Fundamentals of Transportation

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Fundamentals of Transportation/About

This book is aimed at undergraduate civil engineering students, though the material may provide a useful review for practitioners and graduate students in transportation. Typically, this would be for an **Introduction to Transportation** course, which might be taken by most students in their sophomore or junior year. Often this is the first engineering course students take, which requires a switch in thinking from simply solving given problems to formulating the problem mathematically before solving it, i.e. from straight-forward calculation often found in undergraduate Calculus to vaguer word problems more reflective of the real world.

How an idea becomes a road

The plot of this textbook can be thought of as "How an idea becomes a road". The book begins with the generation of ideas. This is followed by the analysis of ideas, first determining the origin and destination of a transportation facility (usually a road), then the required width of the facility to accommodate demand, and finally the design of the road in terms of curvature. As such the book is divided into three main parts: planning, operations, and design, which correspond to the three main sets of practitioners within the transportation engineering community: transportation planners, traffic engineers, and highway engineers. Other topics, such as pavement design, and bridge design, are beyond the scope of this work. Similarly transit operations and railway engineering are also large topics beyond the scope of this book.

Each page is roughly the notes from one fifty-minute lecture.

Authors

Authors of this book include David Levinson [1], Henry Liu [2], William Garrison [3], Adam Danczyk, Michael Corbett

References

[1] http://nexus.umn.edu
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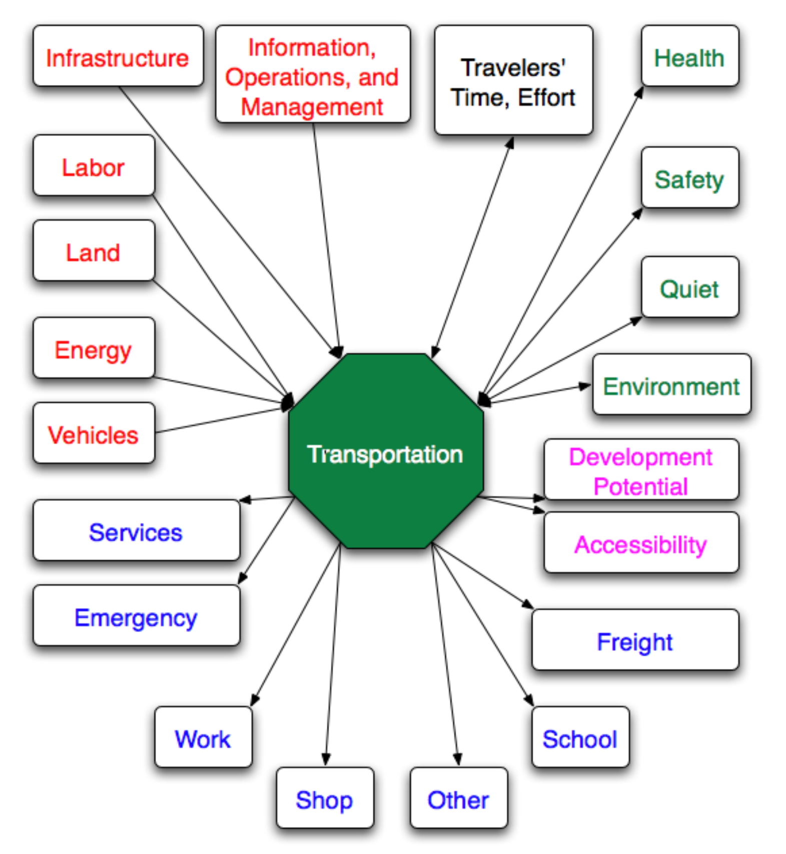
[3] http://en.wikipedia.org/wiki/William_Garrison_(geographer)

Fundamentals of Transportation/ Introduction

Transportation moves people and goods from one place to another using a variety of vehicles across different infrastructure systems. It does this using not only technology (namely vehicles, energy, and infrastructure), but also people's time and effort; producing not only the desired outputs of passenger trips and freight shipments, but also adverse outcomes such as air pollution, noise, congestion, crashes, injuries, and fatalities.



Transportation inputs and outputs

Figure 1 illustrates the inputs, outputs, and outcomes of transportation. In the upper left are traditional inputs (infrastructure (including pavements, bridges, etc.), labor required to produce transportation, land consumed by infrastructure, energy inputs, and vehicles). Infrastructure is the traditional preserve of civil engineering, while vehicles are anchored in mechanical engineering. Energy, to the extent it is powering existing vehicles is a mechanical engineering question, but the design of systems to reduce or minimize energy consumption require thinking beyond traditional disciplinary boundaries.

