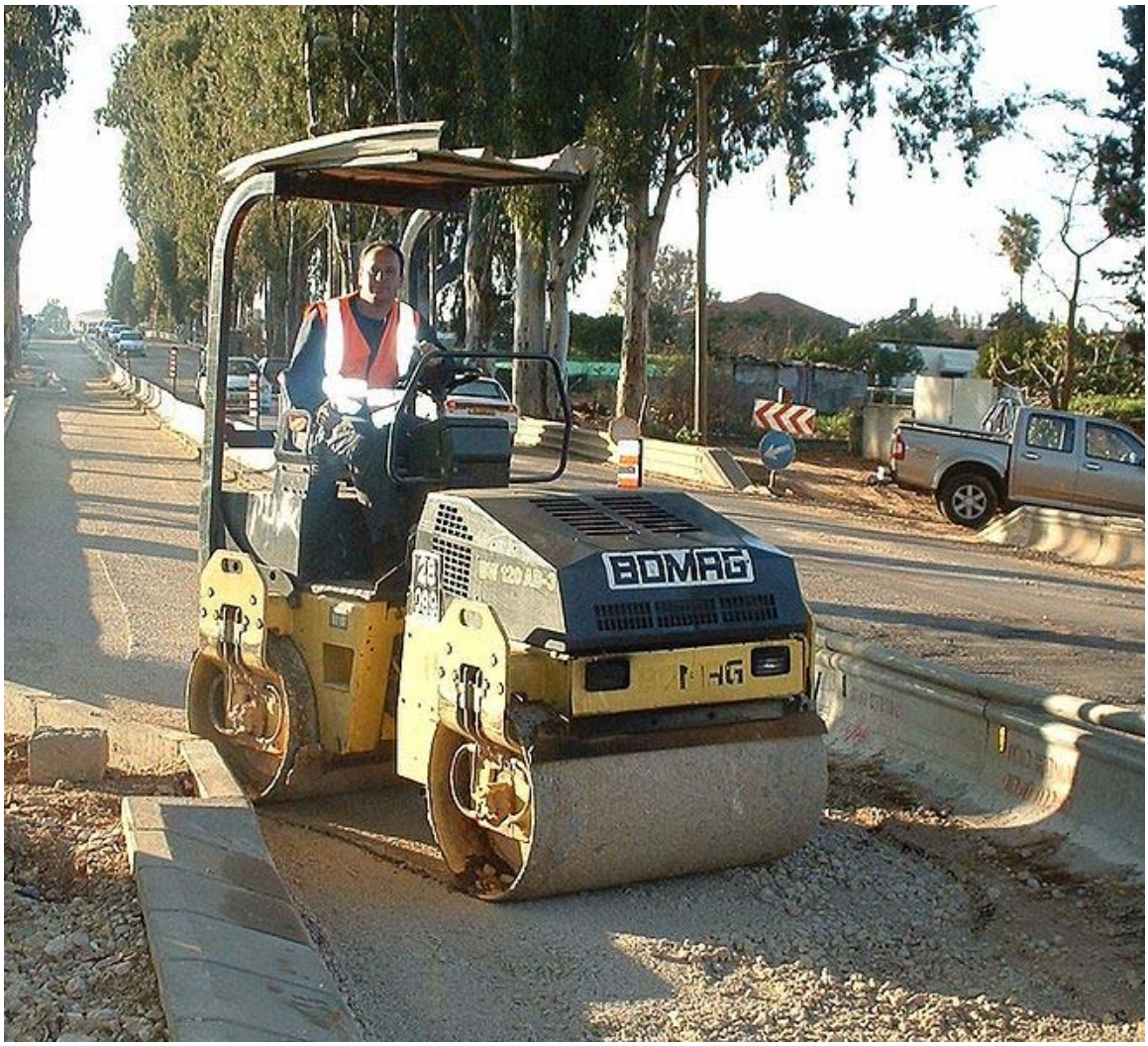
Drums come in various widths: 24-to-84 inches

- Single-drum sheeps/pad-foot (soil)
- Single-drum smooth (asphalt)
- Double-drum (duplex) sheeps/pad-foot (soil)
- Double-drum (duplex) smooth (asphalt)
- 3-wheel cleat with bulldozing blade (landfills)

Variations and features

- On some machines, the drums may be filled with water on site to achieve the desired weight. When empty, the lighter machine is easier and cheaper to transport between work sites.
- Additional compaction may be achieved by vibrating the roller drums, making a small, light machine perform as well as a much heavier one. Vibration is typically caused by a free-spinning hydrostatic motor inside the drum to whose shaft eccentric weights have been attached.

- Water lubrication may be provided to the drum surface to prevent (for example) hot asphalt sticking to the drum
- Hydraulic transmissions permit greater design flexibility, while early examples used direct mechanical drives; hydraulics reduce the number of moving parts exposed to contamination.
- Human-propelled rollers may only have a single roller drum.
- Self-propelled rollers may have two drums, mounted one in front of the other (format known as "duplex"), or three rolls, or just one, with the back rollers replaced with treaded pneumatic tyres for increased traction

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Manufacturers

- AGICO
- Aveling-Barford
- BOMAG
- Buffalo-Springfield Roller Company
- Case CE
- Caterpillar
- CORINSA
- CMI-Terex
- Dynapac (= Atlas Copco)
- Galion
- GEMCO
- Hamm
- Huber
- HYPAC
- Hyster
- Ingersoll Rand
- Ingram Compaction
- Kemna, Breslau
- KMEC
- Lebrero
- LeeBoy
- LiuGong
- Mikasa
- Multiquip/Rammax
- Rex
- Sinoway Industrial (Shanghai) Co.,Ltd
- Stone Equipment
- SuperPac
- Vibromax
- Volvo CE

Chapter 4

Steamroller

A steam powered road roller

A **steamroller** (or **steam roller**) is a form of road roller – a type of heavy construction machinery used for levelling surfaces, such as roads or airfields – that is powered by a steam engine. The levelling/flattening action is achieved through a combination of the size and weight of the vehicle and the *rolls*: the smooth wheels and the large cylinder or drum fitted in place of treaded road wheels.

The majority of steam rollers are outwardly similar to traction engines as many traction engine manufacturers later produced rollers based on their existing designs, and the patents owned by certain roller manufacturers tended to influence the general arrangements used by others. The key difference between the two vehicles is that on a roller the main roll replaces the front wheels and axle that would be fitted to a traction engine.

In many parts of the world, the term *steam roller* is still used regardless of the method of propulsion. This typically only applies to the largest examples (used for road-making).

Configurations

The majority of rollers were of the same basic configuration, with two large smooth wheels at the back and a single wide roll at the front. However, there was also a distinctive variant, the "tandem", which had two wide rolls, one front, one rear. A further steam-powered variant was the tri-tandem, made by Robey, which was a like a tandem but with *two* large rear rolls, one mounted immediately in front of the other.


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A variation of the basic configuration was the "convertible": an engine which could be either a steam roller or a traction engine and could be changed from one form to the other in a relatively short time – *i.e.*, less than half a day. Convertible engines were liked by local authorities, since the same machine could be used for haulage in the winter and road-mending in the summer.

Design features

Although most steam roller designs are derived from traction engines, and were manufactured by the same companies, there are a number of features that set them apart.

Wheels

The most obvious difference is in the wheels. All traction engines were built with large fabricated spoked steel wheels with wide rims. Those intended for road use would have continuous solid rubber tyres bolted around the rims, to improve traction on tarmac. Engines intended for agricultural use would have a series of strakes bolted diagonally across the rims, like the tread on a modern pneumatic tractor tyre, and the wheels were typically wider to spread the load more evenly.

Steam rollers, on the other hand, had smooth rear wheels and a roller at the front. The roller was a single wide cylinder supported at either end. This replaced the separate wheels and axle of a traction engine.


COR

Smokebox

In the conventional arrangement, the front roller is mounted centrally, forward of the chimney. In order to allow enough clearance from the boiler (and hence a larger front roll), the smokebox is extended forward substantially at the top to incorporate a support plate on which to mount the bearing for the roller assembly. This gives the distinctive, hooded look to the front of a steam roller. It also necessitates a different design of smokebox door – it has to drop down, rather than opening sideways, due to the limited access available.

Special equipment

The rear rollers were fitted with **scraper bars**. As the vehicle moved along, these removed any surface material that had become stuck to the roll, to prevent a build-up of material and ensure a flat finish was maintained.

Some steam rollers were fitted with a **scarifier** mounted on the tender box at the rear. They could be swung down to road level and used to rip up the old surface before a road was remade.

Another accessory was a **tar sprayer** – a bar mounted on the back of the roller. This was not a common fixture.

Manufacturers

Britain was a large exporter of steam rollers to the world over the years, with the firm of Aveling and Porter probably being the most famous and the most prolific.

Many other traction engine manufacturers built steam rollers, but after Aveling and Porter, the most popular were Marshall, Sons & Co., John Fowler & Co., and Wallis & Steevens.

In America, the Buffalo-Springfield Roller Company was a large builder. J. I. Case made a roller variant of their famed farm engines, but had a small market share. Other nations had makers including the Czechs, Swiss, Swedes, Germans and Dutch which produced steam rollers.

United States -built 1924 Buffalo Springfield steam roller: a vertical boiler design with tandem rolls. Note position of firebox door, facing out of frames.

Other side of same roller showing offset driving position: driver faces boiler controls (ie 'backwards') and steers with right hand

Usage

A former Bedfordshire County Council Aveling & Porter roller in 2004

In the UK, a number of companies owned fleets of steam rollers and contracted them out to local authorities.

Many were still in use into the 1960s, and part of the M1 motorway was made with the help of steam rollers.

A few steam rollers were still being used for road maintenance in the early 1970s, and this may go some way to explaining why diesel-powered rollers are still colloquially known as *steam* rollers to this day.


ZETTELMEYER
KONZ b. TRIER

Bundesarchiv, B 145 Bild-F001670-0004
Foto: Brodde | Mai 1954

Bundesarchiv, Bild 183-E12033
Foto: o.Ang. | Oktober 1939

Bundesarchiv, Bild 183-E12034
Foto: o.Ang. | Oktober 1939

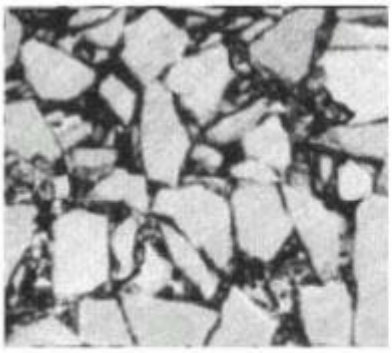
Preservation

Many steam rollers are preserved in working order, and can be seen in operation during special live steam festivals, where operating scale models may also be displayed. At some of the UK steam fairs and rallies, demonstrations of road building using the old techniques, tools and machines are re-enacted by 'Road Gangs' in authentic dress; steam rollers feature prominently in these demonstrations. The annual Great Dorset Steam Fair has a section dedicated to road-making machinery, including a line-up of working steam rollers.

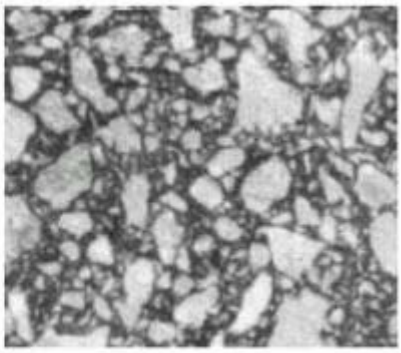
Chapter 5

Stone Mastic Asphalt

Stone mastic asphalt (SMA) was developed in Germany in the 1960s. It provides a deformation resistant, durable surfacing material, suitable for heavily trafficked roads. SMA has found use in Europe, Australia, the United States, and Canada as a durable asphalt surfacing option for residential streets and highways. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with a mastic of bitumen and filler to which fibres are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70−80% coarse aggregate, 8−12% filler, 6.0−7.0% binder, and 0.3 per cent fibre.



(a) Stone mastic asphalt



(b) Dense graded asphalt

The deformation resistant capacity of SMA stems from a coarse stone skeleton providing more stone-on-stone contact than with conventional dense graded asphalt (DGA) mixes. Improved binder durability is a result of higher bitumen content, a thicker bitumen film, and lower air voids content. This high bitumen content also improves flexibility. Addition of a small quantity of cellulose or mineral fibre prevents drainage of bitumen during transport and placement. There are no precise design guidelines for SMA mixes. The essential features, which are the coarse aggregate skeleton and mastic composition, and the consequent surface texture and mixture stability, are largely determined by the selection of aggregate grading and the type and proportion of filler and binder.

Manufacture

SMA is mixed and placed in the same plant as that used with conventional hot mix. In batch plants, the fibre additive is added direct to the pugmill using individually wrapped press packs or bulk dispensing equipment. Mixing times may be extended ensure that fibre is homogeneously distributed throughout the mix and temperatures controlled in order to avoid overheating or damage to the fibre. In drum plants, particular care must be taken to ensure that both the additional filler content and fibre additive are incorporated into the mixture without excessive losses through the dust extraction system. Filler systems that add filler directly into the drum rather than aggregate feed are preferred. Pelletised fibres may be added through systems designed for addition of recycled materials, but a more effective means is addition through a special delivery line that is combined with the bitumen delivery, so that the fibre is captured by bitumen at the point of addition to the mixture.

Placement

The primary difference in placing SMA, compared to DGA is in compaction procedures. Multi-tyred rollers are not used due to the possible working of binder-rich material to the surface of the asphalt and consequent flushing and pick-up. Trafficking of the newly placed asphalt while still warm may have the same effect and it is generally preferable for surfaces to cool below about 40°C before opening to traffic. The preferred method of compaction is to use heavy, non-vibrating, steel-wheeled rollers. If these are not available, vibrating rollers may be used but vibration should be kept to a minimum to avoid fracture of coarse aggregate particles, or drawing of binder to the surface of the mix. The use of polymer modified binder may decreases mix workability and necessitate increased compactive effort to achieve high standards of compacted density. Achieving high standards of compacted density and low field air voids has been identified as an important factor in the performance of all SMA work. SMA is normally placed with a minimum layer thickness of 2.5 to 3 times the nominal maximum aggregate particle size. Greater layer thicknesses assist in achieving appropriate standards of compacted density.

Materials

Aggregates used in SMA must be of high quality – well shaped, resistant to crushing and of suitable polish resistance.

Binders used in SMA include:

- Class 320 bitumen - used in many general applications.
- Multigrade binder - used to provide enhanced performance at higher traffic levels.
- Polymer modified binder - increasingly used in heavy traffic conditions to provide additional resistance to flushing and rutting.

Cellulose fibre is most commonly used in SMA work in Australia. Other fibre types, including glass fibre, rockwool, polyester, and even natural wool, have all been found to be suitable but cellulose fibre is generally the most cost-effective. Fibre content is generally 0.3% (by mass) of the total mix.

Advantages

- SMA provides a textured, durable, and rut resistant wearing course.
- The surface texture characteristics of SMA are similar to Open graded asphalt (OGA) so that the noise generated by traffic is lower than that on DGA but equal to or slightly higher than OGA.
- SMA can be produced and compacted with the same plant and equipment available for normal hot mix, using the above procedure modifications.
- SMA may be used at intersections and other high traffic stress situations where OGA is unsuitable.
- SMA surfacings may provide reduced reflection cracking from underlying cracked pavements due

to the flexible mastic.

- The durability of SMA should be equal, or greater than, DGA and significantly greater than OGA.

Disadvantages

- Increased material cost associated with higher binder and filler contents, and fibre additive.
- Increased mixing time and time taken to add extra filler, may result in reduced productivity.
- Possible delays in opening to traffic as the SMA mix should be cooled to 40°C to prevent flushing of the binder to the surface (bleeding).
- Initial skid resistance (lack of Friction) may be low until the thick binder film is worn off the top of the surface by traffic. In critical situations, a small, clean grit, may need to be applied before opening to traffic.

Concerns over skid resistance

Concerns have been raised in both the UK and Australia over the use of Stone mastic as, under certain conditions, it can take up to two years for the material to offer an acceptable level of skid resistance (grip).

Chapter 6

Road Transport

A truck transporting a container on Interstate 95 in South Florida.

Disruptions in organized traffic flow can create delays lasting hours.

Road transport (British English) or **road transportation** (American English) is transport on roads of passengers or goods. A hybrid of road transport and ship transport is the historic horse-drawn boat.

