Transportation engineering

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That branch of engineering related to the movements of goods and people by highway, rail, air, water, and pipeline. Special categories include urban and intermodal transportation.

Highway transportation

Engineering for highway transportation involves planning, construction, and operation of highway systems, urban streets, roads, and bridges, as well as parking facilities. Important aspects of highway engineering include (1) overall planning of routes, financing, environmental impact evaluation, and value engineering to compare alternatives; (2) traffic engineering, which plans for the volumes of traffic to be handled, the methods to accommodate these flows, the lighting and signing of highways, and general layout; (3) pavement and roadway engineering, which involves setting of alignments, planning the cuts and fills to construct the roadway, designing the base course and pavement, and selecting the drainage system; and (4) bridge engineering, which involves the design of highway bridges, retaining walls, tunnels, and other structures. *See See also:* HIGHWAY ENGINEERING; TRAFFIC-CONTROL SYSTEMS; VALUE ENGINEERING.

Highway transportation engineers face the challenge of moving increasing volumes of traffic over existing routes while improving safety records. Therefore, a major initiative was launched in the United States to develop technology for a nationwide intelligent vehicle highway system (IVHS). In urban areas, such systems are being designed to feature increased use of vehicle detection systems, video cameras, variable message signs, and electronic toll collection with automatic vehicle identification. In more remote areas, sensors on highways are being designed to detect unsafe conditions such as slippery roads, relay the information via radio waves to a central computer, and transmit a warning via satellite to individual vehicles. Eventually, new cars will be instrumented so that the driver can communicate with municipalities and receive directions or other information. Posted speed limits will be changed automatically according to traffic flow.

In modern highway construction, particularly in urban areas, major emphasis is placed on developing regional transportation plans utilizing significant public input. Highways must meet the transportation needs of the public, adhere to strict environmental regulations, and satisfy concerns over traffic and esthetics, in order to gain wide support. Air pollution, noise problems, and destruction of wetlands are some concerns that must be carefully addressed.

Highway pavements must be maintained with surfaces of acceptable riding quality. This places severe demands on paving materials because of heavy traffic volumes, repetitive truck axle loads, weather conditions that may vary from severe freezing to hot summers, and the use of chemicals to aid in snow and ice removal. As a result of a national Strategic Highway Research Program (SHRP) in the United States, an improved asphalt paving system known as Superpave has been developed and has been implemented to improve pavement life substantially. *See See also:* PAVEMENT.

Bridge engineers are now using new or improved materials to develop more cost-effective, longerlasting structures. A high-performance steel (HPS-70W) that provides improved toughness, weldability, and strength has been used to build several bridges. Also, a high-performance concrete (HPC) that provides higher strength and improved workability is being used. Bridge rehabilitation is a major area for infrastructure innovation. Estimates show that approximately one-third of the bridges in the United States are in urgent need of repair. Deterioration of the bridge deck often leads to deterioration of the underlying superstructure, and methods of constructing more durable decks have been developed. This includes the use of epoxy-coated steel reinforcing bars and high-performance concrete with microsilica for deck construction. Precast elements are sometimes effective in deck replacement, because disruption to traffic can be minimized. Bridges are susceptible to the forces generated by seismic events, as evidenced by the destruction resulting from the Loma Prieta and Northridge earthquakes in California. Bridge engineers have developed methods for retrofitting existing structures to resist earthquakes, as well as designing improved details for new construction. To increase load capacity and reliability, posttensioned cables can be added to beams and girders for longer spans. For shorter spans of about 50 ft (15 m) or less, bridges can be replaced with large culverts constructed from prefabricated steel or aluminum components, or from precast concrete units. Other techniques include the use of lead-rubber seismic isolation devices to replace traditional bearings at supports, and constructing steel or fiberglass casings around concrete bridge columns to increase strength and ductility. *See See also:* BRIDGE; EARTHQUAKE; STRUCTURAL MATERIALS.

Rail transportation

Engineering for railway transportation involves planning, construction, and operation of terminals, switchyards, loading/unloading facilities, trackage, bridges, tunnels, and traffic-control systems for freight and passenger service. For freight operations, there is an emphasis on developing more efficient systems for loading, unloading, shifting cars, and operating trains. Facilities include large marshaling yards where electronic equipment is used to control the movement of railroad cars. Also, there is a trend to developing more automated systems on trackage whereby signals and switches are set automatically by electronic devices. To accommodate transportation of containers, tunnels on older lines are being enlarged to provide for double-stack container cars.