On the top of the figure are Information, Operations, and Management, and Travelers' Time and Effort. Transportation systems serve people, and are created by people, both the system owners and operators, who run, manage, and maintain the system and travelers who use it. Travelers' time depends both on freeflow time, which is a product of the infrastructure design and on delay due to congestion, which is an interaction of system capacity and its use. On the upper right side of the figure are the adverse outcomes of transportation, in particular its negative externalities:

- by polluting, systems consume health and increase morbidity and mortality;
- by being dangerous, they consume safety and produce injuries and fatalities;
- by being loud they consume quiet and produce noise (decreasing quality of life and property values); and
- by emitting carbon and other pollutants, they harm the environment.

All of these factors are increasingly being recognized as costs of transportation, but the most notable are the environmental effects, particularly with concerns about global climate change. The bottom of the figure shows the outputs of transportation. Transportation is central to economic activity and to people's lives, it enables them to engage in work, attend school, shop for food and other goods, and participate in all of the activities that comprise human existence. More transportation, by increasing accessibility to more destinations, enables people to better meet their personal objectives, but entails higher costs both individually and socially. While the "transportation problem" is often posed in terms of congestion, that delay is but one cost of a system that has many costs and even more benefits. Further, by changing accessibility, transportation gives shape to the development of land.

Modalism and Intermodalism

Transportation is often divided into infrastructure modes: e.g. highway, rail, water, pipeline and air. These can be further divided. Highways include different vehicle types: cars, buses, trucks, motorcycles, bicycles, and pedestrians. Transportation can be further separated into freight and passenger, and urban and inter-city. Passenger transportation is divided in public (or mass) transit (bus, rail, commercial air) and private transportation (car, taxi, general aviation).

These modes of course intersect and interconnect. At-grade crossings of railroads and highways, inter-modal transfer facilities (ports, airports, terminals, stations).

Different combinations of modes are often used on the same trip. I may walk to my car, drive to a parking lot, walk to a shuttle bus, ride the shuttle bus to a stop near my building, and walk into the building where I take an elevator.

Transportation is usually considered to be between buildings (or from one address to another), although many of the same concepts apply within buildings. The operations of an elevator and bus have a lot in common, as do a forklift in a warehouse and a crane at a port.

Motivation

Transportation engineering is usually taken by undergraduate Civil Engineering students. Not all aim to become transportation professionals, though some do. Loosely, students in this course may consider themselves in one of two categories: Students who intend to specialize in transportation (or are considering it), and students who don't. The remainder of civil engineering often divides into two groups: "Wet" and "Dry". Wets include those studying water resources, hydrology, and environmental engineering, Drys are those involved in structures and geotechnical engineering.

Transportation students

Transportation students have an obvious motivation in the course above and beyond the fact that it is required for graduation. Transportation Engineering is a pre-requisite to further study of Highway Design, Traffic Engineering, Transportation Policy and Planning, and Transportation Materials. It is our hope, that by the end of the semester, many of you will consider yourselves Transportation Students. However not all will.

"Wet Students"

I am studying Environmental Engineering or Water Resources, why should I care about Transportation Engineering?

Transportation systems have major environmental impacts (air, land, water), both in their construction and utilization. By understanding how transportation systems are designed and operate, those impacts can be measured, managed, and mitigated.

"Dry Students"

I am studying Structures or Geomechanics, why should I care about Transportation Engineering?

Transportation systems are huge structures of themselves, with very specialized needs and constraints. Only by understanding the systems can the structures (bridges, footings, pavements) be properly designed. Vehicle traffic is the dynamic structural load on these structures.

Citizens and Taxpayers

Everyone participates in society and uses transportation systems. Almost everyone complains about transportation systems. In developed countries you seldom here similar levels of complaints about water quality or bridges falling down. Why do transportation systems engender such complaints, why do they fail on a daily basis? Are transportation engineers just incompetent? Or is something more fundamental going on?

By understanding the systems as citizens, you can work toward their improvement. Or at least you can entertain your friends at parties

Goal

It is often said that the goal of Transportation Engineering is "The Safe and Efficient Movement of People and Goods."

But that goal (safe and efficient movement of people and goods) doesn’t answer:

Who, What, When, Where, How, Why?