History

The first methods of road transport were horses, oxen or even humans carrying goods over dirt tracks that often followed game trails. As commerce increased, the tracks were often flattened or widened to accommodate the activities. Later, the travois, a frame used to drag loads, was developed. The wheel came still later, probably preceded by the use of logs as rollers. Early stone-paved roads were built in Mesopotamia and the Indus Valley Civilization. The Persians later built a network of Royal Roads across their empire.

With the advent of the Roman Empire, there was a need for armies to be able to travel quickly from one area to another, and the roads that existed were often muddy, which greatly delayed the movement of large masses of troops. To resolve this issue, the Romans built great roads. The Roman roads used deep roadbeds of crushed stone as an underlying layer to ensure that they kept dry, as the water would flow out from the

crushed stone, instead of becoming mud in clay soils. The Islamic Caliphate later built tar-paved roads in Baghdad.

During the Industrial Revolution, and because of the increased commerce that came with it, improved roadways became imperative. The problem was rain combined with dirt roads created commerce-miring mud. John Loudon McAdam (1756–1836) designed the first modern highways. He developed an inexpensive paving material of soil and stone aggregate (known as macadam), and he embanked roads a few feet higher than the surrounding terrain to cause water to drain away from the surface. At the same time, Thomas Telford, made substantial advances in the engineering of new roads and the construction of bridges, particularly, the London to Holyhead road.

Various systems had been developed over centuries to reduce bogging and dust in cities, including cobblestones and wooden paving. Tar-bound macadam (tarmac) was applied to macadam roads towards the end of the 19th century in cities such as Paris. In the early 20th century tarmac and concrete paving were extended into the countryside.

Transportation

A public transport Bus

Transport on roads can be roughly grouped into two categories: transportation of goods and transportation of people. In many countries licencing requirements and safety regulations ensure a separation of the two industries.

The nature of road transportation of goods depends, apart from the degree of development of the local infrastructure, on the distance the goods are transported by road, the weight and volume of the individual shipment and the type of goods transported. For short distances and light, small shipments a van or pickup truck may be used. For large shipments even if less than a full truckload (Less than truckload) a truck is more appropriate. In some countries cargo is transported by road in horse-drawn carriages, donkey carts or other non-motorized mode. Delivery services are sometimes considered a separate category from cargo transport. In many places fast food is transported on roads by various types of vehicles. For inner city delivery of small packages and documents bike couriers are quite common.

People (Passengers) are transported on roads either in individual cars or automobiles or in mass transit/public transport by bus / Coach (vehicle). Special modes of individual transport by road like rickshaws or velotaxis may also be locally available.

Trucking and hauling

Sheep in a B Double truck, Moree, New South Wales, Australia.

Trucking companies (AE) or haulers/hauliers (BE) accept cargo for road transport. Truck drivers operate either independently working directly for the client or through freight carriers or shipping agents. Some big companies (e.g. grocery store chains) operate their own internal trucking operations.

In the U.S. many truckers own their truck (rig), and are known as owner-operators. Some road transportation is done on regular routes or for only one consignee per run, while others transport goods from many different loading stations/shippers to various consignees. On some long runs only cargo for one lag of the route (to) is known when the cargo is loaded. Truckers may have to wait at the destination for the return cargo (from).

A Bill of Lading issued by the shipper provides the basic document for road freight. On cross-border transportation the trucker will present the cargo and documentation provided by the shipper to customs for inspection. This also applies to shipments that are transported out of a Free port.

To avoid accidents caused by fatigue, truckers have to keep to strict rules for drivetime and required rest periods. Known in the U.S. as hours of service, and in the E.U. as drivers working hours. See e.g. "Hours of Work and Rest Periods (Road Transport) Convention, 1979" or . Tachographs record the times the vehicle is in motion and stopped. Some companies use two drivers per truck to ensure uninterrupted transportation; with one driver resting or sleeping in a bunk in the back of the cab while the other is driving.

Truck drivers often need special licences to drive, known in the U.S. as a commercial driver's license. In the U.K. a Large Goods Vehicle licence is required.

For transport of hazardous materials truckers need a licence, which usually requires them to pass an exam (e.g. in the EU). They have to make sure they affix proper labels for the respective hazard(s) to their vehicle. Liquid goods are transported by road in tank trucks (AE) or tanker lorries (BE) (also road-tankers) or special tankcontainers for intermodal transport. For unpackaged goods and liquids weigh stations confirm weight after loading and before delivery. For transportation of live animals special requirements have to be met in many countries to prevent cruelty to animals. For fresh and frozen goods refrigerator trucks or reefer (container)s are used.

In Australia road trains replace rail transport for goods on routes throughout the center of the country. B-doubles and semi-trailers are used in urban areas because of their smaller size.

Modern roads

The Makran Coastal Highway was an ancient road within Pakistan. Now it's a major road leading to the city of Gwadar

Today roadways are principally asphalt or concrete. Both are based on McAdam's concept of stone aggregate in a binder, asphalt cement or Portland cement respectively. Asphalt is known as a flexible pavement, one which slowly will "flow" under the pounding of traffic. Concrete is a rigid pavement, which can take heavier loads but is more expensive and requires more carefully prepared subbase. So, generally, major roads are concrete and local roads are asphalt. Often concrete roads are covered with a thin layer of asphalt to create a wearing surface.

Modern pavements are designed for heavier vehicle loads and faster speeds, requiring thicker slabs and deeper subbase. Subbase is the layer or successive layers of stone, gravel and sand supporting the pavement. It is needed to spread out the slab load bearing on the underlying soil and to conduct away any water getting under the slabs. Water will undermine a pavement over time, so much of pavement and pavement joint design are meant to minimize the amount of water getting and staying under the slabs.

Shoulders are also an integral part of highway design. They are multipurpose; they can provide a margin of side clearance, a refuge for incapacitated vehicles, an emergency lane, and parking space. They also serve a design purpose, and that is to prevent water from percolating into the soil near the main pavement's edge. Shoulder pavement is designed to a lower standard than the pavement in the traveled way and won't hold up as well to traffic. (Which is why driving on the shoulder is generally prohibited.)

Pavement technology is still evolving, albeit in not easily noticed increments. For instance, chemical additives in the pavement mix make the pavement more weather resistant, grooving and other surface treatments improve resistance to skidding and hydroplaning, and joint seals which were once tar are now made of low maintenance neoprene.

Traffic control

Nearly all roadways are built with devices meant to control traffic. Most notable to the motorist are those meant to communicate directly with the driver. Broadly, these fall into three categories: signs, signals or pavement markings. They help the driver navigate; they assign the right-of-way at intersections; they indicate laws such as speed limits and parking regulations; they advise of potential hazards; they indicate passing and no passing zones; and otherwise deliver information and to assure traffic is orderly and safe.

200 years ago these devices were signs, nearly all informal. In the late 19th century signals began to appear in the biggest cities at a few highly congested intersections. They were manually operated, and consisted of semaphores, flags or paddles, or in some cases colored electric lights, all modeled on railroad signals. In the 20th century signals were automated, at first with electromechanical devices and later with computers. Signals can be quite sophisticated: with vehicle sensors embedded in the pavement, the signal can control and choreograph the turning movements of heavy traffic in the most complex of intersections. In the 1920s traffic engineers learned how to coordinate signals along a thoroughfare to increase its speeds and volumes. In the 1980s, with computers, similar coordination of whole networks became possible.

In the 1920s pavement markings were introduced. Initially they were used to indicate the road's centerline. Soon after they were coded with information to aid motorists in passing safely. Later, with multi-lane roads they were used to define lanes. Other uses, such as indicating permitted turning movements and pedestrian crossings soon followed.

In the 20th century traffic control devices were standardized. Before then every locality decided on what its devices would look like and where they would be applied. This could be confusing, especially to traffic from outside the locality. In the United States standardization was first taken at the state level, and late in the century at the federal level. Each country has a Manual of Uniform Traffic Control Devices (MUTCD) and there are efforts to blend them into a worldwide standard.

Besides signals, signs, and markings, other forms of traffic control are designed and built into the roadway. For instance, curbs and rumble strips can be used to keep traffic in a given lane and median barriers can prevent left turns and even U-turns.

Toll roads

Early toll roads were usually built by private companies under a government franchise. They typically paralleled or replaced routes already with some volume of commerce, hoping the improved road would divert enough traffic to make the enterprise profitable. Plank roads were particularly attractive as they greatly reduced rolling resistance and mitigated the problem of getting mired in mud. Another improvement, better grading to lessen the steepness of the worst stretches, allowed draft animals to haul heavier loads.

A *toll road* in the United States is often called a *turnpike*. The term *turnpike* probably originated from the gate, often a simple pike, which blocked passage until the fare was paid at a *toll house* (or *toll booth* in current terminology). When the toll was paid the pike, which was mounted on a swivel, was turned to allow the vehicle to pass. Tolls were usually based on the type of cargo being transported, not the type of vehicle. The practice of selecting routes so as to avoid tolls is called shunpiking. This may be simply to avoid the expense, as a form of economic protest (or boycott), or simply to seek a road less traveled as a bucolic interlude.

Companies were formed to build, improve, and maintain a particular section of roadway, and tolls were collected from users to finance the enterprise. The enterprise was usually named to indicate the locale of its roadway, often including the name of one of both of the termini. The word *turnpike* came into common use in the names of these roadways and companies, and is essentially used interchangeably with *toll road* in current terminology.

In the United States, toll roads began with the Lancaster Turnpike in the 1790s, within Pennsylvania, connecting Philadelphia and Lancaster.

In New York State, the Great Western Turnpike was started in Albany in 1799 and eventually extended, by several alternate routes, to near what is now Syracuse, New York.

Toll roads peaked in the mid 19th century, and by the turn of the twentieth century most toll roads were taken over by state highway departments. The demise of this early toll road era was due to the rise of canals and railroads, which were more efficient (and thus cheaper) in moving freight over long distances. Roads wouldn't again be competitive with rails and barges until the first half of the 20th century when the internal combustion engine replaces draft animals as the source of motive power.

With the development, mass production, and popular embrace of the automobile, faster and higher capacity roads were needed. In the 1920s limited access highways appeared. Their main characteristics were dual roadways with access points limited to (but not

always) grade-separated interchanges. Their dual roadways allowed high volumes of traffic, the need for no or few traffic lights along with relatively gentle grades and curves allowed higher speeds.

The first limited access highways were *Parkways*, so called because of their often park-like landscaping and, in the metropolitan New York City area, they connected the region's system of parks. When the German Autobahns built in the 1930s introduced higher design standards and speeds, road planners and road-builders in the United States started developing and building toll roads to similar high standards. The Pennsylvania Turnpike, which largely followed the path of a partially-built railroad, was the first, opening in 1940.

After 1940 with the Pennsylvania Turnpike, toll roads saw a resurgence, this time to fund limited access highways. In the late 1940s and early 1950s, after World War II interrupted the evolution of the highway, the US resumed building toll roads. They were to still higher standards and one road, the New York State Thruway, had standards that became the prototype for the U.S. Interstate Highway System. Several other major toll-roads which connected with the Pennsylvania Turnpike were established before the creation of the Interstate Highway System. These were the Indiana Toll Road, Ohio Turnpike, and New Jersey Turnpike.

US Interstate Highway system

In the United States, beginning in 1956, Dwight D. Eisenhower National System of Interstate and Defense Highways, commonly called the Interstate Highway System was built. It uses 12 foot (3.65m) lanes, wide medians, a maximum of 4% grade, and full access control, though many sections don't meet these standards due to older construction or constraints. This system created a continental-sized network meant to connect every population center of 50,000 people or more.

By 1956, most limited access highways in the eastern United States were toll roads. In that year, the federal Interstate highway program was established, funding non-toll roads with 90% federal dollars and 10% state match, giving little incentive for states to expand their turnpike system. Funding rules initially restricted collections of tolls on newly funded roadways, bridges, and tunnels. In some situations, expansion or rebuilding of a toll facility using Interstate Highway Program funding resulted in the removal of existing tolls. This occurred in Virginia on Interstate 64 at the Hampton Roads Bridge-Tunnel when a second parallel roadway to the regional 1958 bridge-tunnel was completed in 1976.

Since the completion of the initial portion of the interstate highway system, regulations were changed, and portions of toll facilities have been added to the system. Some states are again looking at toll financing for new roads and maintenance, to supplement limited federal funding. In some areas, new road projects have been completed with public-private partnerships funded by tolls, such as the Pocahontas Parkway (I-895) near Richmond, Virginia.

Pneumatic tires

As the horse-drawn carriage was replaced by the car and lorry or truck, and speeds increased, the need for smoother roads and less vertical displacement became more apparent, and pneumatic tires were developed to decrease the apparent roughness. Wagon and carriage wheels, made of wood, had a tire in the form of an iron strip that kept the wheel from wearing out quickly. Pneumatic tires, which had a larger footprint than iron tires, also were less likely to get bogged down in the mud on unpaved roads.

Road transport and the environment

By subsector, road transport is the largest contributor to global warming (74% of total emissions from transport) .

Chapter 7

Frontage Road

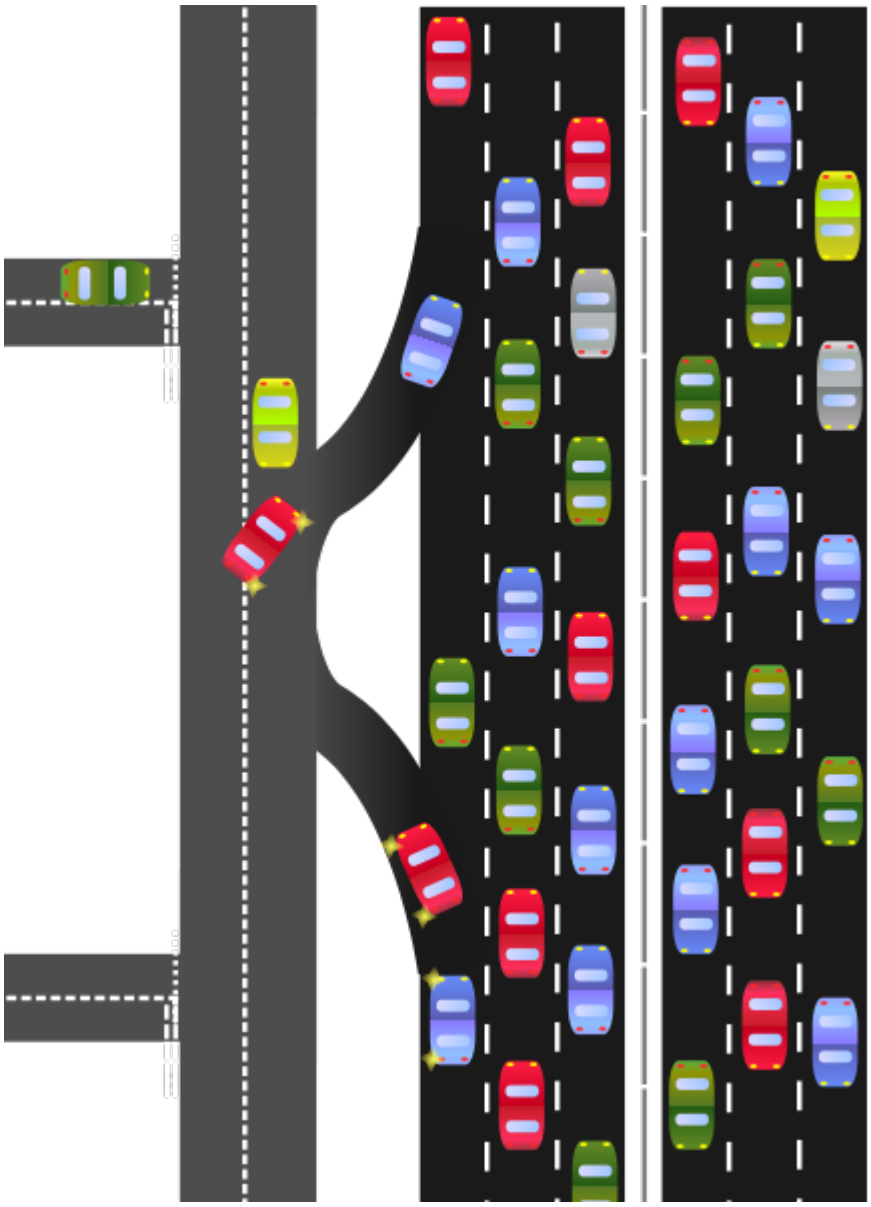


Illustration of a two-way residential frontage road running parallel to a motorway.

A frontage road for U.S. 71 (a freeway) near Carthage, Missouri. The frontage road (called an "outer road" in Missouri) is former Alternate US-71. A second frontage road on the opposite side of the freeway is visible and was built during construction of the freeway.

