

## **Define Infrastructure**

### **1<sup>st</sup> Part: Surface Transportation: the highways, railroads, bridges, canals and tunnels.**

**The infrastructure that is really sculpture done on a massive scale.**

**By Robert H. Lowdermilk**

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The other day a friend said: **Since you were in the highway construction business, I have a question for you: what is infrastructure? I don't really know what it is.**

Infrastructure is all the civil engineered transportation networks that support the movement of large amounts of anything from raw materials to finished products. It is highway and train transportation systems, municipal utility drinking water, sanitary sewers or storm drain systems, and much more. Infrastructure is the physical support system whose continuous operation makes our modern society function efficiently and effectively. It includes airports, seaports, gas and oil pipelines, electrical transmission lines, communication systems, power generation systems, irrigation and water control dams. Infrastructure is so essential to our society and nation that a sudden loss of any part of it, for a period of time, could result in loss of life.

Haiti's earthquake is a classic example. Airports were damaged, no electricity, no drinking water, impassable roads and streets. It will take years to rebuild.

Each part of our infrastructure was created to solve some of our culture's most significant problems. Each is unique and has a fascinating history. Our surface transportation system, drinking water, sanitary sewers and storm drain systems are especially important.

We take our infrastructure for granted. The average person doesn't recognize how essential it is to our modern way of life or the consequences of not having it. Most people don't realize what it was like before we developed our highway and rail transportation systems; or before we could turn on a faucet and instantly get water or get rid of our human waste down a toilet.

**Life was very different hundreds of years ago.** Yes it was. Would you like me to give you a short history and an explanation of surface transportation, municipal water and sewer systems? **Yes, I would appreciate that.**

Let's start with a short history of transportation on our continent. It is visible and so fundamental it should be the first to be described. When the first explorers traversed the shores of North America they saw a land covered with trees. Their assumption was supported by the experiences of the first settlers. No roads existed for them to travel. The only land transportation routes were narrow animal paths and Indian footpaths. Rivers and streams were the principle freight transportation thoroughfares. If the early settlers wanted to haul freight in wagons they had to build their own roads.

Roads were hard to build. Hand tools and a mule were about all they had to work with. That meant felling mature old growth trees, pulling stumps and clearing a path through the forest wide enough for loaded wagons to pass. Once the path was cleared and grubbed the ground had to be smoothed and compacted. Early road builders battled mud and solid rock, rain and snow, rivers, streams and swamps.

**The nations who colonized the North American continent had to fight for the land they claimed didn't they?**

Yes and the size of the land they claimed kept changing. The English, French, Spanish, Dutch and Swedes, all made claims on the East Coast of the New World. Making war on other nations to acquire resources was part of their culture and heritage. That is why throughout history nations boundary's change.

In 1754 England claimed that the area of her North American Colonies extended from the Atlantic seacoast to the Mississippi River. France claimed that the territory of New France included the drainage of the Mississippi River. This meant both countries claimed the area from the top of the Appalachian Mountains to the Mississippi River.

Between 1754 and 1763 England and France fought the first worldwide war on two continents. In Europe it was called the 7-Year War and on the North American Continent it was called the French and Indian War. The English Colonies, with a population was 2.25 million fought using the British Redcoats and the Colonial Armies. New France, whose population was only 70,000 Frenchmen, enlisted the aid of many Indian tribes. The Indians were savage. The term bloodthirsty is an appropriate description. It is recorded that many of their Chiefs encouraged their young braves to drink "soup", the blood of their victims, and participate in forms of cannibalism. In addition many of these same Indians murdered unarmed British and Colonials and their families after their forts had been defeated, they had surrendered and had been given safe conduct by their French captors. The French claimed they could not stop their fanatical Indian allies during these massacres. The Colonial soldiers and their officers hated and distrusted the Indians. The English won both wars and hostilities ended by the signing of the Treaty of Paris in 1763. France's capitulation included ceding Canada to England.

Soon after the English victory, to the astonishment of the Colonists, King George III issued the Proclamation of 1763 that gave the very land that they had been fighting for to the Bloody Indians they had just defeated. To add to this insult the Proclamation required all existing settlers to vacate the new Indian Lands. The Proclamation was to be enforced by the force of arms of King Georges' Redcoats, the soldiers that the Colonists had fought along side of to defeat the French and the enemy Indians. With the acquisition of Canada King George III had decided to keep Canada and use the land west of the Appalachian Mountains to the Mississippi to placate the enemy Indians.