Overview

This wikibook is broken into 3 major units

- Transportation Planning: Forecasting, determining needs and standards.
- Traffic Engineering (Operations): Queueing, Traffic Flow Highway Capacity and Level of Service (LOS)
- Highway Engineering (Design): Vehicle Performance/Human Factors, Geometric Design

Thought Questions

- What constraints keeps us from achieving the goal of transportation systems?
- What is the "Transportation Problem"?

Sample Problem

- Identify a transportation problem (local, regional, national, or global) and consider solutions. Research the efficacy of various solutions. Write a one-page memo documenting the problem and solutions, documenting your references.

Abbreviations

- LOS - Level of Service
- ITE - Institute of Transportation Engineers
- TRB - Transportation Research Board
- TLA - Three letter abbreviation

Key Terms

- Hierarchy of Roads
- Functional Classification
- Modes
- Vehicles
- Freight, Passenger
- Urban, Intercity
- Public, Private

Transportation Economics/ Introduction

Transportation systems are subject to constraints and face questions of resource allocation. The topics of supply and demand, as well as equilibrium and disequilibrium, arise and give shape to the use and capability of the system.

Demand Curve

How much would people pay for a final grade of an A in a transportation engineering class?

- How many people would pay $5000 for an A?
- How many people would pay $500 for an A?
- How many people would pay $50 for an A?
- How many people would pay $5 for an A?

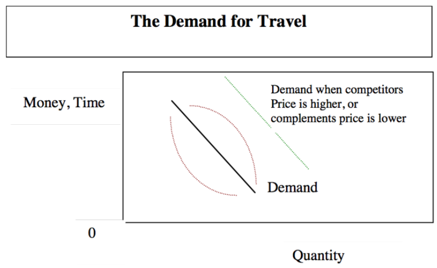
If we draw out these numbers, with the price on the Y-axis, and the number of people willing to pay on the X-axis, we trace out a demand curve. Unless you run into an exceptionally ethical (or hypocritical) group, the lower the price, the more people are willing to pay for an "A". We can of course replace an "A" with any other good or service, such as the price of gasoline and get a similar though not identical curve.

Demand and Budgets in Transportation

We often say "travel is a derived demand". There would be no travel but for the activities being undertaken at the trip ends. Travel is seldom consumed for its own sake, the occasional "Sunday Drive" or walk in the park excepted. On the other hand, there seems to be some innate need for people to get out of the house, a 20-30 minute separation between the home and workplace is common, and 60 - 90 minutes of travel per day total is common, even for nonworkers. We do know that the more expensive something is, the less of it that will be consumed. E.g. if gas prices were doubled there will be less travel overall. Similarly, the longer it takes to get from A to B, the less likely it is that people will go from A to B.

In short, we are dealing with a downward sloping demand curve, where the curve itself depends not only on the characteristics of the good in question, but also on its complements or substitutes.

The Shape of Demand



Demand for Travel

What we need to estimate is the shape of demand (is it linear or curved, convex or concave, what function best describes it), the sensitivity of demand for a particular thing (a mode, an origin destination pair, a link, a time of day) to price and time (elasticity) in the short run and the long run.

- Are the choices continuous (the number of miles driven) or discrete (car vs. bus)?
- Are we treating demand as an absolute or a probability?

- Does the probability apply to individuals (disaggregate) or the population as a whole (aggregate)?
- What is the trade-off between money and time?
- What are the effects on demand for a thing as a function of the time and money costs of competitive or complementary choices (cross elasticity).

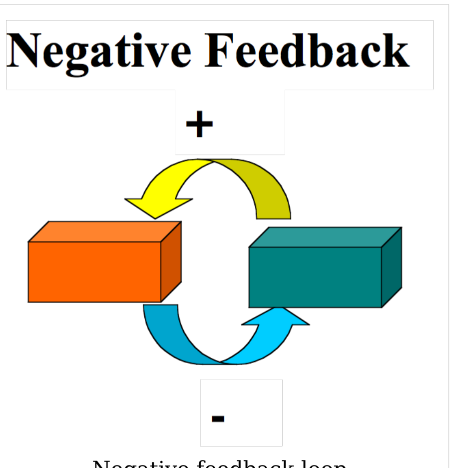
Supply Curve

How much would a person need to pay you to write an A-quality 20 page term paper for a given transportation class?

- How many would write it for $100,000?
- How many would write it for $10,000?
- How many would write it for $1,000?
- How many would write it for $100?
- How many would write it for $10?

