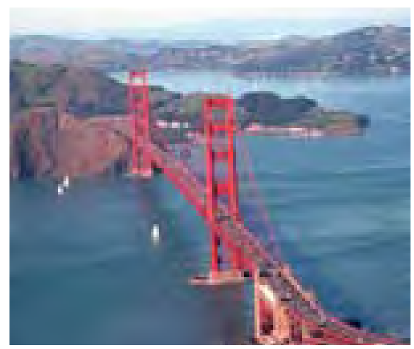
September 2006

Innovative Roadway Design

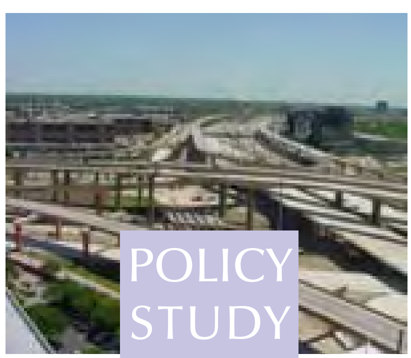
Making Highways More Likeable

By Peter Samuel
Project Director: Robert W. Poole, Jr.








POLICY STUDY 348

The Galvin Mobility Project

America's insufficient and deteriorating transportation network is choking our cities, hurting our economy, and reducing our quality of life. But through innovative engineering, value pricing, public-private partnerships, and innovations in performance and management we can stop this dangerous downward spiral. The Galvin Mobility Project is a major new policy initiative that will significantly increase our urban mobility and help local officials move beyond business-as-usual transportation planning.

Reason Foundation

Reason Foundation's mission is to advance a free society by developing, applying, and promoting libertarian principles, including individual liberty, free markets, and the rule of law. We use journalism and public policy research to influence the frameworks and actions of policymakers, journalists, and opinion leaders.

Reason Foundation's nonpartisan public policy research promotes choice, competition, and a dynamic market economy as the foundation for human dignity and progress. Reason produces rigorous, peer-reviewed research and directly engages the policy process, seeking strategies that emphasize cooperation, flexibility, local knowledge, and results. Through practical and innovative approaches to complex problems, Reason seeks to change the way people think about issues, and promote policies that allow and encourage individuals and voluntary institutions to flourish.

Reason Foundation is a tax-exempt research and education organization as defined under IRS code 501(c)(3). Reason Foundation is supported by voluntary contributions from individuals, foundations, and corporations. The views are those of the author, not necessarily those of Reason Foundation or its trustees.

The Galvin Mobility Project is made possible by the generous support of Robert Galvin.

The Galvin Mobility Project

Traffic congestion is choking our cities, hurting our economy, and reducing our quality of life. Rush-hour delays rob us of time with our families, and commute times often dictate where we live and work. The impact our inadequate transportation network has on our economy is alarming. We waste an estimated $63 billion annually in time and fuel while sitting in traffic. Moreover, businesses and their customers bear enormous costs associated with traffic-related logistics problems, delivery delays, poor transportation reliability, and fewer potential employees within commuting distance.

Reason Foundation is developing practical, cost-effective solutions to traffic congestion with the Galvin Mobility Project, a policy initiative that will significantly increase our urban mobility through innovative engineering, value pricing, public-private partnerships, and innovations in performance and management. Under the leadership of Reason's Director of Transportation Studies Robert Poole, Reason's original research is building comprehensive policy recommendations that enhance mobility and help local officials move beyond business-as-usual transportation planning.

The old canard "we can't build our way out of congestion" is not true. Adding capacity and improving management of roads can eliminate chronic congestion. Public-private partnerships to build and operate toll facilities have sparked innovations in engineering and design, overcoming obstacles such as limited right-of-way and noise pollution. Capital markets also provide access to much-needed investment capital and ensure that new highway capacity is built where it is most needed.

In addition to adding road capacity, changing the way highways are managed can help to maximize the use of the capacity we have. The introduction of Intelligent Transportation System technologies can speed resolution to traffic delays, and electronic toll collection technologies can make extensive tolling practical. More importantly, variable pricing of lanes can keep traffic flowing all day by responding to changing demand.

We can solve our congestion woes. We can upgrade to an innovative, market-driven, world-class transportation infrastructure. We can change the institutions that guide our transportation decisions to create greater responsiveness, robustness, and efficiency. The Galvin Mobility Project provides the ideas and tools needed to make change happen.

Innovative Roadway Design: Making Highways More Likeable

By Peter Samuel
Project Director: Robert W. Poole, Jr.

Executive Summary

Despite today's horrible traffic congestion, it is tough gaining support for expanded road capacity. Amassing the funds for major urban expressway projects is slow under centrally allocated trust funding because of the political pressure to spread annual appropriations over most districts and different modes. Many planners and transit advocates are quietly happy with the growing misery of road congestion. They believe public policy should drive people to transit use, or to higher density living near their jobs. Others believe that no matter how much road capacity we add, it will simply fill up to congested levels. But perhaps the most widespread belief is that there is simply no room left to expand urban highways without enormous negative consequences.

Compounding the problem is that people don't like the look or feel of many of our big highways. They have gotten so large and so bleak that they are offensive, like some kind of alien implant in our urban areas. A dislike of highways predisposes people to dislike all proposed new road projects, even those that are designed with more concern for aesthetics and better mitigation of impacts.

This study argues that in too many American cities, despite much planning, we are planning highways poorly. Traffic generation studies show the optimum expressway network is on a grid of roughly four miles with a denser grid of surface arterials with signalized intersections at intervals of between half a mile and three-quarters of a mile. Instead of planning such a denser grid of modestly sized roads and innovating with new kinds of roadways, we have simply enlarged the existing too-sparse grid of highways to gargantuan proportions.