King George's gift may have pacified some Indians, but it enraged the colonists. George III had given away the colonists' future by taking away the area that they were planning to expand into. That act fostered massive distrust of the British government and it along with other punitive restrictions George III continued to place on the colonies were the real causes of our Revolutionary War.

Between 1776 and 1783 the American British Colonies fought for and won their independence from King George III. The original area of the 13 British colonies in 1775 was 374,674 square miles. At the end of the Revolutionary War in 1783, the United States had won not only the area of the original 13 colonies but also 576,350 square miles that King George III had given to the Indians. The original United States was 932,756 square miles. Colorado, to give you a concept of scale, is approximately 104,000 square miles in area.

The founders of our nation learned many lessons from the violent history that brought about the formation of the United States. Our system of Checks and Balances

codified in our Constitution and the Second Amendment of the Bill of Rights are designed to perpetuate Liberty and prevent the formation of a dictatorial government that might attempt to usurp our nation's citizens' Inalienable Rights. Our nation's founders also learned to appreciate this basic credo of nations: Nations can only keep the territory they can defend. From our beginning much of the area of our nation was inaccessible. Surface transportation was one of the principle ways of enforcing ownership of territory. I believe our surface transportation infrastructure, just as our military, has always been part of the resources used to protect of our nation from enemies both domestic and foreign. This is the reason President Eisenhower, in 1956, advocated for and finally signed into law the National Interstate and Defense Highways Act creating our Interstate Highway System.

**How many people were living in the United States after the Revolution?**

When the Signers adopted our Constitution in 1787 the total population was just under four million people. Approximately 200,000 were Indians and many were assimilating into the American culture.

**What were some of the transportation infrastructure problems we had to overcome and how did we do it?**

When our Revolutionary War ended the cost per ton of anything transported on the crude roads and trails was very expensive compared to the relatively low cost of water transportation. The Appalachian Mountain Range divided the United States in half. The Appalachian's prevented most land transportation between the east coast and the Mississippi drainage. Without adequate access much of the needed resources and large land area of the United States would be wasted.

In 1803 the Louisiana Purchase almost doubled the size of the United States. The Mississippi River and its entire drainage added 828,800 square miles to our nation's territory making the area of the United States 1,761,556 square miles, almost exactly half of its present size. The steamship multiplied the Mississippi's transportation efficiency and expanded the productivity of the area's agriculture and commerce, making its products available for both wider domestic consumption and export.

New York State recognized that it held the key to opening this newly acquired western frontier. Within their state boundaries lay the only efficient route capable of establishing commercial traffic between the newly acquired Louisiana Territory, the Mississippi River, the Great Lakes and the East Coast of the United States. New York State capitalized on this and underwrote the construction of the 363-mile long Erie Canal. The canal joined New York's Hudson River to Lake Erie. It was started in 1818 and completed in 1825. The Erie Canal proved to be so economical that it reduced the cost of transportation of freight from our nation's mid west by an astounding 95%. The Canal's efficiency not only made the agricultural and commercial development of the American Mid-west possible, it supported the development of all of the great cities along the great lakes and made New York City the largest and most prosperous port and financial center in the United States. It not only expanded our nation's internal markets and multiplied the exports we sent to the rest of the world; it changed the policies of other nations. England capitalized on the large quantity of high quality and low cost agricultural products made available to other nations by the Canal by reducing its own agricultural production buying our produce and turning more of its resources to industrial production. Other nations did the same.

**As technology became available it seems that the United States incorporated it as rapidly as possible.** That's right. Efficiency is a major part of our culture. The success of the Erie Canal encouraged the building of other canals, but few were successful and most were replaced with railroads after the 1830s. Railroads could be constructed in more locations than could canals.

Railroads spread through out the northern United States and into the South. In the North railroads were constructed with one standard gage and interconnected so they could rapidly transfer whole railroad cars from one line to another. Southern railroads were much fewer in number, often isolated and when connected, not of a constant gage. This made freight flow between lines in the South inefficient. Too often freight from one line in the South had to unload and reloaded, by hand, onto the next line. The markedly superior railroad transportation system that supported its industry gave the North an incredible advantage when the Civil War finally came in 1861.