If we draw out these numbers for all the potential entrepreneurial people available, we trace out a supply curve. The lower the price, the fewer people are willing to supply the paper-writing service.

Equilibrium in a Negative Feedback System



Negative feedback loop

Supply and Demand comprise the economists view of transportation systems. They are equilibrium systems. What does that mean?

It means the system is subject to a negative feedback process:

An increase in *A* begets a decrease in *B*. An increase *B* begets an increase in *A*.

Example: *A*: Traffic Congestion and *B*: Traffic Demand ... more congestion limits demand, but more demand creates more congestion.

Supply and Demand Equilibrium

As with earning grades and cheating, transportation is not free, it costs both time and money. These costs are represented by a supply curve, which rises with the amount of travel demanded. As described above, demand (e.g. the number of vehicles which want to use the facility) depends on the price, the lower the price, the higher the demand. These two curves intersect at an equilibrium point. In the example figure, they intersect at a toll of $0.50 per km, and flow of 3000 vehicles per hour. Time is usually converted to money (using a Value of Time), to simplify the analysis.

Costs may be *variable* and include users' time, out-of-pockets costs (paid on a per trip or per distance basis) like tolls, gasolines, and fares, or *fixed* like insurance or buying an automobile, which are only borne once in a while and are largely independent of the cost of an individual trip.

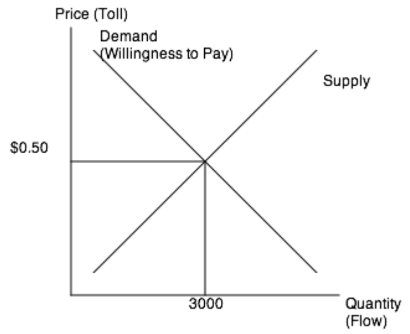


Illustration of equilibrium between supply and demand

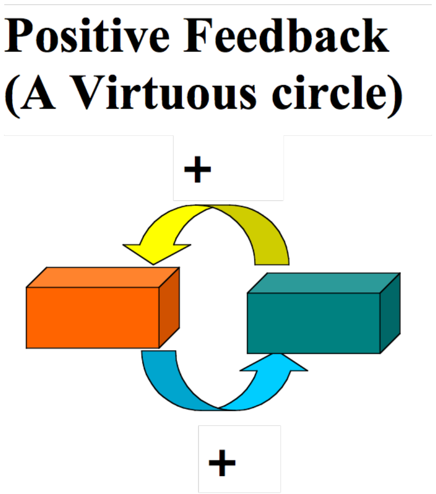
Disequilibrium

However, many elements of the transportation system do not necessarily generate an equilibrium. Take the case where an increase in A begets an increase in B. An increase in B begets an increase in A. An example where A an increase in Traffic Demand generates more Gas Tax Revenue (B) more Gas Tax Revenue generates more Road Building, which in turn increases traffic demand. (This example assumes the gas tax generates more demand from the resultant road building than costs in sensitivity of demand to the price, i.e. the investment is worthwhile). This is dubbed a positive feedback system, and in some contexts a "Virtuous Circle", where the "virtue" is a value judgment that depends on your perspective.

Similarly, one might have a "Vicious Circle" where a decrease in A begets a decrease in B and a decrease in B begets a decrease in A. A classic example of this is where (A) is Transit Service and (B) is Transit Demand. Again "vicious" is a value judgment. Less service results in fewer transit riders, fewer transit riders cannot make as a great a claim on transportation resources, leading to more service cutbacks.

These systems of course interact: more road building may attract transit riders to cars, while those additional drivers pay gas taxes and generate more roads.

One might ask whether positive feedback systems converge or diverge. The answer is "it depends on the system", and in particular where or when in the system you observe. There might be some point where no matter how many additional roads you built, there would be no more traffic demand, as everyone already consumes as much travel as they want to. We have yet to reach that point for roads, but on the other hand, we have for lots of goods. If you live in most parts of the United States, the price of water at your house probably does not affect how much you drink, and a lower price for tap water would not increase your rate of ingestion. You might use substitutes if their prices were lower (or tap water were costlier), e.g. bottled water. Price might affect other behaviors such as lawn watering and car washing though.