A **frontage road** (also **access road**, **service road**, and many other names) is a non-limited access road running parallel to a higher-speed road, usually a freeway, and feeding it at appropriate points of access (interchanges). In many cases, the frontage road is a former alignment of a road already in existence when the limited-access road was built.

In other situations they may be built prior to construction of the limited-access road. In urban areas, frontage roads are frequently one-way roads when they exist on both sides of a highway. In more rural ones, such roads are typically two-way.

Overview

Frontage roads provide access to homes and businesses which would be cut off by a limited access road and connect these locations with roads which have direct access to the main roadway. Frontage roads give indirect access to abutting property along a freeway, either preventing the commercial disruption of an urban area that the freeway traverses or

allowing commercial development of abutting property. At times, they add to the cost of building an expressway due to costs of land acquisition and the costs of paving and maintenance.

However, the benefits of development nearby real estate can more than offset the cost of building the frontage roads. Furthermore, a frontage road may be a part of an older highway, so the expense of building a frontage road may be slight. And finally, the cost to purchase access rights from adjacent property may exceed the costs to build frontage roads. Conversely, the existence of a frontage road can increase traffic on the main road and be a catalyst for development; hence there is sometimes an explicit decision made to not build a frontage road.

A **backage road** is a similar concept, but lies on the other side of the land parcels that abut the frontage road. It serves mainly to provide access to those parcels without using the frontage road.

Collector-express

The successor to the concept of service/frontage roads in urban freeways is the **collector-express** system, which is designed to handle closely spaced interchange ramps without disrupting through traffic. Unlike service roads, the collector lanes are typically high-speed full controlled-access lanes, conforming to freeway requirements.

The collector lanes may also be known as a **collector/distributor road** and slip ramps provide access to and from the express/mainline lanes. Frontage roads may feed into and from collector/distributor roads near some interchanges.

Examples

Argentina

In Argentina, especially around Buenos Aires, frontage roads known as **colectoras** can be found next to freeways. Examples include Avenida General Paz, Ruta 8, and Ruta 9 coming into Buenos Aires.

Canada

In Canada, *collector-express systems* are usually used instead of frontage roads. Seen here is Highway 401 in Toronto, where green signs are used for express (inner) lanes and blue signs for the collector (outer) lanes respectively to minimize confusion for motorists.

The only freeway with a significant remaining network of service roads is the Queen Elizabeth Way (QEW). However, most of the slip ramps between St. Catharines and Mississauga were removed during major reconstruction in the 1970s and 1990s. Service roads are no longer able to directly access the QEW; they have been rerouted to intersections with other major roads which have interchanges with the QEW. Nonetheless, the service roads are positioned too close to the QEW to easily widen the freeway unless all the private properties along the service road are bought out. This would be unlikely in the current political environment.

The only remaining slip ramps connecting to service roads are on the QEW running through St. Catharines. These dangerous low-standard ramps (due to lack of acceleration/de-acceleration lanes) are due to be replaced in a planned extensive reconstruction of the QEW that is currently underway. Similar service roads and slip ramps exist along Highway 401 through Oshawa, but like through St. Catharines, these are also in the process of being replaced with modern ramps.

Highway 427 had its service roads replaced with a collector-express system in the 1970s. However, it has several RIRO access onramps and offramps to serve residential traffic in addition to its standard parclo interchanges with major arterials.

List of Service Roads on the QEW:

- series of broken sections from Cawthra Road in Mississauga to the Garden City Skyway in St. Catharines.

List of Service Roads on the 403:

- North Service Road at QEW/407 junction to Waterdown Rd, Burlington
- Service Service Road at Guelph Line, Burlington

List of RIRO on the 427:

- Gibbs Road onto North 427
- Eva Road onto/off South 427
- Holiday Drive onto/off South 427
- Eringate Drive onto/off South 427
- Valhalla Inn Road onto North 427

From Toronto east to the Ontario-Quebec border, Highway 2 (Ontario) runs almost parallel to Highway 401 (Ontario). Lakeshore Boulevard in Toronto runs parallel with the Gardiner Expressway.

Mexico

In Guadalajara, the López Mateos, Vallarta and Mariano Otero avenues (the latter in the stretch between López Mateos to Niños Héroes) are 2-lane avenues surrounded by two one-way frontage roads. Lázaro Cárdenas Expressway is similar, but with three lanes in both the central road and the frontage roads. Because these frontage roads are considered as part of the avenue itself, the central road is known locally as the "central lanes", whereas the frontage roads are known as "lateral lanes". Turns are always forbidden in the central lanes; drivers wishing to make a turn must leave the central lanes and make the turn from the lateral lanes.

People's Republic of China

In the People's Republic of China mainland, roads running next to expressways, taking outgoing traffic and feeding incoming traffic, are called either **service roads** or **auxiliary roads** (*fudao* locally). Where expressways cross larger urban areas, such frontage roads may run next to the expressway itself. Much of the Beijing portion of the Jingkai Expressway, for example, has, in fact, China National Highway 106 acting as a split-direction frontage road.

Hong Kong

Frontage roads exist both in city and along major expressways between new towns. Gloucester Road has frontage road running parallel of it from east to west. Cheung Tung Road serves as the frontage road for North Lantau Highway, Hiram's Highway for New Hiram's Highway, and Tai Wo Service Road West and Tai Wo Service Road East for Fanling Highway. Castle Peak Road serves the purpose as a frontage road of Tuen Mun Road to some extent.

United States

Michigan

Frontage roads are also common in Metro Detroit, where they are usually referred to as "service drives." As in Texas, they typically run one way with frequent slip ramps to and from the limited access roadway, with Texas U-turns at or near many intersections. Unlike Texas, there is usually little commercial development situated along the frontage road itself (see example); the road serves to provide access to the freeway from existing residential streets and commercial surface thoroughfares. Also unlike in many locales in urban Texas, where an exit ramp may actually precede the entrance ramp for the previous interchange to facilitate access to businesses situated directly on the frontage road (in effect, the two interchanges overlap along the frontage road), Michigan slip ramps to and from frontage roads are generally positioned as they normally would be in the absence of the frontage road. Motorists entering and exiting the freeway are not sharing the frontage road simultaneously to as large a degree, reducing weaving. Access to the frontage road between exits is provided by turnarounds and frequent bridging, generally every 1/2 mile, between exits.

Michigan left hand turns are also quite common at surface street-frontage road intersections, with dedicated turnaround lanes (similar to the Texas U-turn) built over the freeway on separate bridges approximately 100 meters from the main intersection and bridging.

With the exceptions of Interstate 275 and the freeway portion of M-53, every Metro Detroit freeway has a frontage road along it for at least a portion of its length. Several other freeways outside Metro Detroit use these as well.

There are no other Michigan frontage roads running more than one mile in length outside of the Metro Detroit area. New freeway construction in Michigan has not included frontage roads since the completion of Interstate 696, most of which was constructed along the rights of way of major surface arteries, in 1989.

Texas

A frontage road for Texas State Highway 183 (Airport Freeway) in Irving, Texas

Most Texas freeways have frontage roads on both sides. In urban and suburban areas, the traffic typically travels one-way only in the direction of the neighboring main lanes. Most other areas have two-way traffic, but as an area urbanizes the frontage road is often converted to one-way traffic. Over 80% of Houston freeways have frontage roads, which locals typically call feeders. Many frontage roads in urban and suburban areas of Texas have the convenience of Texas U-turns, which allow drivers to avoid being stopped by traffic lights when making a U-turn.

Frontage roads are often built as part of a multi-phase plan to construct new limited access highways. Therefore, they initially serve as a highway with access to local business before the freeway is constructed several years later. Even after the completion of the new freeway, frontage roads serve as a major thoroughfare for local activity, such as with the Katy Freeway project in Greater Houston. In several cases, a long range plan has called for a future freeway, but the design is either changed or the project canceled before completion.

Entering and exiting from access roads can be very confusing to drivers unfamiliar with the system. Signaling is very important not just for the drivers behind, but also for

oncoming traffic in areas where the access road is two-way. In fact, an interesting driving custom has developed in areas with two-way frontage roads. Typically, drivers traveling on the frontage road moving in the same direction as the adjacent freeway traffic will use their left turn signal when entering the on-ramp. In Texas, drivers on a frontage road must yield to traffic entering an on-ramp, so oncoming traffic must stop to allow vehicles to cross in front of them to enter the on-ramp. As a courtesy, many drivers on a two-way frontage road who are not entering the freeway will switch on their *right* turn signal as they approach an on-ramp to indicate that they are staying on the frontage road and that oncoming motorists therefore needn't slow down or stop to yield to them.

Nicknames for frontage roads vary within the state of Texas. In Houston and East Texas they are called feeders. Dallas and Fort Worth residents call their frontage roads "service roads" or "access roads", and "access roads" is the predominant term used in San Antonio. El Paso residents call their frontage roads "gateways." In Austin, however, they use the state's official term of "frontage roads".

In 2002, the Texas Department of Transportation proposed to discontinue building frontage roads on new freeways, citing studies that suggest frontage roads increase congestion. However, this proposal was widely ridiculed and criticized and was dropped later the same year.

The Stemmons Freeway in Dallas illustrates the practicability of the frontage road: the real estate developer John Stemmons offered free land to the Texas Highway commission in which to build a freeway (Interstate 35E) on the condition that the state build the freeway with frontage roads that would give access to undeveloped property until then of slight value that he owned along the freeway corridor. The state was able to reduce its costs (largely the cost of land acquisition) of building the freeway and did not need to acquire and demolish developed property; in return the developer profited handsomely from lucrative development along the freeway. San Antonio developer Charles Martin Wender used the same tactic for his Westover Hills development, offering free land through the middle of his property for SH 151 as well as paying half the costs for the initial frontage road construction. Following Wender's lead, several neighboring landowners also donated right-of-way for the route.

The Carolinas

Frontage roads are common on interstate highways in North Carolina and South Carolina. Some of these road have houses facing the highways which they parallel. They may also have highway services, as most of them are located near interchanges. Most frontage roads in the Carolinas do not have ramps leading to and from their respective highways; rather, as mentioned before, most are located near interchanges, which allows people to exit the highway and go around to the frontage road if needed.

Chapter 8

Passing Lane & Parking Space

Passing Lane

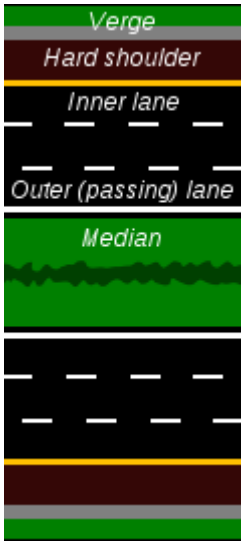


Diagram showing lanes and road layout, with Irish road markings.

A **passing lane** or **overtaking lane** is the lane on a multi-lane highway or motorway closest to the center of the road (the central reservation).

In North American terminology, the passing lane is often known as a **left lane** or **leftmost lane**, due to left hand drive (driving on the right). In British/Irish terminology, the passing lane is termed an **outer lane** or **outside lane**, while a normal lane nearer the hard shoulder is termed an **inner lane** (or **inside lane**). Note that in some other countries, like Hungary, the passing lane is called the inner lane (*belső* sáv in Hungarian), because this lane is the closest to the middle of the road, thus it is the *inner*most.

In modern traffic planning, passing lanes on freeways are usually designed for through/express traffic, while the inner lanes have entry/exit ramps. However, many freeways often have ramps on the passing lane, these are known as "left exits" in North America.

A passing lane is often colloquially referred to as a **fast lane** because it is often used for extended periods of time for through traffic or fast traffic. In theory, a passing lane

should be used only for passing, thus allowing, even on a road with only two lanes in each direction, motorists to travel at their own pace.

Signage

The use of the left lane for faster traffic is sometimes acknowledged with signs using phrases such as "Slower Traffic Keep Right" (in Canada, where the passing lane is to the left). The U.S. state of Rhode Island and Georgia uses the idea of a "Truck Lane" for tractor trailers traveling express through the state In a study by the AASHTO Subcommittee on Traffic Engineering, all 24 states involved used some form of passing lane courtesy signage, nine of which only use those signs for steep graded roads.

Misuse and common practice

Common practice and most law on United States Highways is that the left lane is reserved for passing and faster moving traffic, and that traffic using the left lane must yield to traffic wishing to overtake. The United States **Uniform Vehicle Code** states:

Upon all roadways any vehicle proceeding at less than the normal speed of traffic at the time and place and under the conditions then existing shall be driven in the right-hand lane then available for traffic ...

The Massachusetts Institute of Technology's website on "Keep Right Laws" points out that:

This law refers to the "normal" speed of traffic, not the "legal" speed of traffic. The 60 MPH driver in a 55 MPH zone where everybody else is going 65 MPH must move right..."

It is also illegal in many states in the U.S. to use the "far left" or passing lane on a major highway as a travelling lane (as opposed to passing), or to fail to yield to faster moving traffic that is attempting to overtake in that lane. For example, Colorado's "Left Lane Law" states:

A person shall not drive a motor vehicle in the passing lane of a highway if the speed-limit is sixty-five miles per hour or more unless such person is passing other motor-vehicles that are in a non-passing lane...

Other examples, such as Massachusetts (General Statute 89-4B), New Jersey, Maine, Illinois, Pennsylvania, and others, make it illegal to fail to yield to traffic that seeks to overtake in the left lane, or to create any other "obstruction" in the passing lane that hinders the flow of traffic. As a result, heavy trucks are often prohibited from using the passing lane.

A common problem arising from misuse of the "fast lane" is that it forces faster moving traffic that wishes to overtake on the left to change lanes, do so on the right, and then change lanes again. Further, if the vehicle misusing the passing lane is going slower than the flow of other traffic, it forces those using the middle "travel" lane (but who are moving faster) to pass on the right as well, even though they have no intention of doing so.

A driver hoping to pass a slow motorist in the "fast lane" is stuck in an awkward situation. One strategy is to signal a lane change toward the center median. Another is to flash headlights. A third, which sacrifices safety, is to drive very close to the "fast lane" driver's bumper (this is known as tailgating). In Germany it is common to signal a lane change toward the center of the road, as if there were another lane to the left of the "fast lane".

Most commonly, motorists will attempt to overtake the outer car on the inner lane either to continue at a fast pace or to pass a car that is simply going too slow in the passing lane. For high-capacity multilane freeways (three or more lanes per direction), many motorists often pass on the inner lane, largely in response to misuse of the "passing lane" by slower traffic.

Hammer lane

The **hammer lane** is another term for the passing lane. Its etymology originated with truckers in North America and compares a foot pressing hard on an accelerator pedal with the slamming action of a hammer. Truckers often use the hammer lane in moderate traffic, where it is legal to do so, since they travel long distances. In many areas, tractor trailers are banned from using the hammer lane for safety reasons; these restrictions are normally found along urban, often congested highways with multiple lanes (e.g. Interstate 40 west of Raleigh, North Carolina), or on rural freeways with 6 or more lanes (3 in each direction). HOV lanes are not usually considered hammer lanes, but are also used for express travel by commuters.

Climbing lane

In hilly terrain, some standard highways (not dual carriageway) are built with three lanes, known as the "Climbing" or "Crawler Lane". Two lanes are used for traffic heading in the uphill direction, with one lane being a passing or climbing lane, and one lane is used for downhill traffic. On dual carriageways, the climbing lane may be marked with a broken double white line.