This paper suggests new ways of thinking about highway design. Many of our highways have gotten too big, not because anyone wanted them to be that way, but because widening an existing highway was the simplest thing to do at each point—the line of least political resistance. But ever-wider highways create cascading functional problems. Multilane ramps are needed at interchanges of expressways, while on surface arterials enormous intersections with multiple turn waiting lanes are needed, plus long signal cycles. Overly wide arterials make handling left turns a huge challenge, and in the end limit capacity.

But with the kinds of innovative design concepts discussed in this paper, highways needn't get ever wider. They can be built upward as elevated roadways in certain contexts, using new, cleaner styles of construction. Conventional double decking involves enormous structures, but car-truck separation can make possible far smaller scale double-deck structures for auto-size vehicles only. Creating specialized roadways is one key to a more sensible highway system. Heavy truck volumes can be handled by specialized truck-only roadways. And in some places delivery and pickup, and other high-value commercial trips that will pay for premium service, should be catered to separately.

We need to find ways to build better grids of highways—smaller highways but more of them. At the expressway level denser grids could keep most expressways to six lanes or less, while on surface arterials spaced at half a mile, left turns become manageable without resorting to acres of asphalt at intersections and two-minute signal phases.

The "High Five" interchange, at the intersection of interstate 635 and US Highway 75 in Dallas. Photo by Kevin Brown.

One key to adding more highway corridors is to make use of underutilized railroad rights of way, power line reservations, and flood control channels. These need not be several hundred feet wide to be useful; a four-lane, value-priced congestion-relief roadway for cars and buses needs as little as 60 to 70 feet. New designs handle the left-turn traffic at stressed arterial intersections, using limited grade separations.

The biggest move to make highways more acceptable is likely to be moving some of them underground. A lot of this is already happening overseas in Europe and Australia where urban highways were less developed than in the United States until recently. Where we have need for increased capacity in bottleneck corridors we'll need to look at undergrounding—either beneath the existing corridor or parallel to it several miles away—because no surface facility or elevated structure is acceptable. Undergrounding ranges from entrenching within walls, to caps, cut-and-cover, and more extensive mined tunnels or those built with tunnel-boring machines.

Adding capacity with innovative design concepts is generally more expensive than adding lanes to mammoth freeways. But congestion and loss of mobility from not providing needed highway capacity are also hugely costly. Our productivity and quality of life depend heavily on being able to move ourselves and freight swiftly and predictably around our metropolitan areas. That way people have a wide range of opportunities for jobs, shopping, education and recreation, and employers have the widest choices to hire labor and services and get supplies and shipments handled efficiently. Areas that provide good internal mobility will thrive and prosper while others will languish. Innovative design will be essential to gaining acceptance of needed additions to highway capacity.

The Lone Star detail adorns the supports of several major interchanges in Dallas, Texas. Photo by Kevin Brown.

Table of Contents

Part 1

Introduction

A. Overview

Americans, as the French writer Alexis de Tocqueville observed in 1835, are great problem solvers—practical people who know there's a solution to every problem if only you work hard enough at it. Our urban roadways are a major problem—but we aren't addressing it. Our freeways and arterials are seriously congested, and getting more so every year. Our mobility is increasingly limited, just when we can afford, and need, better mobility. The latest annual urban mobility report from the Texas Transportation Institute estimates the cost to individual drivers—in terms of wasted time and fuel—of being stuck in traffic is $63 billion per year.[1] And that doesn't count whole categories of costs to businesses, such as higher logistics costs when trucks are stuck in traffic and the cost to a metro area's economy when employers can't hire people who, though not that far away in distance, are too far away in travel time. Also uncounted are the costs to individuals of jobs and facilities put beyond their reach by congestion.

An uncharacteristic fatalism has set in about the state of our roads. We can't do much to fix them, is a common sentiment behind the inaction. Obviously there are many reasons for this state of mind. One is the view that somehow the demand for road space is insatiable, that extra lanes conjure up extra traffic to fill them—as if building hospitals would cause more disease, or schools more children to be taught.

Another strand to the anti-roads thinking is that people have to be gotten out of their cars onto transit (trains) and that fixing congestion would just lessen the sense of urgency about this necessary transformation of our way of getting around. Advocates of this view allege that we have a "love affair" with the car, and like a parent who knows better, they plan to redirect youthful lust toward a better quality mate.

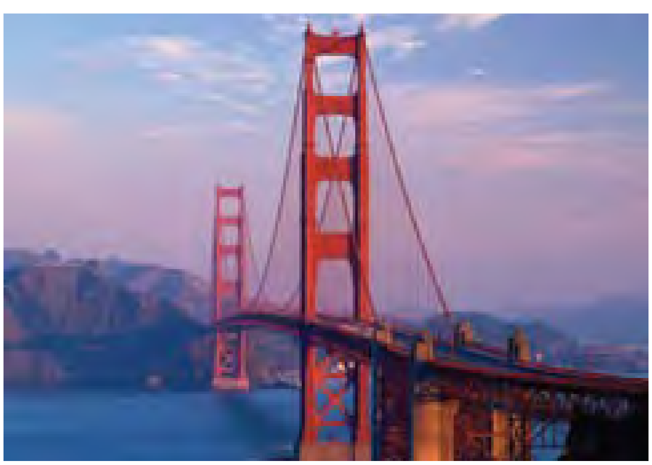
We won't attempt here to tackle these notions except to say that a strong element of ideology and prejudice underlies them. Like the Duke of Wellington, the British prime minister who in 1830 decried railways because they "only encourage the common people to travel around needlessly," so today some disparage the automobile because they resent all the unmanaged travel it enables others to undertake. This distinctly aristocratic disdain for the rights of fellow citizens is hardly likely to gain wide support in a democratic America, but it can motivate diverse groups of people to campaign against expanding highway capacity.

There is also the notion that we "don't have the money" to build better roads. It is true by definition that governments only raise the tax revenues they currently raise for roads, but this outlook suggests that only government-gathered money is available. In fact motorists will willingly pay for mobility when they are given the chance, as we see when new toll roads or toll lanes are opened. There is a huge, untapped source of revenue in the tolls they will pay to escape congestion (recall that $63 billion per year in wasted time and fuel)– a prospective revenue stream that can raise money in the capital markets.