Efforts for more efficient operations have begun to pay dividends. Reversing the declines of earlier years, rail freight volume has been steadily increasing since 1987. New facilities are being built to handle the increased volume, and tracks are being added at points of congestion. Although the total trackage in the United States today is only 113,000 mi (182,000 km), major railroads haul significant tonnage.

In Europe and Japan, rail passenger service has long been an important part of the overall transportation system. In the United States, passenger service is small compared to that of earlier years, but there is a renewed interest in rail passenger service in certain congested urban corridors. In Japan and Europe, high-speed systems have been developed. For example, the French have developed an Aerotrain that is propelled by a fan jet engine and floats on a cushion of low-pressure air on a guideway at 267 mi/h (430 km/h). A more conventional high-speed system introduced in 1994, the Eurostar, operates at service speeds of up to 190 mi/h (300 km/h). One development that has received limited attention in Germany, Japan, and the United States is a magnetic levitation system in which cars on a frictionless magnetic suspension are propelled along guideways by linear induction motors. A proposed line in Germany would be capable of speeds near 300 mi/h (480 km/h). *See* *See also:* MAGNETIC LEVITATION.

Most high-speed rail systems require new alignments to accommodate the increased speed. However, in many areas it is difficult and expensive to construct new alignments. Thus, engineers are challenged to develop high-speed rail passenger cars that can operate on existing trackage. One approach has been to develop suspension systems that tilt the coaches on curves to enhance stability. In the mid-1990s the fastest trains in the United States were running about 100 mi/h (160 km/h). In 1998 the Transportation Research Board initiated a program to develop technologies to upgrade rail systems to higher speeds.

A major accomplishment in intercontinental rail transportation was the completion in late 1993 of the Channel Tunnel. Culminating nearly 8 years of design and construction, the twin tunnels facilitate a trip from London to Paris in 3 h. The tunnel was designed to handle a full range of services, including conventional and intermodal freight operations, motor car and truck carrying services, and high-passenger trains. *See* *See also:* RAILWAY ENGINEERING; TUNNEL.

Air transportation

Engineering for air transportation encompasses the planning, design, and construction of terminals, runways, and navigation aids to provide for passenger and freight service. High-capacity, long-range, fuel-efficient aircraft, such as the 440-seat Boeing 777 with a range of 7200 mi (12,000 km) are desirable. Wider use of composites and the substitution of electronic controls for mechanical devices reduce weight to improve fuel economy. Smaller planes are more efficient for shorter runs. *See* *See also:* AIR TRANSPORTATION; COMPOSITE MATERIALS.

Many airport terminals for smaller population centers are designed with little uncommitted space but with provisions for incremental expansion as traffic grows. In many larger population centers, state-of-the-art facilities and major improvements have been constructed, such as the terminals at Denver and Washington, D.C. (both National and Dulles). As air transportation continues to grow, increased emphasis is placed on terminal designs that facilitate the rapid movement of passengers and baggage. Extensive conveyor belt systems with electronic identifications have been installed in the newer facilities to speed movement of baggage from planes to common central areas. At the larger airports, moving sidewalks are commonly used to move passengers through widely dispersed gate areas. Also, computer-controlled shuttle cars without operators (people movers) are used to move people rapidly from central areas to gate areas. In some cases, rapid transit rail facilities or dedicated busways are available to carry passengers directly from the airport to central business districts. As airways continue to concentrate flights in large hub operations to increase efficiency, engineers and planners focus on developing improved facilities to speed the transfer of passengers and baggage. *See See also:* AIRPORT ENGINEERING.

Air freight cargo facilities are increasingly being automated. An example is the cargo facility at New York's John F. Kennedy Airport, which features a computerized control system, a network of automated distribution conveyors, transfer vehicles, and stacking cranes. A large rack storage building with robotic cranes provides temporary storage and speeds loading and unloading of roll boxes and lightweight containers that hold groups of packages.