Parking Space

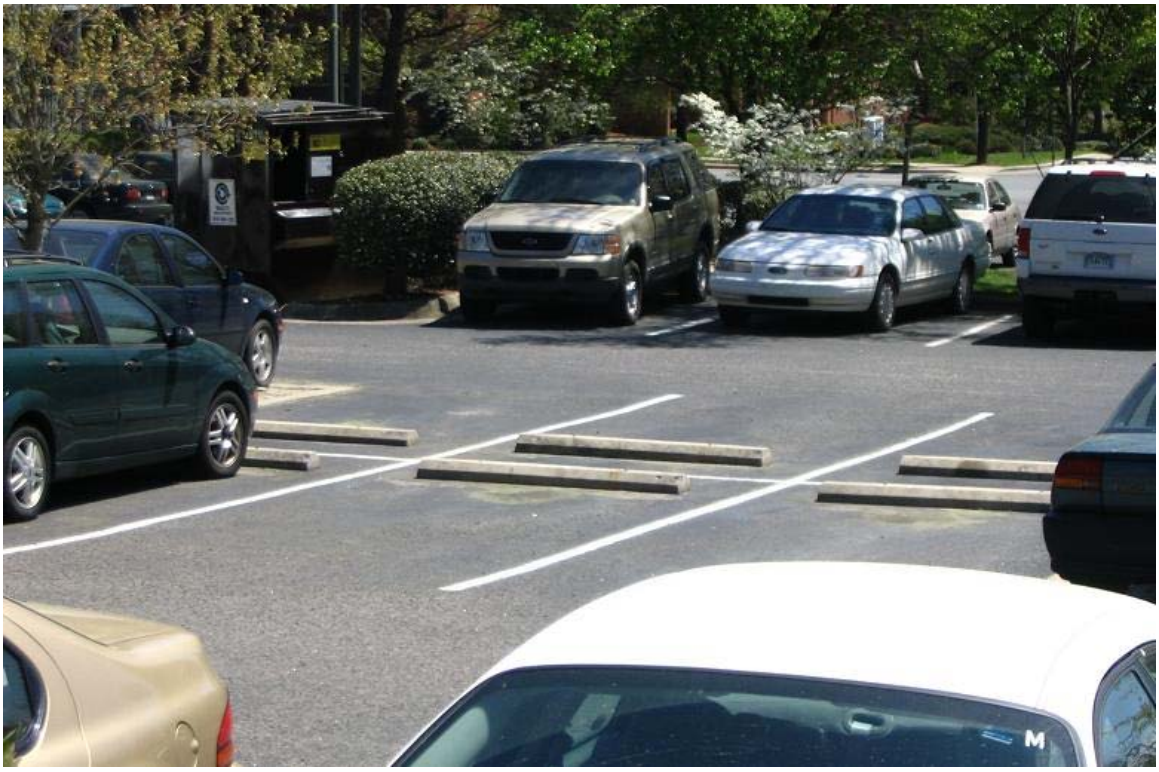
Parking in Vevey, Switzerland.

A **parking space** is a location that is designated for parking, either paved or unpaved.

Parking spaces can be in a parking garage, in a parking lot or on a city street. It is usually designated by a white-paint-on-tar rectangle indicated by three lines at the top, left and right of the designated area. The automobile fits inside the space, either by parallel parking, perpendicular parking or angled parking.

Depending on the location of the parking space, there can be regulations regarding the time allowed to park and a fee paid to use the parking space. When the demand for spaces outstrips supply vehicles may overspill park onto the sidewalk, grass verges and other places which were not designed for the purpose.

Space size



Parking spaces in an American parking lot.

The typical small or compact space is about 12 square metres (130 sq ft), while the average space is about 15 square metres (160 sq ft). Note that this area includes the area for parking space plus the circulation areas, end of aisle areas/landscaping.

Angled or perpendicular parking spaces range from 2.3 to 2.75 metres (7.5–9.0 ft) wide by 3.2 to 5.5 metres (10–18 ft) long. The choice of specific parking dimensions depends upon the function of the parking - the greater the use of the space (high turnover) and/or more retail customer in nature - the larger dimensions are commonly utilized.

A typical parking space adjacent to the curb (parallel) is 2.76 metres (9.1 ft) wide by 6.1 metres (20 ft) long. Parallel spaces are commonly marked 2.1 to 2.34 metres (6.9–7.7 ft) wide. The length of parallel spaces are commonly marked 6.7 to 7.9 metres (22–26 ft) long to account for entry and exit maneuvering.

The dimensions above are for North America. In the UK and mainland Europe spaces are considerably smaller.

People in Japan can't drive or park so their parking spots are alot bigger. They are 20 feet wide so the car can fit in any direction.

Barriers

Paid bike parking in Shibuya, Tokyo

Parking spaces commonly contain a parking chock (wheel stop), which is used to prevent cars from pulling too far into the space and

- obstructing a neighboring parking space, curb, or sidewalk.
- contacting with and then damaging a building wall.

This barrier is usually made of concrete and will normally be a horizontal bar to stop the tires from moving forward or a vertical bar that may cause damage to the vehicle if contact is made. In a parking garage, the barrier will often be a concrete wall.

Disabled parking spaces

An example of a disabled parking place.

Some parking spaces are reserved as handicapped parking, for individuals with disabilities. Handicapped parking spaces are typically marked with the International Symbol of Access, though in practice, the design of the symbol varies widely.

In the United States the Access Board provides guidelines on parking spaces in the Accessible Rights-of-Way: A Design Guide, Revised Draft Guidelines for Accessible Public Right-of-Way and ADA Accessibility Guidelines for Buildings and Facilities (ADAAG).

US curb markings

Curb markings in the United States are prescribed by the Manual of Uniform Traffic Control Devices (MUTCD). Local highway agencies may prescribe special colors for curb markings to supplement standard signs for parking regulation. California has designated an array of colors for curb regulations. A white curb designates passenger pick up or drop off. The green curb is for time limited parking. The yellow curb is for loading, and the blue curb is for disabled persons with proper vehicle identification. The red curb

is for emergency vehicles only - fire lanes (no stopping, standing, or parking). In Oregon and Florida, the yellow curb is utilized to indicate no parking. In Georgia either red or yellow can be used to indicate no parking. In Seattle, Washington, alternating red and yellow curb markings indicate a bus stop.

Chapter 9

Overpass & Hydrogen Highway

Overpass

Overpass in East Potomac Park, Washington, D.C..

Sandgate Flyover, New South Wales, where two main railway lines pass over two dedicated coal lines.

Flyover on Keelung Road in Taipei, Taiwan.

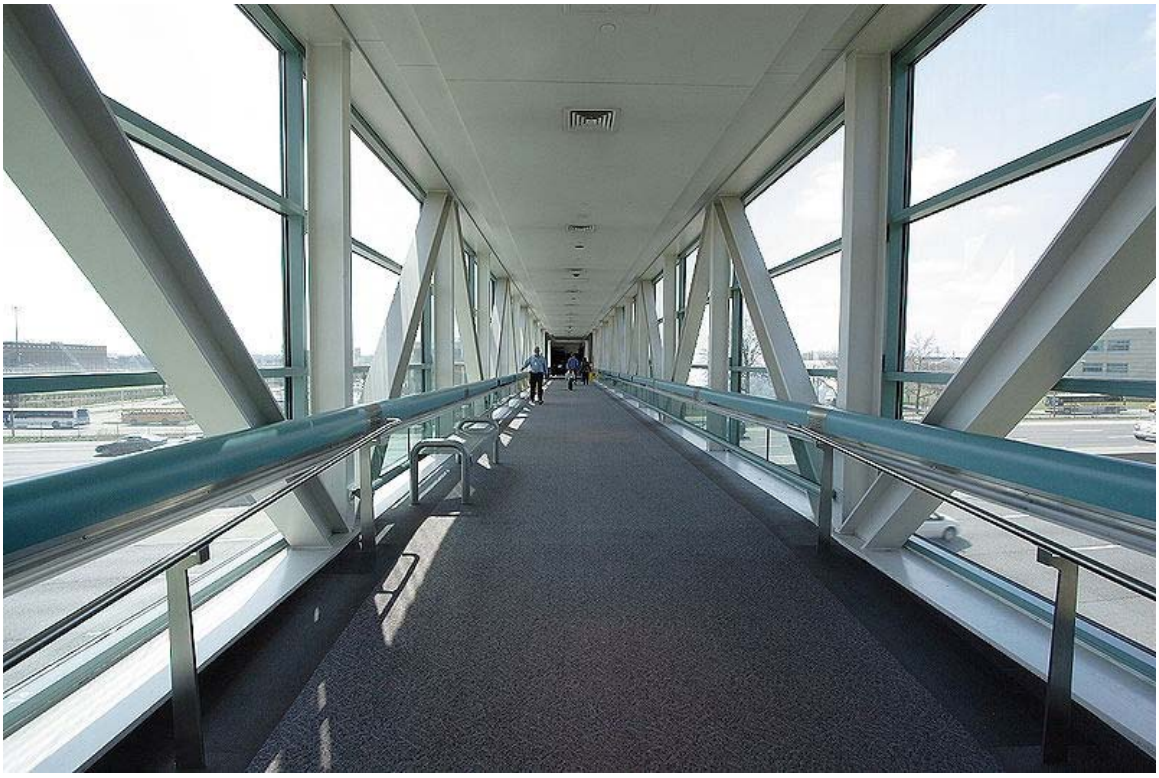
An **overpass** (called a ***flyover*** in the UK and most Commonwealth countries) is a bridge, road, railway or similar structure that crosses over another road or railway. An *overpass* and *underpass* together form a grade separation.

North America

In North America, a **flyover** is a high-level overpass, built above main overpass lanes, or a bridge built over what had been an at-grade intersection. Traffic engineers usually refer to the latter as a *grade separation*. A flyover may also be an extra ramp added to an existing interchange, either replacing an existing cloverleaf loop (or being built in place of one) with a higher, faster ramp that bears left. Such a ramp may be built as a right or left exit.

Pedestrian

A pedestrian overpass allows pedestrians safe crossing over busy roads without impacting traffic.



Pedestrian overpass, I-64, St. Louis, Missouri. This overpass is located at the St. Louis Science Center.

First railroad flyover

The world's first railroad flyover was constructed in 1843 by the London and Croydon Railway at Norwood Junction railway station to carry its atmospheric railway vehicles over the Brighton Main Line.

Hydrogen Highway

A **hydrogen highway** is a chain of hydrogen-equipped filling stations and other infrastructure along a road or highway which allow hydrogen powered cars to travel. It is an element of the hydrogen infrastructure that is generally assumed to be a pre-requisite for mass utilization of hydrogen cars. For instance, William Clay Ford Jr. has stated that infrastructure is one of three factors (also including costs and manufacturability in high volumes) that hold back the marketability of fuel cell cars. (On the flip side, some commentators such as Amory Lovins in *Natural Capitalism*, argue that such infrastructure may not be necessary). Hence, there are plans and proposals to begin developing hydrogen highways through private and public funds.

The use of hydrogen cars has been proposed as a means to reduce local pollution and carbon emissions because hydrogen fuel cell cars emit clean exhaust. However, as long as the majority of hydrogen continues to be produced by burning fossil fuels, some pollution is emitted by the hydrogen manufacturing process.

British Columbia

In British Columbia, Canada, the *BC Hydrogen Highway* is planned to link Vancouver and Whistler. Seven fueling stations were planned. On March 13, 2007, Canadian Prime Minister Stephen Harper announced funding of almost $200 million Canadian for environmental projects in B.C. including the hydrogen highway.

Germany

Germany has a variety of hydrogen initiatives such as National Hydrogen and Fuel Cell Technology Innovation Programme (NIP), promoted by government institutions such as NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology) and industry groups including the Clean Energy Partnership and DWV (German Hydrogen and Fuel Cell Association). These initiatives incorporate development of hydrogen stations. In March 2008, the government of the German state of North Rhine-Westphalia launched the "NRW Hydrogen HyWay" initiative along the existing hydrogen pipeline (total length 230 km) in the Rhine-Ruhr area.

Italy

One of the first hydrogen highways in Europe is the Motorway of Brennero. It runs from Modena to Verona.

Japan

Japan's hydrogen highway is part of the Japan hydrogen fuel cell project. Twelve hydrogen fueling stations have been built in 11 cities in Japan.

Scandinavia

The Scandinavian Hydrogen Highway Partnership (SHHP) links the three current hydrogen highways HyNor, Hydrogen Link and HyFuture.

Norway

HyNor - In Norway, a 7 (planned) station hydrogen highway from Oslo to Stavanger, opened on 11 May 2009 in Oslo.

Sweden

Hydrogen Sweden (formerly Hyfuture / SamVäte i Väst) is the development of a hydrogen highway system in the western region of Sweden.

Denmark

The hydrogen link network is a planned 15 station Nordic Transportation Network (NTN) that serves to link Denmark, Norway, Sweden and Germany.

Spain

The first three Spanish fueling stations are located on the A-23 between Huesca and Zaragoza, opened in June 2010.

United States

There are plans and proposals for hydrogen highways in the United States. In August 2008, fuelcelltoday reported that three new hydrogen fueling stations were opening in the U.S., bringing the total to 70 in the country. In April 2009, however, BNET Auto reported that there are currently 65 hydrogen stations in the U.S.

California

Hydrogen fueling stations began to be built in California by the California Fuel Cell Partnership around 1999. However, they were not systematically positioned to form a hydrogen highway. California Governor Arnold Schwarzenegger, in a State of the State address in 2004, said: *I am going to encourage the building of a hydrogen highway to take us to the environmental future. ... I intend to show the world that economic growth and the environment can coexist. And if you want to see it, then come to California*. Schwarzenegger introduced his "Vision 2010" plan. The main objective was for every citizen in California to have access to hydrogen fuel along the state highways by 2010. The plan included the construction of 150 to 200 hydrogen stations to be spaced out a maximum of every 20 miles.

In 2005, Governor Schwarzenegger signed a Senate Bill (SB) 76 to fund the first year of the California Hydrogen Highway project. The bill provided $6.5 million to build the Hydrogen Highway Networkup, known as CaH2Net, with up to three hydrogen fueling stations, as well as allowing leasing or purchase of hydrogen vehicles by the state and requiring development of standards for hydrogen fuel by 2008. Senate Bill (SB) 1505, signed by Schwarzenegger in 2007, put the environmental requirements described in the California Hydrogen Highway Blueprint Plan into statute. As of July 2007, California had 25 stations in operation.

As of March 2009, according to *Greenwire*, 24 hydrogen fueling stations were operating in California. As of January 2011, there were between 25 and 30, mostly in and around Los Angeles.

Florida

On February 18, 2005, Jeb Bush, Governor of Florida, announced proposed legislation (called the Florida Energy Technologies Act) to promote hydrogen technologies in the state. He made this announcement at the ground-breaking of the first fueling station of a proposed hydrogen highway from Orlando to Tampa.

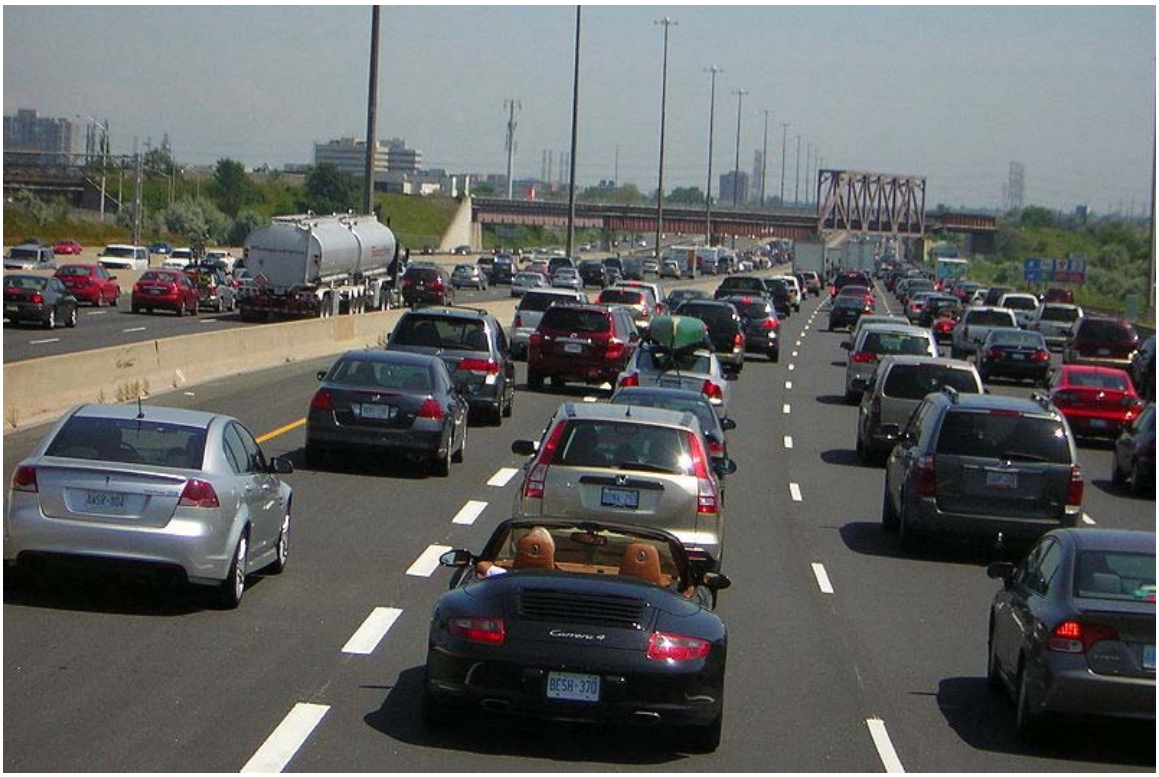
East Coast

The East Coast Hydrogen SuperHighway (or NY Hydrogen H_2IWay) was planned, as of 2006, to extend from New York City to Albany, and further to upstate NY in order to reach Montreal, as well as especially to the west to Buffalo, along the major New York Thruway with further linking to the Interprovincial Hydrogen Corridor planned between Detroit, Toronto and Montreal. No fueling stations have yet been opened.