But the principal question for this policy study is: How can we design urban roadways so people will like them better? The major toll agency in Southern California ran a marketing campaign a couple of years back with the tagline "Is it wrong to love a road?" They picked that phrase because so many of their customers had told them "We love your road." The customers loved the road once it was built and operating and providing them with a quick, hassle-free journey. Many of these same people probably opposed the road when it was being planned.

We love many of our great road bridges. The Golden Gate Bridge is said to be the most photographed manmade construct in the country. On the east coast the Brooklyn Bridge is an object of huge national affection and pride. The dramas of its construction by the Roebling father and son, and the sufferings of the workers coping with the poorly understood caisson disease, are a national epic described in popular books, DVDs and TV documentaries. Thousands of painters have painted it. Tourists come to walk it. At the other extreme, for many Americans, "freeway" is a dirty word.

This antagonism is partly because too many roads are plain ugly. They seem out of scale, too vast and unrelieved in their use of great stretches of concrete and asphalt. And when they become "extended parking lots" they seem dysfunctional as well. Congestion, like any shortage or queuing, is a matter of road capacity not being adequate to meet demand at the prices being charged. It can be remedied by some combination of increased capacity and better management of demand with variable prices—but that is not the main topic of this study either.


San Francisco's Golden Gate Bridge is a landmark recognized around the world.

This study suggests that we need to take design itself more seriously. New design approaches must strive to make new highways, if not lovable like those grand bridges, at least acceptable in urban areas, perhaps even likeable. Better design of course has to address the need for more efficiency and safety. Safe movement of people and their goods is what roads are all about, but if proposed new roads aren't acceptable in their design they won't get built. Design can address the aesthetic impacts of new roads, and help to address their environmental and social impacts as well.

B. The Design Problem

U.S. roadways are an amazing transportation system, ranging from giant expressways to parkways, down through signalized arterials, commercial main streets, collectors, semi-rural two-laners, residential streets, and alleys. The largest expressways are of 14 lanes in four separate roadways and carry as many as a third of a million vehicles a day, while the smallest roads may see only a score each day.[3] The Texans with their frontage roads are going even further, to as many as six parallel roadways and totals of as many as 18 and 20 lanes. By contrast, the most modest roads have such small impact we take them for granted. These are usually little more than a few inches thickness of paving between property lines, while the biggest are dramatic constructs of gargantuan dimensions whose interchanges many levels high are so large they can become the visually defining objects in a whole metropolitan area.

Life is full of trade-offs. Many who don't much like the look of urban freeways will use them for the convenience of rapid movement they provide. But these giant roads are bound to produce passionate reactions.

"Highways can often times be as beautiful and as evocative as a fine piece of art or architecture. They are massive, authoritative sculptures that are experienced by tens of thousands of people on a day-to-day basis," writes Thomas B. Gray, an architect who studies highway design and is strongly critical of much of it.[4] Expressways, as Gray puts it "define the city of today; they are the largest, most intrusive, and most recognizable man-made structures within the modern urban environment. They are landmarks which carve and define entire cities; they are meridians of reference by which everything is located; they are regulators of how a modern city is experienced."

It isn't just a visual issue either. When people and goods can be moved more quickly, reliably and economically—these things usually go together—there are many benefits. As a result of the construction of I-287 in Passaic County in northern New Jersey in the 1980s, residents of Westchester County, New York were able to travel comfortably to shopping malls in Morris and Somerset counties in New Jersey. Also trucks to New England from New Jersey, which previously had to crowd the George Washington Bridge and the Cross Bronx Expressway, were able to take less-crowded Hudson River bridges farther north. In Sydney, Australia the recent opening of the Cross City Tunnel means residents of the

New interchange at I-635 and US-75 in northwest Dallas known as the High Five for its five levels of soaring ramps. Pictures from Texas DOT, Dallas District on Web site of Texas Freeway.

western suburbs can cut a trip to Bondi Beach from 40 minutes to 20 minutes. Trips to the University of NSW on the southeast side of the city suddenly become more feasible to residents of the north and the west, so the university has a larger potential catchment area for students.

All these results affect different interest groups differently. There are arguments about how much a new road attracts traffic off local streets, and how much net new traffic it induces. So long as the facility is priced to reflect its costs there is nothing wrong with "induced demand." Every new invention generates a kind of induced demand. Except for some local businesses unwilling to adapt, few people are against attracting through-traffic off of local streets. It's where that traffic should be, not getting in the way of local movement.

Roads and the rubber-tired vehicles they support are the dominant form of transportation throughout the modern world. Some 87 percent of personal daily trips in this country take place in private motor vehicles, and 88 percent of people commuting to work use their own motor vehicles.[5] Also on the roads, buses provide more than twice as many transit trips as rail.[6] Trucking carries 86 percent of the value of U.S. freight shipments versus rail 3.7 percent, air 3.2 percent, water 1.1 percent and pipeline 1.8 percent.[7] Emergency services, construction, trash collection, and utilities maintenance rely almost 100 percent on the roads. Making use of some 2.5 million miles of paved road are 191 million licensed drivers, who drive 237 million motor vehicles.[8, 9]

There are no realistic alternatives to roads and their rubber-tired vehicles for the vast bulk of the national transport task. For half a century vast subsidies have been made to "alternative transportation," mostly passenger rail, heavy and light. In the name of "balanced transportation" as much as half of local government capital spending on transport projects has been for rail. This huge effort on behalf of "alternatives to the automobile" has hardly slowed, let alone reversed, the steady decline in rail's share of passenger movement, or the growing dominance of rubber-tired vehicles and roads. Like King Canute, governments command the seas of cars back, but the tide of automobility is overwhelming.