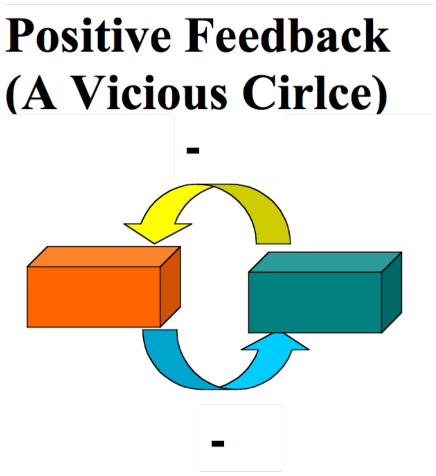


Positive feedback loop (virtuous circle)

Provision

Transportation services are provided by both the public and private sector.

- Roads are generally publicly owned in the United States, though the same is not true of highways in other countries. Furthermore, public ownership has not always been the norm, many countries had a long history of privately owned turnpikes, in the United States private roads were known through the early 1900s.
- Railroads are generally private.
- Carriers (Airlines, Bus Companies, Truckers, Train Operators) are often private firms



Positive feedback loop (vicious circle)

- Formerly private urban transit operators have been taken over by local government from the 1950s in a process called municipalization. With the rise of the automobile, transit systems were steadily losing passengers and money.

The situation is complicated by the idea of contracting or franchising. Often private firms operate "public transit" routes, either under a contract, for a fixed price, or an agreement where the private firm collects the revenue on the route (a franchise agreement). Franchises may be subsidized if the route is a money-loser, or may require bidding if the route is profitable. Private provision of public transport is common in the United Kingdom.

Thought questions

1. Should the government subsidize public transportation? Why or why not?
2. Should the government operate public transportation systems?
3. Is building roads a good idea even if it results in more travel demand?

London Routemaster Bus

Sample Problem

Problem (Solution)

Key Terms

- Supply
- Demand
- Negative Feedback System
- Equilibrium
- Disequilibrium
- Public Sector
- Private Sector

Fundamentals of Transportation/ Geography and Networks

Transportation systems have specific structure. Roads have length, width, and depth. The characteristics of roads depends on their purpose.

Roads

A road is a path connecting two points. The English word ‘road’ comes from the same root as the word ‘ride’ –the Middle English ‘rood’ and Old English ‘rad’ –meaning the act of riding. Thus a road refers foremost to the right of way between an origin and destination. In an urban context, the word street is often used rather than road, which dates to the Latin word ‘strata’, meaning pavement (the additional layer or stratum that might be on top of a path).

Modern roads are generally paved, and unpaved routes are considered trails. The pavement of roads began early in history. Approximately 2600 BCE, the Egyptians constructed a paved road out of sandstone and limestone slabs to assist with the movement of stones on rollers between the quarry and the site of construction of the pyramids. The Romans and others used brick or stone pavers to provide a more level, and smoother surface, especially in urban areas, which allows faster travel, especially of wheeled vehicles. The innovations of Thomas Telford and John McAdam reinvented roads in the early nineteenth century, by using less expensive smaller and broken stones, or aggregate, to maintain a smooth ride and allow for drainage. Later in the nineteenth century, application of tar (asphalt) further smoothed the ride. In 1824, asphalt blocks were used on the Champs-Elysees in Paris. In 1872, the first asphalt street (Fifth Avenue) was paved in New York (due to Edward de Smedt), but it wasn’t until bicycles became popular in the late nineteenth century that the “Good Roads Movement” took off. Bicycle travel, more so than travel by other vehicles at the time, was sensitive to rough roads. Demands for higher quality roads really took off with the widespread adoption of the automobile in the United States in the early twentieth century.

The first good roads in the twentieth century were constructed of Portland cement concrete (PCC). The material is stiffer than asphalt (or asphalt concrete) and provides a smoother ride. Concrete lasts slightly longer than asphalt between major repairs, and can carry a heavier load, but is more expensive to build and repair. While urban streets had been paved with concrete in the US as early as 1889, the first rural concrete road was in Wayne County, Michigan, near to Detroit in 1909, and the first concrete highway in 1913 in Pine

Bluff, Arkansas. By the next year over 2300 miles of concrete pavement had been layed nationally. However over the remainder of the twentieth century, the vast majority of roadways were paved with asphalt. In general only the most important roads, carrying the heaviest loads, would be built with concrete.