South Carolina also has a hydrogen freeway in the works. There are currently two hydrogen fueling stations, one each in Aiken and Columbia, SC. According to the South Carolina Hydrogen & Fuel Cell Alliance, the Columbia station has a current capacity of 120 kg a day, with future plans to develop on-site hydrogen production from electrolysis and reformation. The Aiken station has a current capacity of 80 kg. The University of South Carolina, a founding member of the South Carolina Hydrogen & Fuel Cell Alliance, received funding of 12.5 million dollars from the Department of Energy for its Future Fuels Program.

Chapter 10

Highway



Highway 401, the busiest highway in North America.

A German Autobahn in Lehrte.

The Makran Coastal Highway was an ancient road within Pakistan. Now it's a major road leading to the city of Gwadar

The SP-160, known as Rodovia dos Imigrantes, in southeastern Brazil.

A **highway** is a public road, especially a major road connecting two or more destinations. Any interconnected set of highways can be variously referred to as a "highway system", a "highway network", or a "highway transportation system". Each country has its own national highway system.

Overview

Major highways are often named and numbered by the governments that typically develop and maintain them. Australia's Highway 1 is the longest national highway in the

world at over 14,500 km (9,000 miles) and runs almost the entire way around the continent. The United States has the world's largest network of highways, including both the Interstate Highway System and the U.S. Highway System. At least one of these networks is present in every state and they interconnect most major cities. Some highways, like the Pan-American Highway or the European routes, span multiple countries. Some major highway routes include ferry services, such as U.S. Route 10, which crosses Lake Michigan.

Traditionally highways were used by people on foot or on horses. Later they also accommodated carriages, bicycles and eventually motor cars, facilitated by advancements in road construction. In the 1920s and 1930s many nations began investing heavily in progressively more modern highway systems to spur commerce and bolster national defense.

Major modern highways that connect cities in populous developed and developing countries usually incorporate features intended to enhance the road's capacity, efficiency, and safety to various degrees. Such features include a reduction in the number of locations for user access, the use of dual carriageways with two or more lanes on each carriageway, and grade-separated junctions with other roads and modes of transport. These features are typically present on highways built as *motorways* (*freeways*).

Terminology

In English law, parliament and more formal situations the term is used to denote *any* public road used which include streets and lanes as well as main roads, trunk roads and motorways. Acts of parliament have used the term throughout history from the Highways Act 1555 through to the Highways Act 1980. The rules of the road are outlined in the Highway Code.

In England and Wales, a "Public Highway" is a road or footpath over which the public has the right of access, i.e. the opposite of a "private road".

In American law, the word "highway" is sometimes used to denote any public way used for travel, whether major highway, freeway, turnpike, street, lane, alley, pathway, dirt track, footpaths, and trails, and navigable waterways; however, in practical and useful meaning, a "highway" is a major and significant, well-constructed road that is capable of carrying reasonably-heavy to extremely-heavy traffic. Highways generally have a route number designated by the state and federal road comptroller offices.

California Vehicle Code, Sections 360, 590, define a "highway" as only a way open for use of motor vehicles, but the California Supreme Court has held that "the definition of 'highway' in the Vehicle Code is used for special purposes of that act," and that canals in the town of Venice, California, are "highways" that are entitled to be maintained with state highway funds.

Smaller roads may be termed byways.

History

A German autobahn in the 1930s

Modern highway systems developed in the 20th century as the automobile gained popularity. The world's first limited access road was constructed in Italy in 1922. Construction of the Bonn-Cologne autobahn began in 1929 and was opened in 1932 by the mayor of Cologne.

The Special Roads Act 1949 in the United Kingdom provided the legislative basis for roads for restricted classes of vehicles (later termed motorway). The first section of motorway in the UK opened in 1958 (part of the M6 motorway) and then in 1959 the first section of the M1 motorway.

The Federal Aid Highway Act of 1956 provided appropriating $25 billion for the construction of 41,000 miles (66,000 km) of Interstate Highways over a 20-year period in the United States.

Social effects

Reducing travel times relative to city or town streets, modern highways with limited access and grade separation create increased opportunities for people to travel for

business, trade or pleasure and also provide trade routes for goods. Modern highways reduce commute and other travel time but additional road capacity can also create new induced traffic demand. If not accurately predicted at the planning stage, this extra traffic may lead to the new road becoming congested sooner than anticipated. More roads add on to car-dependence, which can mean that a new road brings only short-term mitigation of traffic congestion.

Where highways are created through existing communities, there can be reduced community cohesion and more difficult local access. Consequently property values have decreased in many cutoff neighborhoods, leading to decreased housing quality over time.

Economic effects

In transport, demand can be measured in numbers of journeys made or in total distance travelled across all journeys (e.g. passenger-kilometres for public transport or vehicle-kilometres of travel (VKT) for private transport). Supply is considered to be a measure of capacity. The price of the good (travel) is measured using the generalised cost of travel, which includes both money and time expenditure.

The effect of increases in supply (capacity) are of particular interest in transport economics, as the potential environmental consequences are significant.

In addition to providing benefits to their users, transport networks impose both positive and negative externalities on non-users. The consideration of these externalities - particularly the negative ones - is a part of transport economics. Positive externalities of transport networks may include the ability to provide emergency services, increases in land value and agglomeration benefits. Negative externalities are wide-ranging and may include local air pollution, noise pollution, light pollution, safety hazards, community severance and congestion. The contribution of transport systems to potentially hazardous climate change is a significant negative externality which is difficult to evaluate quantitatively, making it difficult (but not impossible) to include in transport economics-based research and analysis. Congestion is considered a negative externality by economists.

Environment effects

Highways are extended linear sources of pollution:

Roadway noise increases with operating speed so major highways generate more noise than arterial streets. Therefore, considerable noise health effects are expected from highway systems. Noise mitigation strategies exist to reduce sound levels at nearby sensitive receptors. The idea that highway design could be influenced by acoustical engineering considerations first arose about 1973.

Air quality issues: Highways may contribute fewer emissions than arterials carrying the same vehicle volumes. This is because high, constant-speed operation creates an emissions reduction compared to vehicular flows with stops and starts. However, concentrations of air pollutants near highways may be higher due to increased traffic volumes. Therefore, the risk of exposure to elevated levels of air pollutants from a highway may be considerable, and further magnified when highways have traffic congestion.

New highways can also cause habitat fragmentation, encourage urban sprawl and allow human intrusion into previously untouched areas, as well as (counterintuitively) increasing congestion, by increasing the number of intersections. They can also reduce the use of public transport, indirectly leading to greater pollution.

High-occupancy vehicle lanes are being added to some newer/reconstructed highways in North America and other countries around the world to encourage carpooling and mass-transit. These lanes help reduce the number of cars on the highway and thus reduces pollution and traffic congestion by promoting the use of carpooling in order to be able to use these lanes. However, they tend to require dedicated lanes on a highway, which makes them difficult to construct in dense urban areas where they are the most effective.

Road traffic safety

Road traffic safety aims to reduce the harm (deaths, injuries, and property damage) on the highway system from traffic collisions and includes the design, construction and regulation of the roads, the vehicles that use them and also the training of drivers and other road-users. Improvement of road safety needs to be balanced with the provision of an effective efficient transport system. A report published by the World Health Organization in 2004 estimated that some 1.2m people were killed and 50m injured on the roads around the world each year and was the leading cause of death among children 10 – 19 years of age. The report also noted that the problem was most severe in developing countries and that simple prevention measures could halve the number of deaths. For reasons of clear data collection, only harm involving a road vehicle is included. A person tripping with fatal consequences or dying for some unrelated reason on a public road is not included in the relevant statistics.

Statistics

International sign used widely in Europe denoting the start of special restrictions for a section of highway.

The United States has the world's largest network of highways, including both the Interstate Highway System and the U.S. Highway System. At least one of these networks is present in every state and they interconnect most major cities.

China's highway network is the second most extensive in the world, with a total length of about 3.573 million km. China's expressway network is also the second longest in the world, and it is quickly expanding, stretching some 60,300 km at the end of 2008, In 2008 alone, 6,433 km expressways were added to the network.

- **Longest international highway:** the Pan-American Highway, which connects many countries in the Americas, is nearly 25,000 kilometres (15,534 mi) long as of 2005. The Pan-American Highway is discontinuous because there is a significant gap in it in southeastern Panama, where the rainfall is immense and the terrain is entirely unsuitable for highway construction.

- **Longest national highway (point to point):** The Trans-Canada Highway is 7,821 km (4,857 mi) long as of 2006. The T.C.H. runs east-west across southern Canada, the populated portion of the country, and it connects many of the major urban centers along its route crossing almost all of the provinces, and reaching almost all of the capital cities. The T.C.H. begins on the east coast in Newfoundland, traverses that island, and crosses to the mainland by ferry. It reaches most of the Maritime Provinces of eastern Canada, and a side route using ferries traverses the province of Prince Edward Island. After crossing the two most populous provinces of Quebec and Ontario, the T.C.H. continues westward across Manitoba, Saskatchewan, Alberta, and British Columbia. After reaching Vancouver, B.C., on the Pacific Coast, there is a ferry route west to Vancouver Island and the provincial capital city of Victoria, B.C.

- **Longest national highway (circuit):** Australia's Highway 1 at over 20,000 km (12,427 mi). It runs almost the entire way around the continent's coastline. With the exception of the Federal Capital of Canberra, which is far inland, Highway 1 links all of Australia's capital cities, although Brisbane and Darwin are not directly connected, but rather are bypassed short distances away. Also, there is a ferry connection to the island state of Tasmania, and then a stretch of Highway 1 that links the major towns and cities of Tasmania, including Launceston and Hobart (this state's capital city).

- **Largest national highway system:** The United States of America has approximately 6,430,366 kilometres (3,995,644 mi) of highway within its borders as of 2008.

- **Busiest highway:** Highway 401 in Ontario, Canada, has volumes surpassing an average of 500,000 vehicles per day in some sections of Toronto as of 2006.

- **Widest highway (maximum number of lanes):** The Katy Freeway (part of Interstate 10) in Houston, Texas, has a total of 26 lanes in some sections as of 2007. However, they are divided up into general use/ frontage roads/ HOV lanes, restricting the traverse traffic flow.

- **Widest highway (maximum number of through lanes):** Interstate 5 along a 2-mile section between Interstate 805 and California State Route 56 in San Diego, California, which was completed in April 2007, is 22 lanes wide.

- **Highest international highway**: The Karakoram Highway, between Pakistan and China, is at an altitude of 4,693 m/15,397 ft.

Bus lane

Highway bus lane on Gyeongbu Expressway in South Korea

Some countries incorporate bus lanes onto highways.

Country	Highway	Bus lanes (km)	Section
Canada	Ontario Highway 417	7	Eagleson Road – Ontario Highway 417 (Ottawa)
Canada	Ontario Highway 403	6	Mavis Road – Winston Churchiil Blvd. (Mississauga)
South Korea	Gyeongbu Expressway	137.4	Hannam IC(Seoul) ~ Sintanjin IC(Daejeon)

Korea

In South Korea, in February 1995 - Bus lane (essentially an HOV-9) established between the northern terminus and Sintanjin for important holidays and in 1 July 2008 - Bus lane enforcement between Seoul and Osan (Sintanjin on weekends) becomes daily between 6

AM and 10 PM. On 1 October this is adjusted to 7 AM to 9 PM weekdays, 9 AM to 9 PM weekends.

Highway 401 in London, Ontario

A Polish expressway in Bielsko-Biała

The Pan-American Highway where it serves as the main street in Máncora, Peru

The Pan-American Highway in the Greater Buenos Aires (city of Florida), Argentina

Highway A1 near Bologna, Italy with 10 lanes

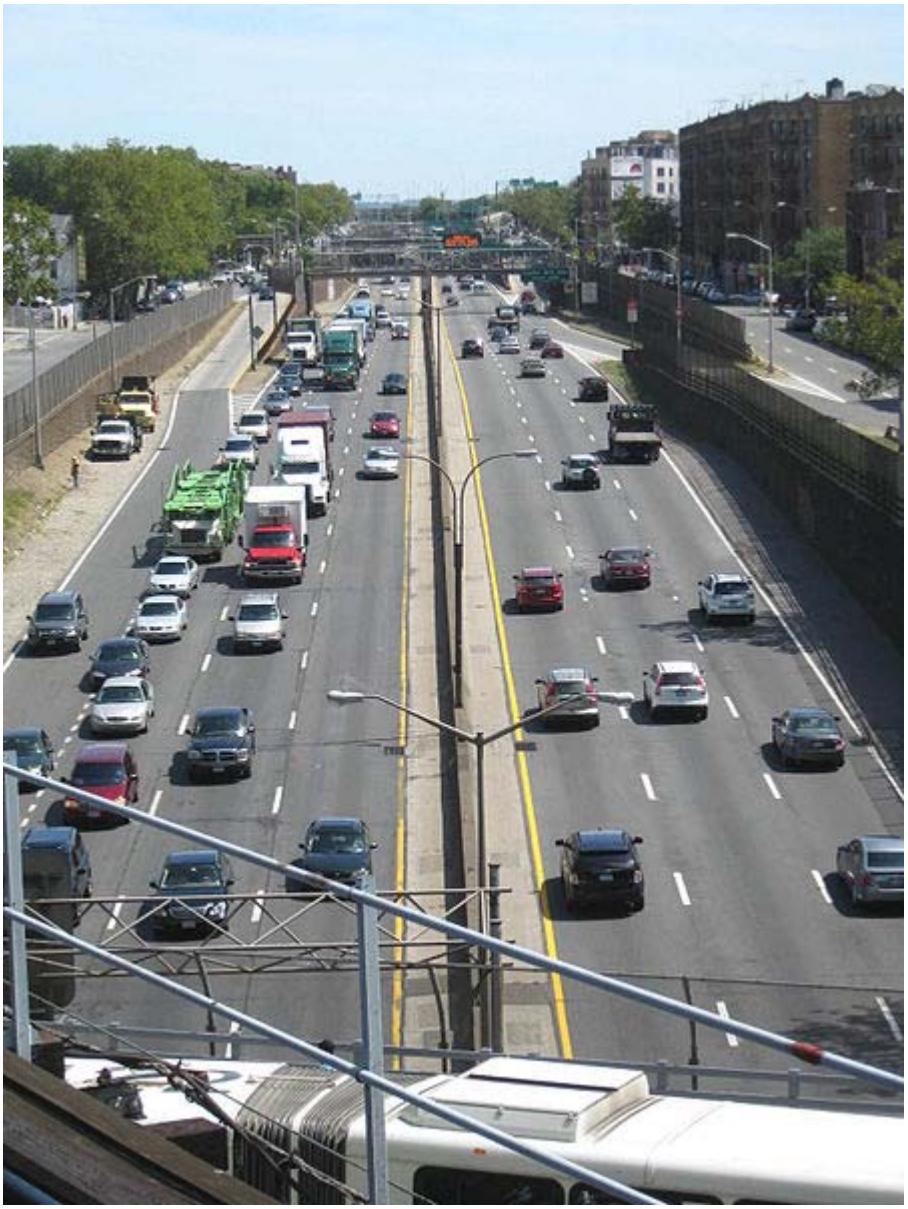
The Dr. Sun Yat-sen Memorial Freeway in Taipei, Taiwan