Growth was amazing in the early United States. Between 1790 and 1860 population grew over 33% per decade. Just before the Civil War population had expanded to 31,443,321 and the size of the United States was 2,870,084 square miles. With the addition of Texas and the territory won in the Mexican American War in 1848 and the Gadsden Purchase in 1853 the United States stretched all the way across the continent from the Atlantic to the Pacific.

Efficiency and a means to tie our newly assembled nation together were all part of Abraham Lincoln's considerations in 1862 when he authorized construction of the Transcontinental Railroad from Omaha Nebraska to Sacramento California. Completed in 1869, it tied the eastern half of the United States to its newly acquired western half. This transportation system was the first of a vast labyrinth of railroads, roads and waterways that opened our nation to settlement, commerce and the development of our resources.

After the Civil War the territory of the United States was again increased when Alaska was purchased from Russia in 1867. This added another 656,425 square miles bringing our total area to 3,526,509 square miles. But Alaska was not contiguous with the rest of the States and its development was relatively slow even after gold was found there in 1880.

As population increased, in the contiguous United States, our network of roads also expanded. But expansion of our nation's roads did little to reduce road ton-mile costs. Wet and muddy conditions were still a persistent problem and the cost of road transport remained high.

The solution came from a totally new direction. In Pennsylvania, on August 27<sup>th</sup>, 1859, Colonel Edwin L. Drake completed the world's first oil well. Drake's original goal had been to find a large source of petroleum. It was refined and produced the lamplight oil kerosene. Once the kerosene had been extracted from the petroleum a waste product remained, asphalt.

In 1871 a market was found for asphalt. It proved to be useful when applied to the top of shaped earth roadways. Sprayed on the surface of a road it prevented water from penetrating the asphalt-coated surface. It caught on quickly. By 1900 approximately 2,600 miles of roads had been paved with a sprayed-on-asphalt surfacing.

**Let me interrupt. I've seen asphalt put down. They use a machine that puts down a thick layer. What happened?** What you saw was modern asphalt pavement. It is made by mixing hot gravel and hot asphalt in a hot plant. The mix is then hauled to a

laydown machine, which then places a layer inches thick on a layer of sprayed on asphalt called a tack coat. The hot asphalt mix is then compacted with heavy rollers and allowed to cool. When asphalt is hot it flows like syrup. When it is compacted and has cooled it forms a hard asphaltic cement that binds the gravel particles together. Asphalt pavements form a strong, economical and virtually impervious armored surface that protects the subgrade under it. It is much stronger than the thin, sprayed on asphalt coating used around 1900. Does that answer your question? **Yes, thank you. Now would you get back to what you were explaining before I interrupted you.**

By the end of WWI the United States had become the world's richest nation. Our nation's transportation system not only mirrored our growth, it was the single most important physical facility in initiating and providing for it.

**That is fascinating to hear, but how do you prove your assertion that our wealth grew?** Okay, listen to these economic facts: Between 1859 and 1919 the value of manufactured goods produced in the United States increased by a factor of 33 times. In 1865 average freight rates were 20 cents per ton-mile. By 1915 they had reduced to as little as 1.75 cents per ton-mile, an example of what improving technology can do to reduce costs. This reduction in freight rates explains why freight carried rose from 10 billion ton-miles in 1865 to 366 billion in 1916.

In 1840 the United States had approximately 3,000 miles of railroad track. In 1850 it was about 9,000 miles and in 1860, nearly 30,000 miles. That rose to 53,000 miles in 1870 and by 1880 it was 164,000 miles peaking by 1916 at 254,000 miles. The building of our nation's wealth coincided with the building of our nation's transportation system. Without the ability to move our resources and accommodate commerce it would have been impossible to expand our nation's wealth.

**Let me interrupt you. She said. You mean transportation was the most important physical reason that our nation became so prosperous?** Yes. Let me continue: The end of the 19<sup>th</sup> century and the beginning of the 20<sup>th</sup> century saw the introduction of the both the automobile and the truck to the United States transportation system. Their reception by our population was incredible. In 1900 there were 8,000 automobiles registered in the United States. In 1905 the number of motorcars made in the United States was 25,000, increasing to 187,000 in 1910. By 1915 it was 969,930 and the total of registered vehicles in the United States was approximately 2.5 million.