Runways must be of sufficient size to safely accommodate landings and takeoffs. The design of pavements for runways and taxiways involves many of the same considerations as for highways, except that runways must be designed to reliably withstand the heavier wheel loads imposed by the aircraft. Navigation aids and other instrumentation, such as for the detection of destructive wind shears or approaching aircraft, are being developed and deployed to enhance safety. *See See also:* AIR NAVIGATION; AIR-TRAFFIC CONTROL.

Water transportation

Engineering for water transportation entails the design and construction of a vast array of facilities such as canals, locks and dams, and port facilities. The transportation system ranges from shipping by barge and tugboat on inland waterways to shipping by oceangoing vessels. Although there is some transportation of passengers, such as on ferries and cruise ships, water transportation is largely devoted to freight.

One important inland waterway in North America is the St. Lawrence Seaway, which connects natural waterways, canals, and the Great Lakes. It permits shipping from the Atlantic Ocean to Duluth, Minnesota. Another is the Ohio-Missouri-Mississippi River System, which extends from Pittsburgh, Kansas City, and Minneapolis to the Gulf of Mexico. Many of the locks and dams in the latter system were constructed many years ago. Engineers are challenged to design and construct larger locks to serve larger barges. Improved navigation systems are needed to enhance safety. *See See also:* CANAL; DAM; RIVER ENGINEERING.

Special facilities are required for loading and unloading oceangoing vessels. For example, supertankers require special offshore mooring where the oil can be rapidly pumped to shore through pipelines. Also, unit trains of 100 or more railcars, carrying bulk products such as grain or coal, require rapid unloading facilities for efficient operations. *See See also:* HARBORS AND PORTS.

Pipeline transportation

Pipeline engineering embraces the design and construction of pipelines, pumping stations, and storage facilities. Pipelines are used to transport liquids such as water, gas, and petroleum products over great distances. Also, products such as pulverized coal and iron ore can be transported in a water slurry.

Water pipelines, probably the most common, can run from minimal sizes to diameters of 20 ft (6 m) or more for large penstocks. Pipelines are often underground, but may run aboveground, particularly in lightly populated areas. Either submerged lines or bridges are required at stream crossings. One aboveground line is the 798-mi (1280-km) 48-in.-diameter (1200-mm) Trans-Alaska pipeline, which was constructed under difficult conditions to transport oil from near Prudhoe Bay on the Arctic Ocean to the city of Valdez on the Gulf of Alaska.

Consideration must be given to route selection, determining the appropriate diameter and thickness of pipe, installation (trench construction, backfilling, and compaction), and durability. Installation under highways, rivers, and other difficult areas is sometimes done using microtunneling techniques to avoid disturbing the surface. With this method, the pipe is advanced underground by jacking from one side, using a laser-controlled guidance system to maintain pipe alignment. Design of pumping facilities requires study of power requirements for different types of material moved, standby facilities, and related considerations. *See See also:* PIPELINE; STORAGE TANK.

Urban transportation

Engineering for urban transportation concerns the design and construction of light rail systems, subways, and people-movers, as well as facilities for traditional bus systems. To enhance public acceptance of new and expanded systems, increased use is being made of computer-aided design (CAD) to visualize alternatives for stations and facilities. Also, animated video systems are used for interactive visualization of plans. *See See also:* COMPUTER-AIDED ENGINEERING.

As congestion in urban areas grows, increased emphasis is being placed on the construction and expansion of subways in major cities. Tunnel-boring machines and segmental liners are often used, along with various techniques to mobilize the strength of the surrounding soil or rock. Light-rail cars are used interchangeably aboveground on controlled right-of-ways or underground through tunnels. *See See also:* SUBWAY ENGINEERING.

In some cities, high-occupancy vehicle lanes have been used to encourage car pooling. Typically these special lanes are reserved during rush hours for vehicles with three or more passengers.

Intermodal transportation

Intermodal transportation, often referred to as containerization, entails the use of special containers to ship goods by truck, rail, or ocean vessel. Engineers must design and construct intermodal facilities for efficient operations. The containers are fabricated from steel or aluminum, and they are designed to withstand the forces from handling. The ships are constructed with a cellular grid of compartments for containers below deck, and they can accommodate one or two layers on deck as well. Advantages include savings in labor costs, less pilferage, and lower insurance costs.