Highway 401 in Oshawa, Ontario

The Metropolitan Expressway in Tokyo, Japan

A typical expressway in Mainland China

3/4 highway interchange in Dubai, United Arab Emirates

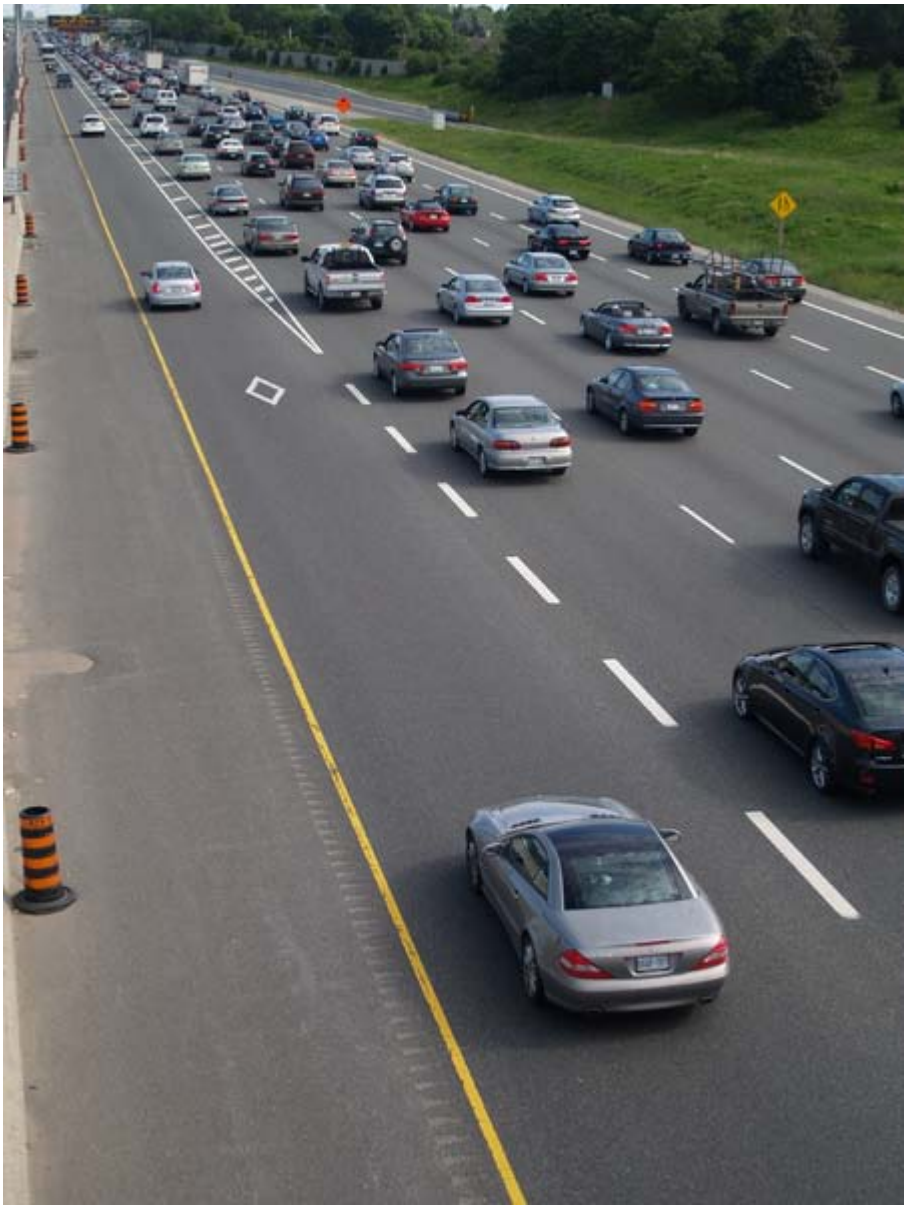


The Cross Bronx Expressway in New York, United States

A highway in Tehran

32-lane toll plaza at an Indian expressway

Expressway at Delhi.



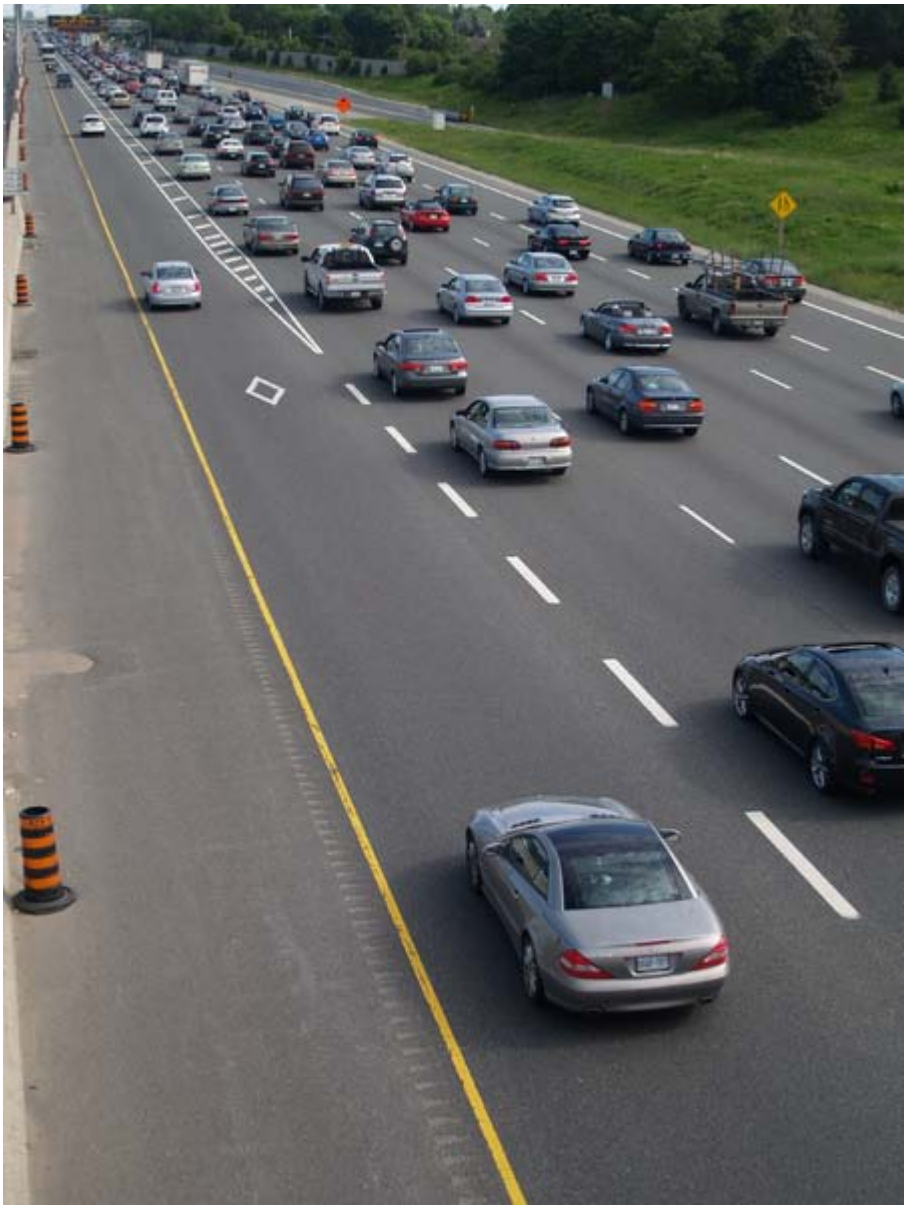
Highway 404 southbound, with HOV lanes

Highway split

Chapter 11

High-Occupancy Vehicle Lane

A permanent, separated high-occupancy vehicle lane on I-91 near Hartford, Connecticut



The HOV lanes in the Greater Toronto Area, including this one on Highway 404, are separated by a stripped buffer zone at most points. This buffer zone breaks occasionally to allow vehicles to enter and exit the HOV lane.

In transportation engineering and transportation planning, a **high-occupancy vehicle lane** (also called an **HOV lane** or **carpool lane**) is a lane reserved for vehicles with a driver and one or more passengers. These lanes are also known as **carpool lanes**, **commuter lanes**, restricted lanes, diamond lanes, express lanes, and are called transit lanes in Australia and New Zealand.

Qualified vehicles

Qualification for HOV status varies by locality, for instance, in some cases it may require more than two passengers. When an automobile is used as an HOV, the group of people using it is often called a carpool, though the term HOV includes buses and vans. However, bus lanes may not necessarily be intended for use by carpools. An HOV or carpool may be allowed to travel on special road lanes, usually denoted with a diamond marking in the United States and Canada, on which vehicles not meeting minimum occupancy are prohibited, called **restricted lanes**, **carpool lanes** or **diamond lanes**. In some cases, single occupant vehicles are allowed provided that they are hybrid vehicles or use native fuels. U.S. federal law states that HOV lanes "must allow motorcycles and bicycles to use the HOV facility, unless either or both create a safety hazard." In Canada, no such exemptions exist, but (as of 2009) the city of Winnipeg, Manitoba is planning to add HOV lanes around its downtown area. In some areas, such as Atlanta, Southern California, Hartford, Connecticut, Seattle Area, Boston Area, Salt Lake City and the Greater Toronto Area, the HOV lanes are full-time, while in others, such as the San Francisco Bay Area, Phoenix, Dallas-Fort Worth, Long Island, and Northern New Jersey, they are usable by other vehicles outside of peak hours. Honolulu uses a "zipper" barrier to create an additional HOV lane on the westbound side of Interstate H-1, and Boston shifts one lane of traffic from north to southbound on a six mile stretch of Interstate 93 between Quincy and Dorchester.

In some regions, buses are allowed to travel on the road shoulder when traffic becomes heavy, but it is often still illegal for cars (even HOVs) to take the shoulder to get around traffic jams. Highway 403 in Mississauga, Ontario, Canada (near Toronto) and Highway 404 in York Region and Toronto for instance had their shoulders widened in 2003 and 2004 respectively, so they serve a dual purpose as bus lanes and accident lanes. Although full HOV lanes are available for carpooling traffic, buses still continue to use shoulders along the 403. In Columbus, Ohio, shoulders on I-70 are HOV lanes reserved for buses at all times.

In emergency situations, an HOV "cordon" is sometimes placed prohibiting all vehicles from crossing the cordon during specified times. The cordon is enforced through the use of police checkpoints. For example, Midtown and Lower Manhattan were placed under cordons during the morning peak hours in the aftermath of the September 11, 2001 attacks and during the 2005 New York City transit strike.

Theory and practice

Traffic sign used for high-occupancy traffic lanes in Norway.

Standard restrictive traffic sign in the United States. The lozenge symbol (◊) indicates a preferential-only lane restriction, in this case an HOV with two or more passengers

HOV lanes used on I-24 in Nashville omit solid line separation which typically divides the adjacent traffic flow. This setup allows the operator to leave when desired.

California's decal to identify clean air vehicles that are allowed to use HOVs regardless of the number of passengers.

The relative rarity of high-occupancy vehicles compared to single occupancy vehicles—estimated at 7% of the traffic—in the United States and Canada makes HOV lanes work for the drivers who can use them. When it is uncongested, an HOV lane can move at full speed even when parallel (non-HOV) lanes suffer delays from queueing at bottlenecks. In theory, an HOV lane moves more people per lane at a higher speed while moving fewer vehicles.

In practice for some communities, including Atlanta, Houston, Los Angeles, Washington, D.C., and Seattle, HOV lanes regularly carry more people than adjacent regular lanes of travel, as reported by the Transportation Research Board HOV Committee.

Various organizations and services make it easier for commuters to utilize HOV lanes. Regional and corporate sponsored vanpools, carpools, and rideshare communities give commuters a way to increase occupancy. For locales where such services are lacking, online rideshare communities can serve similar purpose.

Reversible lanes

Some cities that use separated HOV lanes make them reversible; i.e. usable only by inbound traffic during the morning rush and usable only by outbound traffic during the evening rush. This method met with criticism after an August 1995 incident in Pittsburgh,

Pennsylvania, in which a negligent highway employee failed to close the gate preventing access to the HOV lanes of Interstate 279. This led to a high-speed head-on collision that killed six people.

Houston is a city which employs reversible HOV lanes. Seattle runs some of its HOV lanes in the express lanes of I-5 and I-90; others run in the mainline, outside of the express lane area. San Diego uses a reversible, separated 2-lane HOV route along an eight mile stretch of I-15 that travels south-bound in the morning and north-bound in the afternoon and evening. This route also doubles as a toll-road for single occupant vehicles using the CalTrans FasTrak system. Montreal employs reversible lanes on Park Avenue, and has reversible bus lanes on the Champlain Bridge. The Crescent City Connection in New Orleans features two reversible HOV lanes. I-394 from Highway 100 to I-94 in Minneapolis also has a reversible HOV lane that is simultaneously tolled for single passenger automobiles through the MnPASS system when it is open for traffic.

Separate systems

Some HOV lanes are built on completely separate roadways from their corresponding general use lanes; some are constructed on parallel roads separated by a concrete barrier, while others are built on grade-separated (i.e. elevated or underground) roadways. One example is the Harbor Freeway in Los Angeles, California, where four HOV lanes travel on the upper deck of the freeway. This type of construction is said to maintain optimal efficiency by keeping general use traffic from merging back and forth into the HOV lanes, and by maximizing space on the main roadway for general use traffic. Additionally, major interchanges on such routes are often equipped with HOV-only ramps, which minimizes haphazard cross-freeway merging.

Queue jumping

Most cities use HOV lanes to allow carpool traffic to bypass areas of regular congestion. For example, in Metro Vancouver, British Columbia, HOV traffic is separated from general traffic and given priority access to the entrance to George Massey Tunnel. This method is also used extensively in Seattle (Washington) to allow HOV traffic to bypass ramp meters at freeway entrances and proceed directly onto the freeway without stopping.

HOV-only highway

An extreme example is Interstate 66 in the Northern Virginia suburbs of Washington, D.C. During rush hour, on a 10-mile (16 km) segment of I-66 between the Capital Beltway and the Theodore Roosevelt Bridge (Virginia state line/Washington city limit), the entire roadway in the direction of rush-hour traffic (eastbound in the morning, westbound in the evening) is reserved for HOV. However traffic heading westbound to Dulles Airport is exempt from the HOV requirement, although the Dulles Access road is 3 miles before I-495; thus making HOV violators an easy target in that stretch. State and

local police regularly stop all traffic to ensure HOV requirements are met. Violators face a $1000 fine and 6 demerit points for the fourth violation.

Criticism

The traffic speed differential between HOV and general purpose lanes creates a potentially dangerous situation if the HOV lanes are not separated by a barrier. (A Texas Transportation Institute study found that HOV lanes lacking barrier separations caused a 50% increase in injury crashes.)

Critics cite recent unpublished research of San Francisco-area HOV lanes that found the HOV system increased congestion, delays, and pollution while not increasing carpooling.

The National Motorists Association in the U.S. opposes HOV lanes on the grounds that motorists are entitled to full use of highway systems paid for by their taxes. Similar arguments from other motorist advocacy groups put forth the argument that the best gains to be made in reducing high-density traffic is when all lanes are available for all vehicles, thus allowing a maximum of traffic to filter forward during peak travel times.

In the Netherlands, the first HOV lane in Europe was opened on the Rijksweg 1 on 27 October 1993. On the first day, a former Minister of Transport and Water Management drove on the lane alone in his car in order to draw forth a test case. The judge ruled that Dutch traffic law lacked the concept of a "car pool" and thus that the principle of equality was violated. At the end of the following year, the lane was opened to all traffic as a reversible lane.

Possible future directions

A number of cities are considering converting under-utilized HOV lanes to high-occupancy toll (HOT) lanes, and others intend to build new highway infrastructure. This would permit single-occupant vehicles to buy the right to use the HOV lanes for a toll, but total flow would be regulated (with automatically determined variable pricing based on demand), to ensure total speeds on the HOV lane do not drop noticeably.

In August 2010, the Utah Department of Transportation implemented such a program for traffic along Interstate 15 from Layton in the north to Lehi in the south. The system uses RFID transmitters to monitor entry and exiting of the lane and charges drivers between 25 cents to one dollar, depending on demand. The transmitters can be turned off in the event that the driver has two or more occupants in their vehicle.

User phenomena

One symptom of HOV lanes that challenges the contention that HOV lanes are not effective has been the slugging phenomenon in the Northern Virginia suburbs of Washington, D.C. *Slugging* is the term used to describe a unique form of commuting

where drivers go to pre-arranged "slug lines" and pick up commuters who need a ride. The driver shouts out his destination, and people in the line going to that destination enter the car on a first-come-first-served basis. There is very specific etiquette to the system to ensure a fair, consistent, and agreeable commute for all. Slugging benefits drivers by enabling them to use the HOV lane, benefits "sluggers" by getting them free rides, and benefits the community by decreasing the number of cars on the road.

In San Francisco and surrounding communities, designated casual carpool sites allow drivers to pick up passengers to the same destination.

When HOV lanes were first introduced in California in the 1970s, some drivers placed an inflatable person in the passenger seat in an attempt to fool regulators. This was soon outlawed, but the practice persists. In the UK in 2005, a camera that was claimed to distinguish mannequins or dolls from humans was being tested on the Forth Road Bridge in an effort to thwart cheaters.

Chapter 12

Raised Pavement Marker

The amber markers separate opposing traffic lanes. The blue marker denotes a fire hydrant on the left sidewalk.

A **raised road marker** or **raised pavement marker** is a safety device used on roads. These devices are usually made with plastic, ceramic, or occasionally metal, and come in a variety of shapes and colors. Many varieties include a lens or sheeting that enhance their visibility by reflecting automotive headlights. Some other names for specific types of raised pavement markers include Botts' dots, delineators, cat's eyes, road studs, or road turtles. Sometimes they are simply referred to as reflectors.