In 1917 there were 391,000 motor trucks in the United States. By the end of 1918 that number had grown to 605,000 trucks. With the automobile and the truck came a mobility that neither this vast nation nor the world had ever seen before.

**It was an incredible technological revolution, wasn't it? Didn't it crowd the roads and cause congestion? She asked.** The biggest problem was not road congestion; it was road destruction. Our nation's earliest earth, brick, asphalt and even macadam roads were built for horses and wagons. They could not stand up under the pounding workload of these new heavy trucks.

Rather than horses and wagons traveling on the roads with loads of 3 tons or less at speeds of 4 miles per hour, heavy motor trucks carried loads of 8 to 12 tons at speeds of 20 miles per hour. These early solid rubber wheeled trucks were loaded to the capacity of the truck's engine instead the capability of the road. "If there is a space, fill it," was the motto of those early truckers. It was not unusual to see trucks of that time with loads piled higher than their cab and extending over and around the cab.

**What happened to all the horses? She asked.** The population of our nation's horses and mules peaked at 26 million in 1918 and by 1929 that population was declining rapidly. In 1916 it was found that the truck was 16 times more efficient than a horse and wagon. In addition you don't have to feed a truck when it isn't working and you don't have to clean up their manure or remove the horse's heavy carcass when it dies. It didn't take long before trucks took over. Trucks could do a lot more a lot faster. One of the other reasons trucks replaced horses is that trucks didn't pollute as much as horses.

**That's a perspective I never thought of before. She said.**

**I have another question: What happened to prevent the roads from being destroyed? She asked.** There was great demand by the traveling public to fix our road's problems. Some wanted to reduce the capacity of the trucks to the capacity of the roads. But most recognized that strategy would be a step backward. All the increased efficiency of the trucks would be lost. The best answer lay in doing a better job of engineering and construction on our nation's roads and highways. In 1909 the Office of Public Roads and scores of public and private organizations that were interested in preparing our nation's roads for the future, encouraged engineering efforts to achieve that end.

Standards for the United States' improved new roads came from engineering and construction knowledge acquired in Europe during WWI. Army engineers had found that roads capable of handling the movement of heavy guns and tanks could be constructed of compacted earth. Properly built, they could withstand heavy truck transports for long periods of time; a small amount of water added to a roadway's earthen fill would lubricate each earthen particle enough to overcome its dry friction. These particles, when compacted, would slide together with other surrounding particles and form a mass that was so tight it could support the weight of many loaded trucks passing over its surface for a long time without deforming.

Compacted earth can be used to build the most economical roadbeds possible, as long as standing water is not allowed to soak into the roadway surface. There is an optimum amount of moisture needed to build roads capable of handling truck traffic. Water puddles destroy the strength of a compacted earthen roadway surface by infiltrating between the earthen particles. An over optimum amount of water over lubricates and eliminates the tight particle-to-particle locking friction by pushing them apart, actually separating them with a thin layer of water. Too much water creates mud.

Shaping the surface of a road to drain and not accumulate water is essential for a long useful life. This is done by crowning the roadway and using ditches, culverts or bridges that are properly engineered to accommodate high water volumes. Today, the basic design concept of our nation's roads and highways is shaped-compacted-earth technology that is armored with a compacted gravel and bituminous cement or concrete surface.

**I still don't understand why compacted earthen highways are preferred. Why not use bridges and tunnels?**

The real answer is that bridges and tunnels cost approximately fifteen to twenty-five times as much per linear foot as does an earthen highway and highway engineers are trained to be as economically efficient with our highway money as possible and not build expensive structures when they are not necessary. Bridges or tunnels should only be used when they will reduce the total cost of building a highway. When rivers are encountered

a bridge may be the least expensive solution available. Highway interchanges and flyover bridges actually pay for their cost in transportation savings by allowing vehicles to proceed without stopping. This reduces travel times, fuel consumption and pollution. Tunnels, properly placed, may economically shorten the distance from one point and another. At present there is not enough money to build all the highways we need. We shouldn't build unneeded structures and waste our highway money. Highways are built to give its users the lowest cost per ton-mile possible over the life of that highway. Highways are intended to contribute to our economy by saving lives and reducing the cost of transportation.