Seaports have special facilities for handling the containers, which arrive by rail or truck. For example, a modernization project in Boston, Massachusetts, provides a 13-acre (5.2-hectare) yard for container storage with

1950 ft (594 m) of continuous berth face for ships. Containers are handled by two special 30-ton-capacity (27-metric ton) gantry cranes that travel on rails with a 96-ft (29-m) gage, and provide an outreach of 115 ft (35 m). Such facilities, which are found throughout the major port cities, are designed to speed the transfer of freight. At major inland centers, intermodal facilities combine loading and handling facilities for containers from truck trailers and rail flatcars. *See* *See also:* HOISTING MACHINES; MARINE CONTAINERS; MERCHANT SHIP.

Environmental considerations

The environment is a major consideration in planning, designing, and constructing transportation facilities. Extensive legislation at both federal and state levels has set forth requirements with the objective of protecting the health and welfare of the general public.

Beginning with the National Environmental Policy Act (NEPA) of 1970, over 25 major federal laws and countless amendments have been enacted. One provision of NEPA is the requirement for approved environmental impact statements (EIS) for federally funded projects. The EIS must document how the environment will be affected, including identification of any unavoidable adverse effects. Opportunities for public involvement in the process must be provided, and alternatives must be identified. To help control air quality, the Clean Air Act administered by the Environmental Protection Agency (EPA) requires review and approval of any new highway with an anticipated average daily traffic volume of more than 20,000 vehicles, or any new parking facility for 1000 cars or more. Approvals are also required for major modifications that increase capacity. The Noise Control Act limits noise levels from surface transportation, often requiring the construction of noise walls adjacent to highways in urban areas. To control water pollution, the Clean Water Act requires permits for discharges into streams and wetlands, both from construction activities and from storm water runoff of the completed facility. *See* *See also:* AIR POLLUTION; WATER POLLUTION.

To avoid exposure of both workers and the public to lead poisoning, special precautions must be taken in the removal and containment of old, deteriorating paint systems from steel bridges. Regulations of the Occupational Safety and Health Administration (OSHA) must be met. Lead-based paint systems were used until the early 1980s, but new steel bridge construction uses either bare weathering steel or modern lead-free paint systems.

Because of the vast material quantities used to construct and maintain transportation systems, opportunities abound for the use of reclaimed and recycled resources. For example, in the production of new pavement, 20% or more of the content can be from old asphalt pavement that has been removed in repaving operations. Old concrete pavements can also be recycled, as aggregate for new concrete or for base layers. Industrial wastes such as fly ash and blast-furnace slag can be used in concrete. Many uses have been found for scrap tires, such as for erosion control devices, for safety devices (tire-sand inertial barriers), in chipped form to create a lightweight bridge approach embankment or to reduce earth pressure against abutment walls, and in the manufacture of rubber asphalt. *See* *See also:* RECYCLING TECHNOLOGY.

Energy considerations

Engineers must help meet the challenge to reduce energy consumption by designing efficient transportation systems. About 97% of transportation energy in the United States is derived from oil. Indeed, the transportation system uses about 65% of all oil consumed by the United States. Although the fuel economy of vehicles has been improved significantly, this factor has been offset by a trend toward decreased vehicle occupancy rates. As a result, total usage of energy in highway passenger transportation is increasing. Despite significant gains that have been made in energy efficiency for commercial air travel and for rail freight, total energy consumption for transportation of all types continues to grow.

Efforts to curb energy use arise from a variety of concerns, including national security issues and environmental implications. Limiting carbon dioxide emissions to stem global warming is a significant consideration. In addition to fuel economy standards, legislative approaches to date have focused on promoting cleaner and more efficient alternative fuels. As an example, natural gas is now used to fuel certain commercial vehicles in some areas. However, because personal travel in light-duty vehicles consumes over 50% of transportation energy, effective efforts in energy conservation must be directed toward them. Further improvements in fuel economy will likely lead to lighter-weight vehicles with higher first costs. Efforts to relieve congestion in urban areas through incentives to make greater use of car pooling, such as special freeway lanes, and encouraging greater use of mass transit, deserve further emphasis.

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