Reflective raised pavement markers

In the United States, Canada, as well as Australia, these plastic devices commonly have two angled edges facing drivers and containing one or more corner reflector strips. In areas where snowplowing is frequent, conventional markers are placed in a shallow groove cut in the pavement, or specially designed markers are used which include a protective metal casting that is embedded in recesses in the pavement, allowing the marker to protrude slightly above the pavement surface for increased visibility, much like a cat's eye. In areas with little snowfall, reflective raised pavement markers are applied directly to the road surface rather than being embedded into the surface.

Snowplowable reflective marker

The device's reflective surface enables the device to be clearly visible at long distances at night and in rainy weather. The devices come in multiple colors which vary in usage depending on local traffic marking standards.

Usage of color in Europe

In almost all European countries, such markers will include reflective lenses of some kind. Most appear white or gray during daylight; the colors discussed here are the color of light they reflect. Because of their inconspicuousness during the day, they are always used in conjunction with painted retro-reflective lines, they are never seen on their own.

- White markers — for lane markings. When used on dual-carriageways, motorways or one-way roads they may illuminate red on the reverse, to indicate drivers are traveling the wrong way.
- Yellow or amber markers — These are found next to the central reservation (U.S.: median) on motorways and dual carriageways.
- Red markers — These are found by the hard shoulder on motorways and at the edge of the running surface on other roads. They are also occasionally used to indicate a no-entry road.

- Green markers — These are used where slip-roads (U.S.: off ramp) leave and join the main carriageway.
- Blue markers — Are used to indicate the entrance to police reserved slip-roads (these do not lead anywhere, they are to allow police to park and monitor motorway traffic).

The exception to the above rules are:

- Fluorescent yellow markers — These are used to indicate temporary lanes during roadworks on major roads and are glued to the road surface, they are never embedded in it. Any painted markings will be removed from the road surface if they contradict the markers. They are fluorescent yellow in color, so they stand out in the day, but reflect white light at night. Where used they are much more numerous and dense than standards markers, as they are not used in conjunction with painted lines.

Usage of color in North America

A white reflective raised pavement marker (Stimsonite design)

A blue raised pavement marker (for marking the location of fire hydrants)

- White markers — for lane markings or to mark the right pavement edge.
- Yellow or amber markers — These separate traffic moving in opposite directions, or mark the left pavement edge on one-way roadways.
- Blue markers — Usually used to mark the location of fire hydrants.
- Green markers — Usually used to indicate that emergency vehicles can open gates to enter a gated community.

Colors can also be combined, with a different color facing each direction:

- White and red or yellow and red — white or yellow for normal use in one direction, and red to indicate "do not enter" in the other direction
- White and black — white for marking lane restrictions (such as an HOV diamond) in one direction on a roadway that has "reversible" traffic flow, and black in the other direction when the markings don't apply

The current trend for lane markings is to intersperse retroreflective paint lines with reflectors as seen on the majority of American highways.

Usage of color in Australia

A red raised pavement marker

A yellow raised pavement marker used to mark a stop valve.

While Australian designs generally follow those in the U.S., the colors generally follow European usage. Differences from European usage include:

- Blue — Usually used to mark the location of fire hydrants, as in North America
- Yellow — In addition to marking the median of freeways, single yellow reflectors are used with broken yellow lines to denote tram tracks on which motorized traffic can drive, and double yellow reflectors are used with solid yellow lines to denote tram tracks on which motorized traffic may not drive other than to cross.

History

Cat's eyes were the earliest form of reflective pavement markers, and are in use in the United Kingdom and other parts of the world. They were invented in the United Kingdom in 1933 by Percy Shaw and patented in 1934 (UK patents 436,290 and 457,536), and the United States in 1939 (U.S. patent 2,146,359). On March 15, 1935, Shaw founded Reflecting Roadstuds Ltd, which became the first manufacturer of raised pavement markers.

The designs now used widely throughout the United States didn't appear until more than a decade later. They are based on the invention of engineer Sidney A. Heenan in the

course of his employment with the Stimsonite Corporation in Niles, Illinois. Heenan filed an application for a patent on October 23, 1964. Patent No. 3,332,327 was subsequently granted on July 25, 1967.

Stimsonite went on to become the leading manufacturer of raised pavement markers in the United States and was acquired in the mid-1990s by Avery Dennison Corporation. For about a decade, Avery sold Stimsonite's line under its Sun Country brand. In 2006, Avery sold its raised pavement marker division to Ennis Paint, one of the largest manufacturers worldwide of paint for pavement markings (particularly lane markings). Ennis Paint (based in Ennis, Texas) now markets the Stimsonite product line (and descendants) under the Stimsonite brand. Other manufacturers of reflective raised pavement markers sold in the United States under various designs include 3M, Apex Universal, and Ray-O-Lite.

Cat's eyes

Cat's eyes, in their original form, consist of two pairs of reflective glass spheres set into a white rubber dome, mounted in a cast iron housing. They are generally more durable than Botts' dots (they are snowplough safe) or other forms of markers and also come in a variety of colors. They have enjoyed widespread usage in the British Isles and elsewhere around the world.

Botts' dots

A round, white Botts' dot

Nonreflective raised pavement markers (also known as Botts' dots) are usually round, are white or yellow, and are frequently used on highways and interstates in lieu of painted lines. They are glued to the road surface with an epoxy and as such are not suitable in areas where snow plowing is conducted. They are usually made out of plastic or ceramic materials.

Pedestrian crossing studs

A Toucan crossing with markers visible. In this case thermoplastic paint has been used.

In the UK, the area in which pedestrians should cross at pelican crossings is marked out by a series of markers. Occasionally these are painted as squares on the road but more often a metal stud is used. These are usually square and made from unpainted steel or aluminum.

Delineator

Delineators are tall pylons (similar to traffic cones or bollards) mounted on the road surface, or along the edge of a road, and are used to channelize traffic. These are a form of raised pavement marker but unlike most such markers, delineators are not supposed to be hit except by out-of-control or drifting vehicles. Unlike their smaller cousins, delineators are tall enough to impact not only a vehicle's tires but the vehicle body itself. They usually contain one or more reflective strips. They can be round and open in the center or curved (45 degree sections) of plastic with a reflective strip. They are also used in low reflective markers in a "T" shape. They can also be used to indicate lane closures as in cases where the number of lanes is reduced.

The name delineator is also used for reflective devices attached to other objects which are technically not pavement markers.

Chapter 13

Reversible Lane

The Lions Gate Bridge from the south end in Stanley Park, Vancouver.

A **reversible lane** (called a **counterflow lane** or **contraflow lane** in transport engineering nomenclature) is a lane in which traffic may travel in either direction, depending on certain conditions. Typically, it is meant to improve traffic flow during rush hours, by having overhead traffic lights and lighted street signs notify drivers which lanes are open or closed to driving or turning.

Reversible lanes are also commonly found in tunnels and on bridges, and on the surrounding roadways — even where the lanes aren't regularly reversed to handle normal changes in traffic flow. The presence of lane controls allows authorities to close or reverse lanes when unusual circumstances (such as construction or a traffic mishap) require use of fewer or more lanes to maintain orderly flow of traffic.

Signals and markings

In the United States and Canada, reversible lane markings are typically a dashed or broken double yellow line on both sides. Most often done on three-lane roads, the reversible lane is typically used for traffic in one direction at morning rush hour, the opposite direction in the afternoon or evening, and as a turning lane at most other times. There is also a transition period (typically 30–60 min) between reversals during which traffic is prohibited to prevent collisions.

Sometimes, lane control signals are placed over the roadway at regular intervals (within sight of each other) indicating which lanes are allocated to which travel direction; a red X indicates the lane is closed or reserved for the opposite direction; a green arrow indicates a permitted travel lane. The center lane is marked with either one of those (depending on time of day), and often a flashing yellow X at other times to indicate an imminent closure of a lane, becoming solid yellow before turning red. Other setups had double-turn-lane signs backlit with white fluorescent lighting instead of the flashing yellow X.

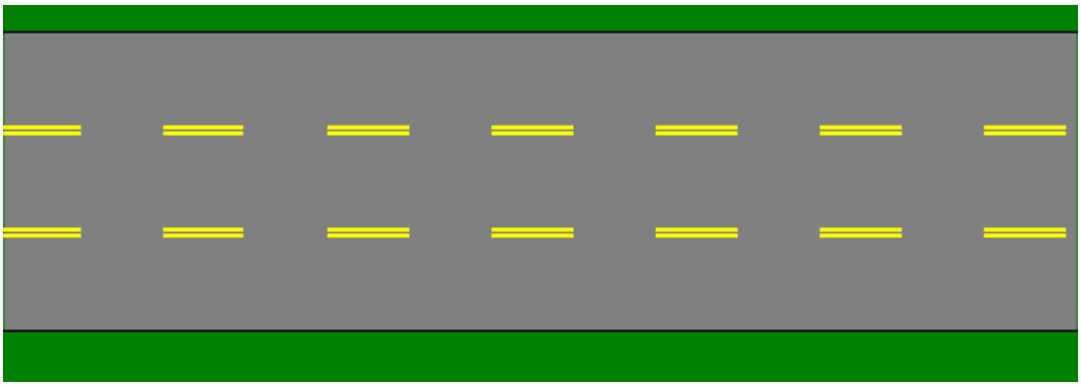
Other streets with reversible lanes (including several in Washington, D.C.) simply have signs posted indicating what lanes are open to which direction when.

Separation of flows

Some more recent implementations of reversible lanes use a movable barrier to establish a physical separation between allowed and disallowed lanes of travel. In some systems, a concrete barrier is moved during low-traffic periods to switch a central lane from one side of the road to another; some examples are the Coronado Bridge in San Diego, California, the seven lane Tappan Zee Bridge on the Hudson River in New York and the 8 lane Auckland Harbour Bridge across the Waitemata Harbour in Auckland, New Zealand. Other systems use retractable cones or bollards which are built into the road, or retractable fences which can divert traffic from a reversible ramp. The two center lanes of the six-lane Golden Gate Bridge are reversible; they are southbound during morning rush hour and northbound at evening rush hour, and are demarcated by vertical yellow markers placed manually in sockets in the roadway.

Many urban freeways have entirely separate carriageways (and connecting ramps) to hold reversible lanes (the reversible lanes in such a configuration are often referred to as "express lanes"). Generally, traffic flows in one direction or another in such a configuration (or not at all); the carriageways are not "split" into two-lane roadways during non-rush periods. Typically, this sort of express lane will have fewer interchanges than the primary lanes, and many such roadways only provide onramps for inbound traffic, and offramps for outbound traffic.

Passing lanes



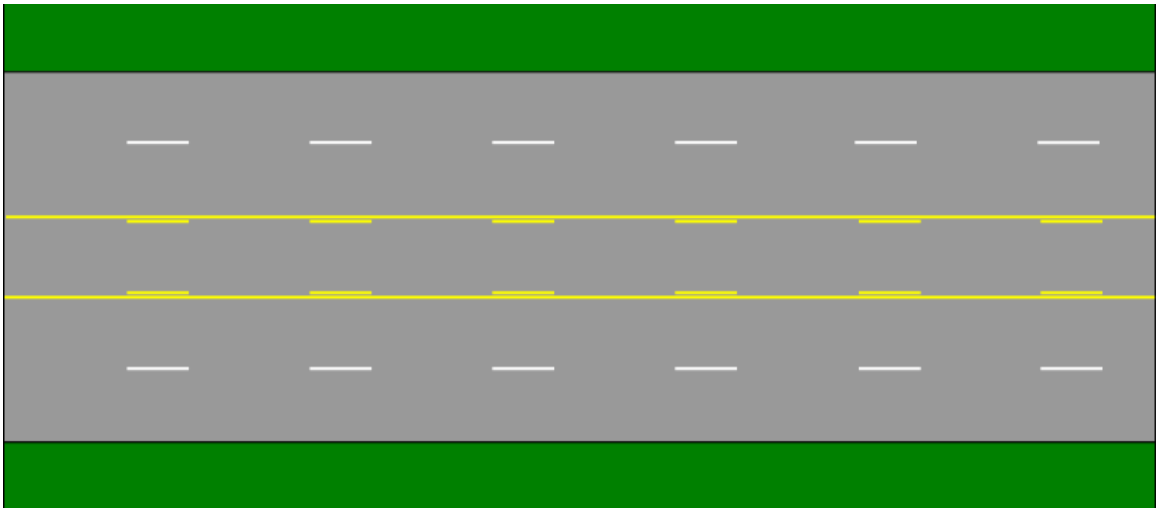
Typical striping on an old-style suicide lane setup in the United States

Historically, a **suicide lane** has also referred to a lane in the center of a highway meant for passing in both directions. Neither direction has the right-of-way, and both directions are permitted to use the lane for passing. In a similar layout, three lanes are striped with two in one direction and one in the other, but traffic in the direction with one lane is allowed to cross the centerline to pass.

2+1 roads have replaced some of these in Europe and North America.

Turn lanes / flush median

A turn lane (called a 'flush median' in New Zealand parlance), with a raised median in the forefront.



This is a typical 5-lane arterial equipped with a center-turn lane. These are often found in cities, towns and developed areas near cities. In the United States, the sequence line is

located on the inside of the lane. In Canada it is the same for all provinces with the exception of Ontario where the sequence line is located on the outside.

Another type of center two-way lane is a **center left-turn lane** (for countries which drive on the right), *center turn lane* or *median turn lane*, a single lane in the center of the road into which traffic from both directions pulls to make a left turn. While this is sometimes also called a "suicide lane", it is actually far safer, as traffic collisions occur at far lower speeds.

These roads are very common in suburban areas and less common in rural areas, though developed areas near Interstate Highway bypasses of a small city often have them. Many were divided highways before the median was demolished or otherwise filled with the turn lane. Many four-lane streets with a double-yellow line are being phased out in favor of five-lane streets with center turn lanes, because the center lane allows for less disruption of traffic flow. For routes with moderate traffic, other movements involve downgrading four-lane undivided streets to three-lane streets with a turn-only center lane.

This center lane can be used by emergency vehicles like police cars, ambulance, and fire trucks to avoid traffic traveling in either direction. Drivers are not allowed to use the center lane of such a highway for passing slow-moving vehicles, except when funding or space constraints dictate use of it as a rush hour "travel lane" when traffic is largely asymmetric between a central business district and its suburbs.

Bus transit

In bus transit, a contraflow lane is a lane reserved for buses in which the direction of bus traffic is opposite the flow of traffic on the other lanes.

Examples

No (or minimal) lane controls

- Connecticut Avenue in Washington, D.C.
- Chain Bridge in Washington, D.C.
- Bailey Bridge, in Coquitlam, B.C..

Lane controls and no (or minimal) physical separation

Trans-national

- The Peace Bridge between the U.S. and Canada, connecting Fort Erie, Ontario to Buffalo, New York. Three lanes total, all marked reversible, 1 reversed in the direction of rush hour flow with the possibility of all lanes flowing in the same direction based on traffic needs.
- The Lewiston-Queenston Bridge connecting Niagara-on-the-Lake, Ontario to Lewiston, New York. Five lanes total, all marked as reversible, 1 to 4 lanes

marked daily in the same direction depending on traffic needs. In addition to the directional signals, special signals are also fitted to specify what type of vehicle may use the lane.