C. Taming the Car on City Streets

The historian and commentator on cities Lewis Mumford wrote in 1979: "Forget the damned motor car and build the cities for lovers and friends."[10] This splendidly cavalier statement captures an important strain of 1970s thinking among opponents of roads and automobiles. "No cars" and "Ban the automobile" became a theme of various movements for walkable communities and such. In this period anti-car planners and activists popularized the notion of car-free pedestrian malls—streets from which cars were completely banished. Many sections of main streets were converted to pedestrian plazas, some with attractive stone paving, public seating, raised planting beds, new ornate lighting, some even with fountains, ponds, and sculptures. This was dubbed "civic revitalization."

Almost all of these pedestrian-only plazas were a dismal failure.[11] Without automobile access the businesses on the car-less streets lost customers. Deliveries were difficult. Surveillance by police and security guards was awkward, and got neglected. The seating and lawns attracted mostly homeless people and alcoholics. Regular folks shunned the plazas. Vandalism flourished. Maintenance was expensive, and became intermittent. Business abandoned the streetfronts of pedestrian plazas, and they became dead zones. Business and economic life moved elsewhere—to where there was automobile access. That is what comes of forgetting "the damned motor car"—a huge public policy fiasco of waste, unintended consequences and frustration all around.

Most planners now acknowledge the need for maintaining some automobile movement through main street. They may provide more sidewalk and trees, and reduce road space. They may time signals to discourage through traffic. But they provide controlled access for motor vehicles. A balance needs to be struck.

For their part, car enthusiasts need to concede there are zones of cities where the role of cars should be minimized. Historic central areas with narrow streets lose much of their charm and life if overwhelmed by cars. Judicious limits on, or pricing of access to, special areas makes sense. In central Rome and several other Italian cities there is now priority for local residents and priced entry for others. Likewise a variety of developments will limit internal traffic: academic or medical campuses, sports complexes, office parks, shopping centers, and gated residential communities. These are all planned for the convenience and safety of pedestrians and local residents. Through-traffic can be routed around the central areas of such campuses or special districts, with deliveries and parking organized via small spur alleys from the periphery toward the center so that pedestrians don't have to cross busy streets. Some downtown areas or sub-centers within metro areas too may well choose to control access and give pedestrians priority.

But such local "traffic calming" measures will not detract from the overall importance of motor vehicles in the broad metropolitan area, where the trucks and cars will continue to provide the overwhelming majority of goods movements and people trips. Any serious urban reformer acknowledges this reality and gets interested in how we can design—and redesign—our roads to live better with the cars and trucks we are destined to have. Only the ideologically driven or the blind continue to put their faith in "getting people out of their cars" on a metropolitan scale. As Rutgers University professor James A. Dunn observed in his classic book on the subject, it is far more realistic "to get the pollution out of cars than to get the people out of cars."[12]

D. What Follows

The remainder of this study will concentrate on urban expressways and arterials.

Nationally, limited access roadways (expressways) total about 57,000 miles or just 2.3 percent of the center-line length, but they do 31 percent of the "work" as measured by vehicle-miles traveled on an average day. In urban areas the 24,620 miles of expressways do 35 percent of the urban road work. At 57,272 miles, major surface arterials do another 23 percent of the work. That leaves 42 percent of the urban road work done by 872,000 miles of urban minor arterials, collectors and local streets. This study will only concern itself with design issues in the first two categories—the expressways and major surface arterials. These can be called highways to distinguish them from the three categories of smaller urban roads that we can call streets.[13]

Part 2 looks into innovative ways of adding to the urban expressway network—but without destroying neighborhoods or "paving over the city." Part 3 reviews current highway design standards and suggests that we may make progress by moving away from today's all-purpose roadways and letting some specialize in either cars or trucks. In Part 4 we look at ways of making urban arterials work better, via both technology and better design of intersections. In Part 5, we sum up.

Part 2

Innovative Urban Expressways

Studies of trip generation in contemporary American cities have shown that to provide a high level of road service there are certain rather clearly defined highway needs. These are four to eight lanes of expressway on a grid about three to five miles apart, together with arterials feeding those expressway interchanges and providing sub-expressway mobility. The trip generation data suggests these arterials need only be four lanes if they are about a half mile apart. However, as the arterials are spaced farther apart, they need to be built wider to handle the traffic. At a frequency of something less than a mile, the trip generation modeling says, arterials need six lanes.[14]

Very few American cities meet these criteria—parts of Houston, Minneapolis, Kansas City, and the New York area come close, in one aspect or the other. Most come nowhere near. The shortfalls are reflected in our traffic problems.

Congestion sets up various dynamics. Where land for new development is cheap, people and businesses tend to move away from the areas of chronic congestion to places where mobility is better because of low density. This provides some traffic relief, but usually only temporarily because highway roadspace tends to be systematically underprovided in the new areas as well.

Where outward development is constrained by zoning and restrictions, population densities, and hence traffic generated by them, may increase. In the face of underprovision of new highway capacity the need for mobility is reflected in severe congestion that threatens economic viability and the quality of life. Hence the search for ways to provide extra road capacity.

Most of the increase in highway capacity provided in the past couple of decades in American cities has been through rebuilding and enlargement of highways. Original grass medians in expressways have been paved to provide new lanes on the inside. Often expressways have been widened outward too, so eight- and even ten-laners are common. Many people find highways as wide as this overwhelming in scale. They see in them an ugliness they do not find in a four-lane expressway. The eight- and ten-laners also deliver volumes of traffic at interchanges that are difficult to handle without connecting arterials and surface intersections of as many as nine lanes including turning lanes. A human scale is lost.

Ideally we would have smaller-scale expressways but on a denser grid, but history bequeaths us networks which are difficult to change except incrementally. That said, in most of our developed areas there are new routes which can be developed—old railroad rights of way which are little used, high-voltage power line corridors, and strips of low-intensity service industry.

It is commonly said, even by planners who should know better, that "there's no space left" for adding lanes to existing expressways. If space for roads is important enough it can be manufactured by one of three methods. First, real estate can be bought, and converted to space for roadway. Or, second, space can be constructed by going up in the air—elevating the new roadway within an existing right of way. Or, third, you can make space by going underground, leaving other uses for the surface. The choice will depend on relative costs and the local context, including, importantly, community acceptance.