Roads are generally classified into a hierarchy. At the top of the hierarchy are freeways, which serve entirely a function of moving vehicles between other roads. Freeways are grade-separated and limited access, have high speeds and carry heavy flows. Below freeways are arterials. These may not be grade-separated, and while access is still generally limited, it is not limited to the same extent as freeways, particularly on older roads. These serve both a movement and an access function. Next are collector/distributor roads. These serve more of an access function, allowing vehicles to access the network from origins and destinations, as well as connecting with smaller, local roads, that have only an access function, and are not intended for the movement of vehicles with neither a local origin nor destination. Local roads are designed to be low speed and carry relatively little traffic.

The class of the road determines which level of government administers it. The highest roads will generally be owned, operated, or at least regulated (if privately owned) by the higher level of government involved in road operations; in the United States, these roads are operated by the individual states. As one moves down the hierarchy of roads, the level of government is generally more and more local (counties may control collector/distributor roads, towns may control local streets). In some countries freeways and other roads near the top of the hierarchy are privately owned and regulated as utilities, these are generally operated as toll roads. Even publicly owned freeways are operated as toll roads under a toll authority in other countries, and some US states. Local roads are often owned by adjoining property owners and neighborhood associations.

The design of roads is specified in a number of design manual, including the AASHTO Policy on the Geometric Design of Streets and Highways (or Green Book). Relevant concerns include the alignment of the road, its horizontal and vertical curvature, its super-elevation or banking around curves, its thickness and pavement material, its cross-slope, and its width.

Freeways

A motorway or freeway (sometimes called an expressway or thruway) is a multi-lane divided road that is designed to be high-speed free flowing, access-controlled, built to high standards, with no traffic lights on the mainline. Some motorways or freeways are financed with tolls, and so may have tollbooths, either across the entrance ramp or across the mainline. However in the United States and Great Britain, most are financed with gas or other tax revenue.

Though of course there were major road networks during the Roman Empire and before, the history of motorways and freeways dates at least as early as 1907, when the first limited access automobile highway, the Bronx River Parkway began construction in Westchester County, New York (opening in 1908). In this same period, William Vanderbilt constructed the Long Island Parkway as a toll road in Queens County, New York. The Long Island Parkway was built for racing and speeds of 60 miles per hour (96 km/hr) were accommodated. Users however had to pay a then expensive $2.00 toll (later reduced) to recover the construction costs of $2 million. These parkways were paved when most roads were not. In 1919 General John Pershing assigned Dwight Eisenhower to discover how quickly troops could be moved from Fort Meade between Baltimore and Washington to the Presidio in San Francisco by road. The answer was 62 days, for an average speed of 3.5 miles per hour (5.6 km/hr). While using segments of the Lincoln Highway, most of that road was still unpaved. In response, in 1922 Pershing drafted a plan for an 8,000 mile (13,000 km) interstate system which was ignored at the time.

The US Highway System was a set of paved and consistently numbered highways sponsored by the states, with limited federal support. First built in 1924, they succeeded some previous major highways such as the Dixie Highway, Lincoln Highway and Jefferson Highway that were multi-state and were constructed with the aid of private support. These roads however were not in general access-controlled, and soon became congested as development along the side of the road degraded highway speeds.

In parallel with the US Highway system, limited access parkways were developed in the 1920s and 1930s in several US cities. Robert Moses built a number of these parkways in and around New York City. A number of these parkways were grade separated, though they were intentionally designed with low bridges to discourage trucks and buses from using them. German Chancellor Adolf Hitler appointed a German engineer Fritz Todt Inspector General for German Roads. He managed the construction of the German Autobahns, the first limited access high-speed road network in the world. In 1935, the first section from Frankfurt am Main to Darmstadt opened, the total system today has a length of 11,400 km. The Federal-Aid Highway Act of 1938 called on the Bureau of Public Roads to study the feasibility of a toll-financed superhighway system (three east-west and three north-south routes). Their report Toll Roads and Free Roads declared such a system would not be self-supporting, advocating instead a 43,500 km (27,000 mile) free system of interregional highways, the effect of this report was to set back the interstate program nearly twenty years in the US.

The German autobahn system proved its utility during World War II, as the German army could shift relatively quickly back and forth between two fronts. Its value in military operations was not lost on the American Generals, including Dwight Eisenhower.

On October 1, 1940, a new toll highway using the old, unutilized South Pennsylvania Railroad right-of-way and tunnels opened. It was the first of a new generation of limited access highways, generally called superhighways or freeways that transformed the American landscape. This was considered the first freeway in the US, as it, unlike the earlier parkways, was a multi-lane route as well as being limited access. The Arroyo Seco Parkway, now the Pasadena Freeway, opened December 30, 1940. Unlike the Pennsylvania Turnpike, the Arroyo Seco parkway had no toll barriers.