Australia

- The Sydney Harbour Bridge in Sydney, New South Wales (8 lanes total, 3 (formerly 4) potentially reversible, 3 reversed daily. AM peak 6 South 2 North. PM peak 3 South 5 North. Other times, 4 South 4 North),
- The Spit Bridge, Sydney, New South Wales (4 lanes total. AM peak 3 South, 1 North. PM peak 3 North, 1 South. All other times 2 North, 2 South).
- The Alfords Point Bridge in the south-western suburbs of Sydney, New South Wales. 3 lanes total, with the centre lane reversible using manual placement of plastic bollards. Originally this bridge was built with two lanes, and was to be part of twin spans, but only the foundations and excavations for approach works were built for the Eastern span, and the bridge was opened with one lane used in each direction. New approach works commenced in January 2007 for the second span, at a cost of 45 million AUD, eliminating the need for a reversible lane. However, a 300-metre reversible centre lane will still remain on Alfords Point Road over Henry Lawson Drive, approximately 500 meters north of this proposed bridge.
- General Holmes Drive generally has 4 north lanes and 4 south lanes, but during morning peak hour one southbound lane is divided from the others with a plastic island with signes placed along the top. The island is shifted across by the RTA with a specialized veichle. This lane is used as a northbound lane for local traffic to get to Botany and Mascot from the St George area.
- Flagstaff Road in the southern suburbs of Adelaide, South Australia. 3 lanes total, with the centre lane reversible.
- Johnston Street, Melbourne, Victoria. 5 lanes total, with the centre lane reversible.
- Queens Road, Melbourne, Victoria. 5 lanes total, with the centre lane reversible.
- Tasman Bridge, Hobart, Tasmania. 5 lanes total, with center lane reversible

Canada

- The Lions' Gate Bridge in Vancouver (3 lanes total, 1 reversible)
- The Angus L. Macdonald Bridge, Chebucto Road and the Herring Cove Road in Halifax, Nova Scotia (3 lanes total, 1 reversible)
- Jarvis Street in downtown Toronto (5 lanes total, centre lane reversed daily for AM/PM rush hours) - now converted to 2 lanes each direction + bicycle lane
- The Champlain Bridge in Ottawa (3 lanes total; 1 reversible)
- Sherman Access and Sherman Cut in Hamilton, Ontario (2 lanes, both reversible)
- The George Massey Tunnel in Delta and Richmond, B.C. (4 lanes total, 2 reversible, with access controlled by gates)
- Connors Road in Edmonton (4 lanes, 3 reversible)
- 170th Street from north of 137th Avenue to Levasseur Road in Edmonton (3 lanes total, 1 reversible)

- 97th Street from 118th Avenue to 127th Avenue in Edmonton (7 lanes total, 3 reversible)
- Centre Street from 20th Avenue N to 6th Avenue S in Calgary (4 lanes total, 2 reversible; standard configuration is 2 out, 2 in; morning rush is 1 out, 3 in; and evening rush is 3 out, 1 in)
- 10th Street NW / 9th Street SW from 5th Avenue NW to 4th Avenue SW in Calgary (4 lanes total, 2 reversible; standard configuration is 2 out, 2 in; morning rush is 1 out, 3 in; and evening rush is 3 out, 1 in)
- Park Avenue in Montreal, five lanes total, centremost lane is reversible, sidemost lanes are reserved for public transport during rush hour; morning rush is 2 in, one out (not including bus lanes), evening rush is reversed
- Champlain Bridge in Montreal, rush hour bus lanes
- Jacques Cartier Bridge in Montreal, five lanes total, two for both directions, one rush hour central reversible lane
- During the 2010 Winter Olympics, British Columbia Highway 99 was subject to lane control in three-lane sections of the highway, via signs on the side of the road that were changed manually.

Croatia

- State Route 102 near Kraljevica leading southbound to the Krk Bridge used to have a three-lane passing lane combination, blind curves, and a steep grade. It was later changed to a passing lane combination that makes the northbound traffic dominant.

Turkey

- Reversible lanes are frequently used in hilly sections of highways with heavy truck traffic. Most of them were built during the 1980s and 1990s.

United Kingdom

- The A38 road across the Tamar Bridge and through the Saltash Tunnel in Saltash, England. The middle lane is reversible, allowing for control of traffic flows in holiday periods and during rush hour.
- The A61 Queens Road in Sheffield, England, although it is a very short section (4 lanes total, 1 reversible: allowing for either 3 out, 1 in, or 2 out, 2 in).
- The A470 North Road in Cardiff, Wales, A section of around 1 mile long between the Maindy Road Junction and College Avenue where the road drops from a dual two-lane to a three-lane section. One lane is always dedicated to Northbound (out of town) traffic, and one lane to Southbound (city centre bound traffic) with the centre lane reversing depending on the time of day - i.e. in the morning 2 lanes into the city, 1 lane out, in the evening 2 lanes out of the city, 1 lane in.
- The A15 in Lincoln (Canwick Road) has a short three-lane section of tidal flow.

United States

Alabama

- In Montgomery, Norman Bridge Road through the Garden District and Old Cloverdale has a center lane with reversible markings and traffic flow lights between Burton Street and Legrand Place.

Arizona

- In Phoenix on 7th Avenue between McDowell Road and Northern Avenue, and 7th Street between McDowell Road and Cave Creek Road/Dunlap Avenue. On both roads, the lane configuration is 2 southbound and 3 northbound, with the center lane open for southbound traffic between 6-9am and open to northbound traffic between 3-6pm. No left turns are permitted during these hours for either direction.

California

- The Golden Gate Bridge (6 lanes total, 2 reversible, vertical median markers provide minimal physical separation) connecting San Francisco with suburban Marin County
- Doyle Drive (U.S. Route 101) in San Francisco
- Lafayette Street in Santa Clara - the center lane is used for northbound traffic on weekday mornings, southbound traffic for weekday afternoons, and as a center turning lane at other times.
- The Barry-Baker Tunnel, one of only two means of access to the Marin Headlands from U.S. Route 101 in Marin County, is not wide enough to accommodate bidirectional traffic. It consists of a single reversible lane for automobiles and two bicycle lanes. The direction of automobile traffic alternates every five minutes, controlled by a traffic light at each end of the tunnel. The bicycle lanes, one for each direction, are located on either side of the reversible lane; buttons on either side of the tunnel trigger flashing signs alerting drivers entering the tunnel to the presence of cyclists.

Connecticut

- Asylum Avenue in Hartford

Florida

- Bay Street in Jacksonville

Georgia

- Northside Drive in Atlanta: the center lane of three is reversed using overhead lane-use control signals.
- Vineville Avenue in Macon: the center lane of three is reversed using overhead lane-use control signals.

Kentucky

- The Clay Wade Bailey Bridge in Covington (3 lanes total, 1 reversible)
- Nicholasville Road (U.S. Highway 27) in Lexington, has reversible lanes (lane signals, no physical separation) starting at its intersection with Rose Street at the University of Kentucky campus and ending at New Circle Road, the city's inner beltway. During morning rush hour, southbound traffic (away from the UK campus and downtown) is restricted to one lane between campus and Southland Drive, and two lanes from Southland to New Circle. Northbound traffic faces the same restrictions in the evening rush hour. During off-peak hours, an equal number of lanes are dedicated to traffic in each direction.
- Baxter Avenue and Bardstown Road (U.S. Highway 31E) in Louisville have reversible lanes (lane signals without any physical separation) for 2½ miles starting at their intersection with Lexington Road and ending at Douglass Boulevard. Southbound traffic leaving downtown Louisville is restricted to one lane during the morning rush hour, with northbound traffic having the same restriction during the evening rush hour. Electronic signs over the roadway alert motorists to the traffic flow dedication of each lane.

Indiana

- In Indianapolis, Fall Creek Parkway North Drive between Central Avenue and Evanston Avenue has 5 lanes (7 in some sections) with 1 lane marked as reversible. Configuration is typically designed to allow for 3 in 2 out during morning rush hours, and 2 in/3 out during afternoon rush hours. Due to Fall Creek Parkway's proximity to the Indiana State Fairgrounds, lane configurations change periodically to facilitate traffic flow during events at the fairgrounds.

Maryland

- The Chesapeake Bay Bridge near Annapolis (5 lanes total, all marked reversible, 1 usually reversed for normal peak traffic). However, due to its dual spans, when there are 2 eastbound lanes and 3 westbound the opposing sides are completely divided, this is the usual configuration.
- The Hanover Street Bridge in Baltimore has 5 lanes total marked reversible, with 1 usually reversed for normal peak traffic).
- Georgia Avenue in Silver Spring has 7 lanes. During most hours, the center lane is marked with a yellow lit *X* as a left turn lane for both directions. During morning and evening rush hours, the lane is marked with a down facing green arrow – southbound in the morning, northbound in the evening – or a red *X* –

northbound in the morning, southbound in the evening – and left turns are prohibited.
- Colesville Road in Silver Spring has 6 lanes. During off-rush hours, three lanes go in each direction. During morning rush hours, four lanes (marked with green arrows) go southbound, while northbound (marked with Xs in those lanes) is relegated to two lanes. During afternoon rush, the process is reversed.

Michigan

- The Mackinac Bridge near St. Ignace treats the passing lane of the southbound side as a temporary northbound lane during the Labor Day bridge walk, at which timee the northbound side is used for pedestrians.

Nebraska

- Dodge Street between Turner Boulevard and 68th Street in Omaha: no physical separation; lanes marked with overhead lane-use control signals.

New York

- Delancey Street in New York City has two lanes on the eastbound side adjacent to the median used for westbound traffic in the morning rush hour between the Williamsburg Bridge and Allen Street. All traffic in these lanes must continue to and then turn left onto Allen, during these times left turns are prohibited from the regular westbound roadway onto Allen Street.
- Manhattan Bridge (New York City) lower level has three lanes, which can have all lanes used in one direction or reversible with two lanes one way and the other for the opposite direction.
- The upper level of the Queensboro Bridge in New York City has 4 lanes and can have all flowing outbound (PM peak), or two lanes each direction in normal configuration.

North Carolina

- 7th Street in Charlotte
- Tyvola Road in Charlotte
    - Since the closure (2005) and implosion (2007) of the former Charlotte Coliseum (II), this road is no longer reversible; all lights have been removed and lane signs are permanent. It was designed this way for Coliseum traffic from NBA games and concerts.
- U.S. Route 29 in Charlotte
    - This road is the access road to Charlotte Motor Speedway from the city, and links to Interstate 485. It is used for any events at the Speedway.
- High Point Road in Greensboro
- Edwards Mill Road in Raleigh

Ohio

- At least one road in Sandusky has reversible lanes, for the purpose of allowing quick departure of Cedar Point guests.

Pennsylvania

- The Liberty Bridge near the southern terminus of I-579 in Pittsburgh has 4 lanes, all of which are potentially reversible, and 2 of which are reversed based on rush-hour times.
- The West End Bridge in Pittsburgh has 4 lanes, which are all potentially reversible.
- West General Robinson Street near Heinz Field in Pittsburgh has 4 lanes, and 2 are reversible.

Texas

- West Alabama Street and North Main Street in Houston – both are three-lane streets, which operate in a 2 in, 1 out configuration during the morning rush, a 1 in, 2 out configuration during the evening rush, and a 1 each way + two-way left turn lane at other times.
- Interstate highway 10 and highway 290 in Houston have contraflow HOV lanes intended to help ease rush hour traffic.

Lane controls and physical separation

- The A38(M) motorway (also known as the Aston Expressway) in Birmingham, England. The road connects the city centre with Spaghetti Junction on the M6. It is a 2-mile, 7-lane section of motorway with no central reservation, and a lower than usual speed limit of 50 mph. Constructed in 1971, it was the United Kingdom's first contraflow road. Overhead lane control signals allow for 4 lanes in and 2 out in the morning rush hour, reversed in the evening, and 3 lanes each way at all other times. One dividing lane is closed to traffic at all times, and motorcycles are permanently prohibited from using the central, red-surfaced lane (with a fixed sign) owing to its use as an off-camber drain. The lane control signals can be set to allow travel in either direction for any lane in exceptional circumstances, which has been used for single-lane, reduced-speed running in each direction (or 2+1 with no divider) during road work, allowing the expressway to remain largely open even during major repairs. However, the 7-lane section splits at both ends to fully divided sets of 4x2 lane slip roads, with the central red lane ending in a barrier, so full use of this flexibility is uncommon and occasional overnight closure is required.
- The U.S. Route 78 portion in Snellville, GA, United States, has 6 lanes in total. This occurs from the limited access portion through Stone Mountain Park to G.A. State Route 124 (Scenic Highway) for several miles. The middle two lanes are reversible (usually occurring during rush hour) with a varying lane always

reserved a center turn lane while the 3 lanes are used for one side and 2 for the other. Example of an intersection on U.S. 78. However, due to rising traffic volumes during peak hours that made traffic flows equivalent, the reversible lane system was removed in 2009.
- The Caldecott Tunnel between Oakland, California and Contra Costa County, California has three separate bores, with the middle bore switching direction twice daily for rush hour traffic.

Lane controls and physical separation by movable barrier

- Benjamin Franklin Bridge, Walt Whitman Bridge, Commodore Barry Bridge, and Betsy Ross Bridge in Philadelphia, PA
- Tappan Zee Bridge in New York
- Theodore Roosevelt Bridge in Washington, D.C.
- Auckland Harbour Bridge in Auckland, New Zealand
- Coronado Bridge in San Diego, California
- Southeast Expressway in and near Boston, Massachusetts
- A contraflow line, also called a zipper lane, is in used on eastbound Interstate H-1 for traffic heading from leeward Oahu to Pearl Harbor. It is open from 5:30 to 8:30 a.m.

Third (reversible) carriageways on freeways

- Bundesautobahn 7, New Elbe Tunnel, Hamburg, Germany (actually two reversible carriageways, plus two fixed)
- Warringah Expressway in Sydney, Australia
- Interstate 5 in Seattle, Washington, and Interstate 90 between Seattle and Bellevue, Washington
- Interstate 15 in northern San Diego, California
- Interstate 25 and US-36 in Denver, Colorado
- Interstate 394 through Minneapolis, Minnesota and its western suburbs
- Interstate 90/Interstate 94 (Kennedy Expressway portion) in Chicago, Illinois
- Interstate 70 through St. Louis, Missouri
- Lee Roy Selmon Crosstown Expressway from Brandon to Tampa, Florida
- Interstate 64 in Norfolk, Virginia (center carriageway reserved for HOV traffic during rush hour)
- Interstate 395 and Interstate 95 through Washington, D.C. and its Virginia suburbs (center carriageway reserved for HOV traffic during rush hour)
- Lincoln Tunnel between Weehawken, New Jersey and New York, New York has three tubes with two lanes each. The center tube carries two lanes in peak direction weekdays (with a reserved inbound bus lane during the AM rush period) and a single lane each direction off-peak (nights, weekends, holidays).
- Interstate 93 through Boston, Massachusetts
- Caldecott Tunnel (on California State Route 24), soon to be gone (additional tunnel bore being added to remove need for reversible lanes).

Entire roadway routinely reversed

South and Marion Roads in Adelaide, provide access to the Southern Expressway at its northern end. Here, southbound access to the expressway from South Road is restricted.

- The Anchieta/Imigrantes highway system in Brazil contains the world's longest fully reversible road (The Imigrantes variant at a length of 58.5 km). It comprises a total of 10 lanes distributed over 4 separate roadways (3+3+2+2), each of which can be reversed. Traffic flow is unidirectional on up to three roadways at a time, in different combinations, depending on demand. Since this highway system is the only quick route from São Paulo to the beach, the majority of the traffic on Fridays and Sundays are cars on weekend trips, creating highly asymmetrical demand.
- The Southern Expressway in Adelaide, South Australia is the world's longest exclusively one-way reversible road, spanning 21 km though the city's southern suburbs. It changes direction to carry peak hour traffic to the city centre in the morning and away from the city in the evening. On weekends the directions are reversed.
- In Washington, D.C., the Rock Creek and Potomac Parkway between the Lincoln Memorial and Calvert St. is converted from two lanes in each direction to one-way southbound in the morning and one-way northbound in the evening rush hour Monday through Friday, excluding federal holidays. The P Street exit, usually

unavailable northbound, is an allowed left exit in the evening. South of Virginia Avenue, two lanes are closed during rush hours to facilitate the merge to or from Virginia Avenue. There are no overhead markings, but police barricades block wrong-way entrances to the roadway.

- In Washington, D.C., parts of 15th Street NW and 17th Street NW are one-way during certain hours. There are no overhead markings on either road.
- Canal Road in Washington, D.C. (between Foxhall Road and Arizona Avenue)
- Sherman Access in Hamilton, Ontario. 2 lanes total, both marked as reversible, with both lanes flowing in the same direction during rush hour each weekday.
- Assembly Street and Bluff Road (both part of South Carolina 48), along with Shop Road and George Rogers Blvd, in Columbia, South Carolina, are one-way during gridiron football matches at Williams-Brice Stadium/
- The lower deck of the Centre Street Bridge in Calgary, Alberta is fully reversible. It normally allows for two way traffic, but both lanes flow in the same direction during rush hour each day.
- Victoria Bridge, in Montreal, Quebec, normally allows for two-way traffic. But during rush hours, it only allows one-way traffic, northbound in the morning, and southbound in the afternoon.
- Farnam Street in Omaha is a normally two-way, two-lane street that during rush hour becomes one-way eastbound in the morning and westbound in the evening.
- Sierichstraße in Hamburg, Germany, a fully-reversible, two-lane city street.
- The 4th Street Bridge in Los Angeles, a fully reversible street controlled by overhead signals. It switches direction every rush hour and on weekends. In case of emergencies, the bridge can be one-way to or from Los Angeles.