Since this report focuses on innovative design ideas, we will not further discuss the option of simply buying more conventional right of way, either to add lanes to existing roadways or to build entirely new routes. That remains an option, and in some cases will be the most feasible option. We focus here on the more difficult modes—going up, going under, or making use of existing corridor rights of way which are not currently being used for roads.

A. Elevated Expressways

1. Old and New Examples

Elevated roads are the most in-your-face alternative. In a dense urban setting with multiple cross streets, most expressways are either raised up as an elevated structure or depressed below ground level. That's because having many cross streets raised over a surface expressway is too awkward and costly. Early on, elevated expressways were built in many downtowns but in recent years some have been torn down and relocated or not replaced. The John Fitzgerald Expressway in Boston was replaced by the underground Central Artery (also known as the Big Dig), a major section of San Francisco's Embarcadero Freeway was simply demolished, and the earthquake-damaged Cypress Freeway in Oakland was rebuilt but on a different (still-elevated) alignment. By contrast the Chicago Skyway is in the course of a complete rehab and rebuild. The double-deck elevated I-35 through Austin, Texas is planned for replacement by a wider (depressed) expressway. In Seattle, the Alaskan Way Viaduct expressway is to be replaced by an underground facility. In Birmingham, Alabama, a new 10-mile elevated is being considered down the middle of US 280, currently a signalized arterial. The future of other elevateds remains in contention—notably the Gowanus Expressway in Brooklyn, a section of I-95 between downtown Philadelphia and the Delaware River, the Gardiner Expressway in Toronto, and the Whitehurst Freeway in Washington, DC. But other elevated expressways have been repaired and even expanded—

notably I-15 through the middle of Salt Lake City. And some new ones have been built: the I-110 "Harbor Transitway" HOV lanes south of downtown Los Angeles and the reversible lanes "bridge" down the middle of the Crosstown Expressway in Tampa, Florida.

Elevated expressways are still being built overseas. In Mexico City the energetic Mayor Andres Manuel Lopez Oprador, spoken of as a possible 2006 presidential winner, has made downtown civic improvement and improved transport the centerpiece of his electoral program. This has consisted of about a dozen bus rapid transit routes and bikeways plus arterial road underpasses and flyovers. The most spectacular have been new elevated expressways known as Segundo Piso, literally "second story" roads. The largest are of soaring concrete segmental box girder construction, adding multiple lanes to two heavily trafficked existing expressways, El PerifÈrico, and Viaducto in the northern part of the city. The present program of elevated highways is for 22 miles of Segundo Piso. It is a populist program carried out by a politician determined to "get something done" by bulldozing through all opposition, so it has been enormously controversial and heavily politicized.

A number of Asian cities have major elevated highways involving double-decking, notably Manila, Bangkok, Osaka and Tokyo. In Japan the first generation of expressways was almost all built as elevated double-deckers over existing surface roads. They were built with a pair of narrow 10.7-foot lanes compared to the U.S. 12-foot standard. To minimize property acquisition, these early Japanese expressways had sharp curves and steep ramps (slopes as much as 8 percent) and only 20-inch shoulders. Design and posted speeds are a mere 37 mph. Tokyo has some 22 routes totaling some 154 miles of such highly constrained, mostly double-deck elevated expressways. Japan's second metro area, Osaka, has a similar network, only slightly less extensive.

Elevateds will generally be cheaper to build and to maintain than subsurface roads, and a lot cheaper than tunnels—which is an adequate argument in itself for the overhead solution to be considered among alternatives. The narrower an elevated is the more acceptable it is likely to be because of the lesser shadow cast. In New York City virtually all of the 4-track rail elevateds of early in the 20th century were taken down. However narrower 2-track elevateds survive—a notable one is the High Line on the Lower Westside, demolition of which is strongly opposed by a powerful coalition.[15]

Elevateds don't have to be ugly like the first generation, which were generally built trestle-like of many steel plate or prefab concrete I-beam girders laid atop the caps on rows of close-spaced utilitarian piers—a cluttered and messy look.

Concrete segmental box girder construction atop single flared concrete piers allows longer spans with a clean sculpted look.[16] Best of all, the new good-looking elevated can be cheaper to build—at least on longer projects where set-up costs can be spread over a large project.

Typical trestle-type construction as seen on the early segment of the Selman Crosstown Expressway through downtown Tampa. Picture from Tampa Hillsborough County Expressway Authority.

Visualizations of the Reversible Lanes Bridge under construction 2004-2007 by the Tampa Hillsborough County Expressway Authority east of downtown Tampa.

The outstanding example of a modern elevated is known as the Reversible Lanes Bridge under construction in Tampa.[17] The elevated structure extends five miles down the median of the Lee Roy Selman Crosstown Expressway from Brandon to downtown Tampa. It will have 218 central piers six feet square about every 140 feet. The three-lane roadway atop the piers is built out of about 3,000 match cast segments, each 80 tons in weight, about nine feet long, and 60 feet wide. The segments comprise both the box-shaped girder section and the full 60-foot width of the road deck cast in one piece. Made in a factory and trucked to the jobsite, they are "match cast" in the sense that the end of one segment provides a form for the casting of the adjacent segment so they fit tightly together when erected on a temporary erection truss. Once a full span is assembled out of 15 segments on the temporary truss, they are compressed into a single girder by steel cables drawn through cast-in conduits and put permanently into tension. Then the span will more than support its own weight and the erector truss is removed to help build the next stretch.

In their more exuberant moments, the project sponsors have pitched the Reversible Lanes Bridge as "six lanes on six feet" on the basis that it will provide three lanes inbound in the morning in the peak direction, and three lanes outbound in the evening with a mere 6 feet footprint.