A new National Interregional Highway Committee was appointed in 1941, and reported in 1944 in favor of a 33,900 mile system. The system was designated in the Federal Aid Highway Act of 1933, and the routes began to be selected by 1947, yet no funding was provided at the time. The 1952 highway act only authorized a token amount for construction, increased to $175 million annually in 1956 and 1957.

The US Interstate Highway System was established in 1956 following a decade and half of discussion. Much of the network had been proposed in the 1940s, but it took time to authorize funding. In the end, a system supported by gas taxes (rather than tolls), paid for 90% by the federal government with a 10% local contribution, on a pay-as-you-go” system, was established. The Federal Aid Highway Act of 1956 had authorized the expenditure of

$27.5 billion over 13 years for the construction of a 41,000 mile interstate highway system. As early as 1958 the cost estimate for completing the system came in at $39.9 billion and the end date slipped into the 1980s. By 1991, the final cost estimate was $128.9 billion. While the freeways were seen as positives in most parts of the US, in urban areas opposition grew quickly into a series of freeway revolts. As soon as 1959, (three years after the Interstate act), the San Francisco Board of Supervisors removed seven of ten freeways from the city's master plan, leaving the Golden Gate bridge unconnected to the freeway system. In New York, Jane Jacobs led a successful freeway revolt against the Lower Manhattan Expressway sponsored by business interests and Robert Moses among others. In Baltimore, I-70, I-83, and I-95 all remain unconnected thanks to highway revolts led by now Senator Barbara Mikulski. In Washington, I-95 was rerouted onto the Capital Beltway. The pattern repeated itself elsewhere, and many urban freeways were removed from Master Plans.

In 1936, the Trunk Roads Act ensured that Great Britain's Minister of Transport controlled about 30 major roads, of 7,100 km (4,500 miles) in length. The first Motorway in Britain, the Preston by-pass, now part of the M-6, opened in 1958. In 1959, the first stretch of the M1 opened. Today there are about 10,500 km (6300 miles) of trunk roads and motorways in England.

Australia has 790 km of motorways, though a much larger network of roads. However the motorway network is not truly national in scope (in contrast with Germany, the United States, Britain, and France), rather it is a series of local networks in and around metropolitan areas, with many intercity connection being on undivided and non-grade separated highways. Outside the Anglo-Saxon world, tolls were more widely used. In Japan, when the Meishin Expressway opened in 1963, the roads in Japan were in far worse shape than Europe or North American prior to this. Today there are over 6,100 km of expressways (3,800 miles), many of which are private toll roads. France has about 10,300 km of expressways (6,200 miles) of motorways, many of which are toll roads. The French motorway system developed through a series of franchise agreements with private operators, many of which were later nationalized. Beginning in the late 1980s with the wind-down of the US interstate system (regarded as complete in 1990), as well as intercity motorway programs in other countries, new sources of financing needed to be developed. New (generally suburban) toll roads were developed in several metropolitan areas.

An exception to the dearth of urban freeways is the case of the Big Dig in Boston, which relocates the Central Artery from an elevated highway to a subterranean one, largely on the same right-of-way, while keeping the elevated highway operating. This project is estimated to be completed for some $14 billion; which is half the estimate of the original complete US Interstate Highway System.

As mature systems in the developed countries, improvements in today's freeways are not so much widening segments or constructing new facilities, but better managing the roadspace that exists. That improved management, takes a variety of forms. For instance, Japan has advanced its highways with application of Intelligent Transportation Systems, in particular traveler information systems, both in and out of vehicles, as well as traffic control systems. The US and Great Britain also have traffic management centers in most major cities that assess traffic conditions on motorways, deploy emergency vehicles, and control systems like ramp meters and variable message signs. These systems are beneficial, but cannot be seen as revolutionizing freeway travel. Speculation about future automated highway systems has taken place almost as long as highways have been around. The Futurama exhibit at the New York 1939 World’s Fair posited a system for 1960. Yet this technology has been twenty years away for over sixty years, and difficulties remain.

Layers of Networks

The road is itself part of a layer of subsystems of which the pavement surface is only one part. We can think of a hierarchy of systems.