**In the past, I know highways were accused of polluting the air.**

Our highway system doesn't pollute the air. Some of the vehicles built before 1970 or whose pollution abatement system is broken may pollute the air but the highways are clean. In addition, 95% of the vehicles that travel on our highways meet strict Federal Emissions Standards and will emit even less in the future.

In the past some bad political decisions were made when "the perfect was allowed to interfere with the good." Our economic culture is actually the result of an efficient coordination of a labyrinth of industrial and financial systems. Interfering with a significant part of our infrastructure will reduce the future efficiency of our economy.

In 1975 a political effort was initiated to reduce the number of miles of needed highways built in Colorado. It was done ostensibly to reduce the air pollution coming from the exhausts of automobiles and trucks. It was a shortsighted political effort and, it has backfired by causing more automobile and truck pollution while increasing the cost of transportation.

**What caused those decisions, what was their result and what has happened since then?**

In 1977 Denver's air was the second worst in the nation. It is now among of the best in the United States. Before 1975 the Colorado Department of Highways proposed a plan that would have maintained convenient highway transportation for the Denver Metro area well into this century. They proposed building an Interstate circumferential route around Denver and two more Interstate Highways diagonally across Denver. If these routes had been built, I believe our air would be even better than it is now. In addition, the amount of fuel we would have used, for the same trips made since then, would have been considerably less. But even with the present congestion we now experience with our present inadequate highway system, our city's air quality is very good. Much thanks to the excellent pollution abatement engineering done by the automobile companies.

**What is pollution abatement?** It is the vehicle exhaust emissions cleaning system and it is very effective. 1970 was the first year all new cars sold in the United States were required to use pollution abatement systems to reduce tailpipe emissions. In 1982 and again in 1992 the new car pollution abatement systems were upgraded and made more effective. Since 1992 all new cars sold in the United States are required to conform to the 1992 standard. As cars built after that year began driving Colorado's highways in greater numbers our state's air has gotten progressively cleaner. Colorado's air is now among the cleanest in the nation. Pollution abatement equipment removes approximately 95% of the emissions of a pre-1970 car.

In 2005 all gasoline and in 2006 all diesel used on our nation's public roads were required to meet ultra low sulfur specifications. Gasoline's allowable sulfur content is 30 parts per million. Diesel's sulfur limit is 15 parts per million or below.

Ultra low sulfur gasoline reduces a car's emissions and makes its catalytic converter more efficient. All new diesel engines sold in the United States from 2010 on must have a pollution abatement system and use ultra low sulfur diesel. A representative of EPA told me that complying 2010 diesel engines will emit only atmospheric nitrogen, carbon dioxide and water. He said: "you can't even smell their emissions."

**What makes a pollution abatement system work?** The workhorse of the pollution abatement system is the catalytic converter. It removes pollutants from a car engine's exhaust emissions. The catalytic converter has to be hot in order to work. A car emits the most pollution when it is first started and the engine is cold. Once the engine warms sufficiently the pollution abatement system kicks in. This allows the catalytic converter, with all its computer controls, oxygen sensors and feedback system, to scavenge exhaust emissions. It reduces tailpipe exhaust pollutants by approximately 95%. It is a truly efficient system. The pollution abatement system was the real answer to reducing vehicle pollution, not stopping the construction of highways, especially Interstate Highways. It is now possible to see what a waste that misdirected political effort was.

**Why are you such an advocate for Interstate Highways?** Interstate Highways provide the lowest emissions and the best fuel economy. I can go more than twice as far on a gallon of gas on an Interstate highway as I can in city traffic. They are not only safer they also allow vehicles to get far better mileage. My car is very similar to all newer cars. I have measured my fuel economy in Denver street traffic and on Interstate highways. When I travel on streets controlled by traffic lights and stop signs my fuel economy goes down to less than 11 miles per gallon. When I travel at a constant Interstate highway speed of 75 miles per hour I can get 27 miles per gallon. Crossing the Rocky Mountains on Interstate 70 my car gets 22 miles per gallon.