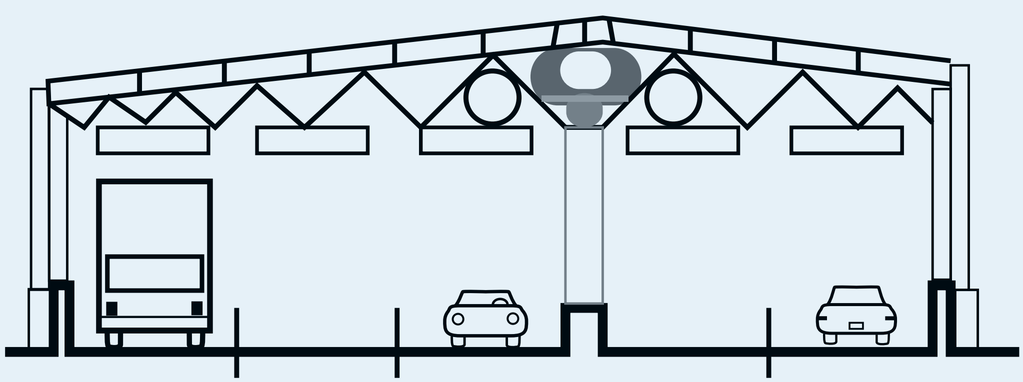
2. Sound Mitigation

Such elegant new designs meet much of the aesthetic criticism of older generation elevated roadways. But another major objection to elevated roadways has always been noise. Fortunately, there have been advances in noise mitigation for elevated highways. Most of these are custom designed to contain traffic noise where the roadway runs close to buildings. Some are quite imaginative architecturally. Melbourne CityLink, a downtown urban toll road that opened in August 1999, has 1,000 feet of "sound tube" where an elevated portion gets within some 500 feet of high-rise apartment buildings in North Melbourne. The tube is a striking architectural feature.

Drawings of a sound tube on the Melbourne, Australia CityLink tollroad, with construction detail shown. Courtesy Denton Corker Marshall [DCM] architects.

Its main structural element is a pair of sweeping, curved and tapered C-shaped elements somewhat akin to aircraft frames. They seem to spring from under the six-lane roadway and enclose it in an oval-shaped frame. The frames are 140 feet wide (well clear of the sides of the roadway), provide 18-foot clearance at the edges, and soar to 26 feet above it in the middle. Thin tubular struts span the gap between each frame longitudinally making it a high-tech pergola. The sound-attenuating cladding is strategically located to shelter the nearby buildings but for the rest the frame is open. If new high-rises were to be built near the roadway, new sections of sound attenuation could be applied to the frame in the appropriate place. Its shielding effect is readily adapted to changing needs. This is an outstanding example of how imaginative design can tackle a problem and produce a practical and attractive solution. Standard acoustic walls would have done the job. However they would have been quite high, unsightly, and a problem to secure against high wind.[18]

In Switzerland special sound-attenuating glass walling is increasingly used on urban motorways. There's a design for one that is fully enclosed inside a structure very like a long commercial greenhouse—glass walls and a pitched glass roof on light, steel, greenhouse-type trusses.



Swiss design for a motorway fully enclosed in an elongated greenhouse-like structure called in German "Glasbilt."

Sound berm on the A92 motorway near Freising in southern Germany is used to mount arrays of photovoltaics called Das Projekt PV-Soundless. Photo from solarintegration.de.

That attenuates sound and also eliminates snow and ice problems in winter.[19] In Hong Kong there is an elevated motorway which has been entirely enclosed. It has curved glass walls, very slick and high-tech, and a conventional solid flat roof. In Germany, the Netherlands, Austria and Switzerland, where the "green" movement is strong, there is extensive deployment of continuous photovoltaic (PV) or solar electric panel on sound-attenuating berms of motorways. For example, on the A92 autobahn near Freising there is 0.8 miles of sound berm covered entirely with PV panels—called Das Projekt PV-Soundless.[20] It is rated at 499kW.

On the San Joaquin Hills Toll Road in Orange County, California another approach was used to deal with road noise. The Toll Roads agency paid for glass sound walls on residents' decks to reduce noise problems while retaining light and views.

On the new $2.5 billion Woodrow Wilson Bridge on the Capital Beltway in the Washington, DC area, engineers faced the need to protect residents of Old Town Alexandria from traffic noise without building unsightly solid walls on the bridge. They are installing a 16-foot high wall of 40mm thick acrylic polymer glass for some 1,550 feet along the north side between the bridge's traffic lanes and its pedestrian walkway. The material is estimated to reduce noise in Alexandria by 7 decibels. The glass wall is costing $1,800/foot or close to $10 million per mile—about three times the cost of a conventional heavy masonry sound wall of the same height.[21] However solid walling is ruled out by the aesthetics of the bridge.

In Europe, where such glass walling is quite common, there is also a major push to reduce sound at the source—where the rubber meets the road. That means no hard concrete pavement surfaces and specially blended asphalt. It's not easy, though. There are tradeoffs with cost, pavement life, and traction in slippery conditions. There are other sources of highway noise apart from the wheel-road effects. Vehicle engines, brakes, and air turbulence also generate noise, so sound-attenuating pavement is no panacea. More streamlined vehicles and quieter engines will be required for further progress in reducing highway noise.