- Places
- Trip Ends
- End to End Trip
- Driver/Passenger
- Service (Vehicle & Schedule)
- Signs and Signals
- Markings
- Pavement Surface
- Structure (Earth & Pavement and Bridges)
- Alignment (Vertical and Horizontal)
- Right-Of-Way
- Space

At the base is *space*. On space, a specific *right-of-way* is designated, which is property where the road goes. Originally right-of-way simply meant legal permission for travelers to cross someone's property. Prior to the construction of roads, this might simply be a well-worn dirt path.

On top of the right-of-way is the *alignment*, the specific path a transportation facility takes within the right-of-way. The path has both vertical and horizontal elements, as the road rises or falls with the topography and turns as needed.

Structures are built on the alignment. These include the roadbed as well as bridges or tunnels that carry the road.

Pavement surface is the gravel or asphalt or concrete surface that vehicles actually ride upon and is the top layer of the structure. That surface may have *markings* to help guide drivers to stay to the right (or left), delineate lanes, regulate which vehicles can use which lanes (bicycles-only, high occupancy vehicles, buses, trucks) and provide additional information. In addition to marking, signs and signals to the side or above the road provide additional regulatory and navigation information.

Services use roads. Buses may provide scheduled services between points with stops along the way. Coaches provide scheduled point-to-point without stops. Taxis handle irregular passenger trips.

Drivers and *passengers* use services or drive their own vehicle (producing their own transportation services) to create an *end-to-end trip*, between an origin and destination. Each origin and destination comprises a *trip end* and those trip ends are only important because of the *places* at the ends and the activity that can be engaged in. As transportation is a derived demand, if not for those activities, essentially no passenger travel would be undertaken.

With modern information technologies, we may need to consider additional systems, such as Global Positioning Systems (GPS), differential GPS, beacons, transponders, and so on that may aide the steering or navigation processes. Cameras, in-pavement detectors, cell phones, and other systems monitor the use of the road and may be important in providing feedback for real-time control of signals or vehicles.

Each layer has rules of behavior:

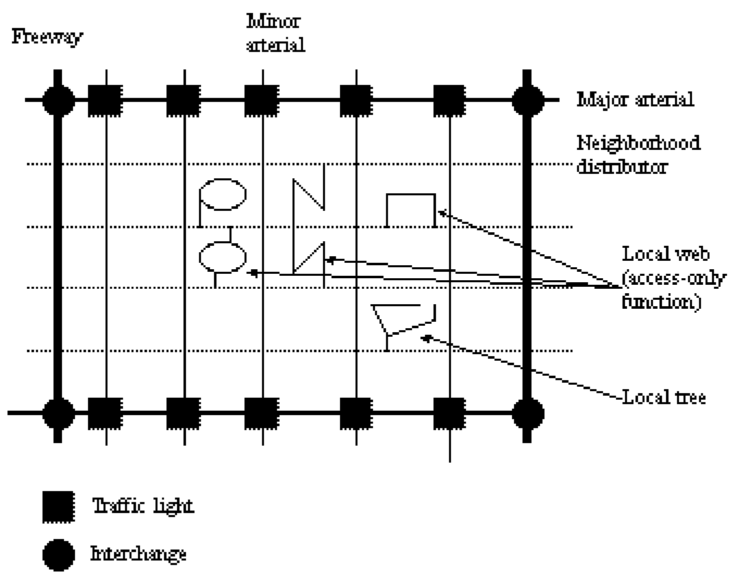
- some rules are physical and never violated, others are physical but probabilistic
- some are legal rules or social norms which are occasionally violated

Hierarchy of Roads

Even within each layer of the system of systems described above, there is differentiation.

Transportation facilities have two distinct functions: through movement and land access. This differentiation:

- permits the aggregation of traffic to achieve economies of scale in construction and operation (high speeds);
- reduces the number of conflicts;
- helps maintain the desired quiet character of residential neighborhoods by keeping through traffic away from homes;
- contains less redundancy, and so may be less costly to build.



Hierarchy of roads

Functional Classification	Types of Connections	Relation to Abutting Property	Minnesota Examples
Limited Access (highway)	Through traffic movement between cities and across cities	Limited or controlled access highways with ramps and/or curb cut controls.	I-94, Mn280
Linking (arterial:principal and minor)	Traffic movement between limited access and local streets.	Direct access to abutting property.	University Avenue, Washington Avenue
Local (collector and distributor roads)	Traffic movement in and between residential areas	Direct access to abutting property.	Pillsbury Drive, 17th Avenue