I get the worst mileage when I accelerate away from a required traffic stop. The more frequent stops I have to make in city traffic the lower my mileage gets. Eliminate the need to stop at stop signs and lights and your mileage can more than double. Acceleration is where fuel economy is lost. Travel on the Interstates and stay off the city streets and your mileage improves.

**Too bad they didn't build the additional Interstates in and around Denver. It might have reduced the congestion we are now experiencing. But, don't cry over spilled milk, she said.** You're right. I replied. Now congestion is lapping at our heels. Our city is so spread out and in-filled with homes and businesses that I believe the only possible solution that is economically and politically viable is for the United States auto industry to pursue the creation of autonomous vehicle technology and replace most of our current vehicles. It doesn't seem like we have either enough time, funding nor political will to build the lane miles needed to eliminate our projected future congestion and save ourselves from the coming gut wrenching congestion that will eventually suffocate us. The Denver Regional Council of Governments (DRCOG) is warning us of the coming catastrophe now. They estimate that the average travel time in Metro Denver will increase by 353% by 2035 if we don't take corrective action. **That is awful! How can a society function with that great in increase in travel times? She asked.** I don't

know. Simple maintenance of our existing road and highway system by only repaving and replacing old structures will not do it. We need more lane miles to relieve the congestion problem. The goal is to increase traffic speed. I know of only two ways to do that. Either increase highway funding in order to add lane miles of highways and increase capacity or develop autonomous vehicles. The first solution can probably be accomplished more rapidly than the second. But, probably we should do both.

**What is an autonomous vehicle?** We are now building airplanes that take off by themselves, travel to prescribed locations, perform designated tasks along the way and then land by themselves. They can do all this without any instructions from the ground during the flight, the take off or the landing. Computers take over. We are now experimenting with autonomous cars. We already have cars that park themselves, adjust their speed to keep us a specific distance from the car in front of us, warn us when cars are in the lanes on either side of our car. When backing up they warn us when we are getting close to an obstacle behind us. In addition they can help us stop quicker, when we have an emergency stop driving in town.

My wife and I saw a full size experimental model autonomous vehicle at Georgia Tech a few years ago. It is one of many that are being developed by many organizations to accommodate our future highway transportation needs. When fully developed they will start, find and analyze the desired travel route, maneuver, accelerate, evade obstacles like other cars going any direction and proceed more rapidly and safely than vehicles driven by human beings. Traffic signals and stop signs will no longer be necessary.

Theoretically, one line of autonomous vehicles will be able to safely pass perpendicularly through another line of autonomous vehicles without stopping. Sensors and computer controls on autonomous vehicles will identify all other vehicles and obstacles near them. Speed controls, directional adjustments and spacing coordination will then allow each autonomous vehicle to automatically evade all obstacles.

Autonomous cars will operate like taxicabs do today. We will tell them where we want them to go and then sit back and enjoy the ride by the fastest and most efficient route possible. This technology can replace mass transit and give us the same freedom of choice we now have in our cars and at a low cost per mile traveled. In addition autonomous vehicles will operate on the same roads, streets and highways we use today.

Trucks using autonomous technology should greatly reduce the cost per ton-mile of haulage. They will be able to operate twenty-four hours per day seven days per week. **You mean that autonomous vehicles could further reduce congestion by operating at night when the highways are least congested?** That's right. It is possible that at night the major arterial highways may look like a fast moving train of trucks. Moving in unison along the main travel ways and then peeling off at the interchanges and going to their designated destinations to deliver or pick up their freight. Autonomous vehicles, if properly developed, offer us improved efficiency and better utilization of resources than is possible today. They may be the next great leap forward in surface transportation.

Well, after all that, do you have any thoughts? **Yes, I now understand how important surface transportation is to our economy and our culture. I also have a better understanding of how our highway system became inadequate and how misdirected political efforts can prevent or interfere with an improving future trend. Because of past interference highway congestion is going to get much worse in the near future if proper highway funding is not found. In addition, your**

**suggestion that a possible improvement in the distant future exists is intriguing. With enough time and resources the development of autonomous technology for automobiles and trucks seems altogether possible. In the long run autonomous technology may be the only answer available to significantly reduce congestion and greatly improve travel times. With our basic road and highway infrastructure already in place, and the specter of incredible highway congestion in 25 years if something is not done, autonomous technology is probably the least expensive solution to our highway transportation needs. (5,413 words)**