3. Land-Use Considerations

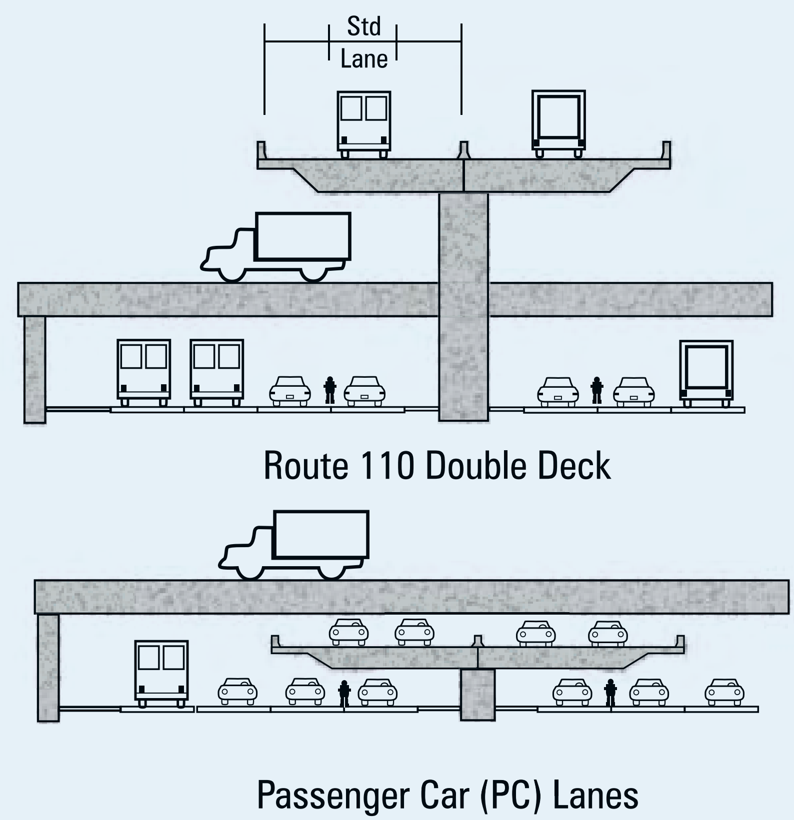
Land uses in the corridor will often determine whether an elevated highway is acceptable. In commercial and light industrial areas an elevated will often be found compatible with surrounding land uses. The elevated I-110 Harbor Transitway on the south side of Los Angeles was accepted because of the industrial character of that area.

In Texas, expressways are built with frontage roads alongside. These therefore tend to become commercial corridors (or "strips" if you disapprove). Hence there is relatively little opposition to road widening, higher interchanges, and elevated construction because the adjacent land uses are mostly commercial.

I-110 Transitway, just south of downtown Los Angeles is elevated above the cross bridges as well as the main lanes.

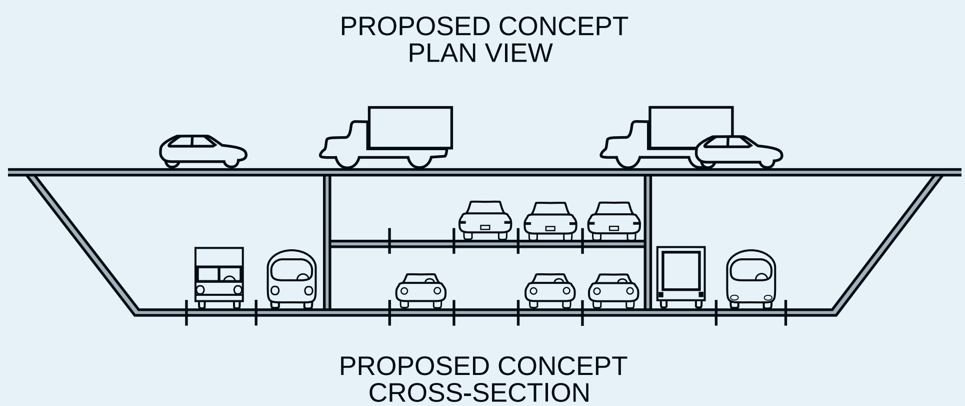
4. Reduced Dimensions

Adding a second deck to an existing expressway is often advocated but not often implemented. One reason is that such projects typically require a much higher second deck than might be thought at first glance. The arithmetic is as follows. To accommodate modern tractor trailers, general-purpose traffic lanes are these days built to 16-foot overhead clearance, allowing two feet for signage above 14-foot-high trucks. To that 16 feet is added up to six feet for the thickness of the bridging structure, so the second deck has to be 22 feet higher than the first. Add cross streets to the structure and there is a 44 foot difference. With some parapet walls you are up to 48 feet, almost the height of a five-story building.

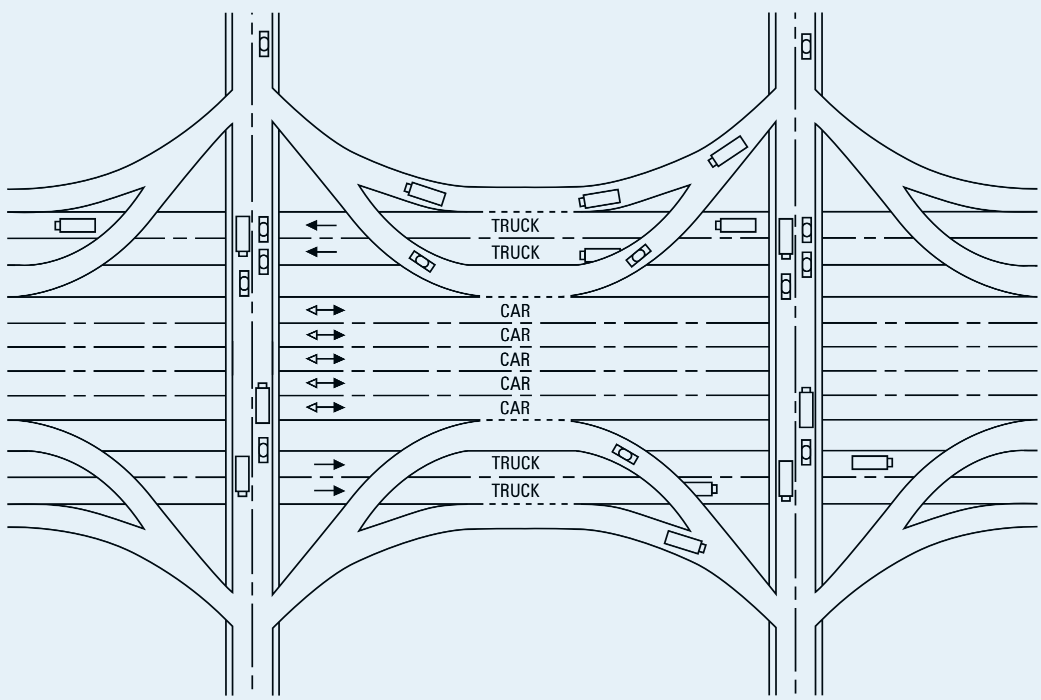


Gary Alstot's diagram showing a less intrusive form of doubledecking. By doubledecking cars-only roadways with lower overhead clearance they can more readily both be placed under overbridges of cross streets instead of looming way overhead as on I-110 in Los Angeles.

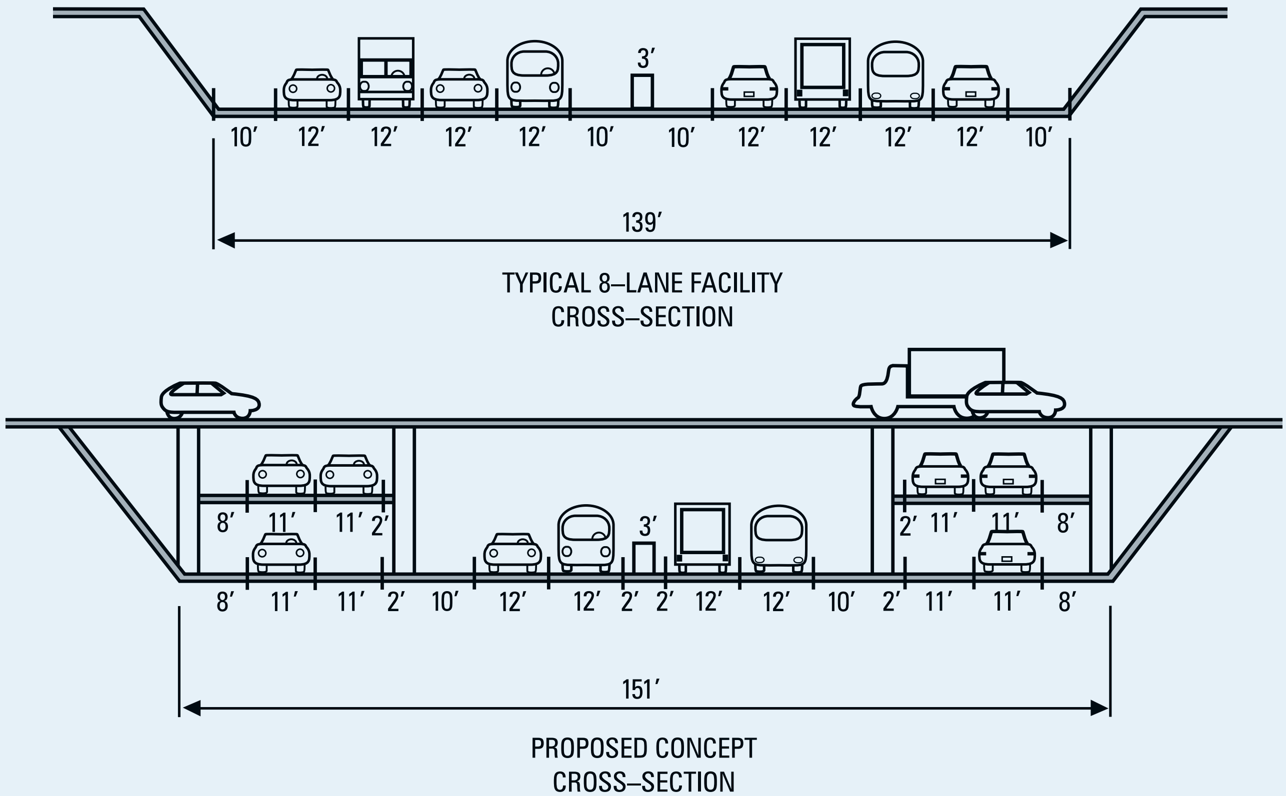
Civil engineers Joel Marcuson and Gary Alstot have suggested (separately) that on high-volume urban expressways cars and other low-height vehicles should run at two levels while trucks run at a single level.[22] The French are practicing the same principle of separating vehicles by height in the A86 West tunnel in Paris. With a height limit of 8 foot 4 inches, they can accommodate two levels of cars in the same sized tunnel as permits only one level for trucks. An American standard for overhead clearance for light vehicles would have to be 10 feet given the number of vans and SUVs in this country's vehicle fleet. But with two decks and a thinner girder depth, the double-decker for light vehicles could be kept to, say, 28 feet below cross streets. This is much less intrusive and less expensive than 44 feet height.



Joel Marcuson's proposal for converting an 8-lane all-vehicles expressway into 12 lanes comprising 8-lanes of cars-only low clearance and 4 lanes trucks or all-vehicles with high clearance on the outsides.



Aerial view of proposal seen above.



An alternative format using 4 lanes with all vehicles in the center and doubledecked structures for low vehicles on the outsides.

Cofiroute, a French toll company, is building a doubledeck tunnel for low vehicles with an overhead clearance of 8 feet 4 inches (2.55m) providing two travel lanes and a breakdown lane on each level. Tunnel-boring machines are now available with diameters of up to 46 feet (14m) allowing greater height, which we think would be advisable in any U.S. application of this principle.

Dimensions of the A86 West tunnelway project. Within a 34-foot (10.4m) diameter tube built with a tunnel-boring machine, two decks provide 8 feet 4 inches overhead clearance for three levels plus a pair of ten foot travel lanes plus a breakdown shoulder lane. Drawing from Cofiroute.

B. Going Underground

Despite the best efforts of designers, in many areas surface and elevated roads will be regarded as visual blight and an unwanted barrier. However elegant the architecture of an elevated roadway, if it has a certain mass and spread, there is bound to be a gloomy underside to it. In these cases undergrounding needs to be considered.

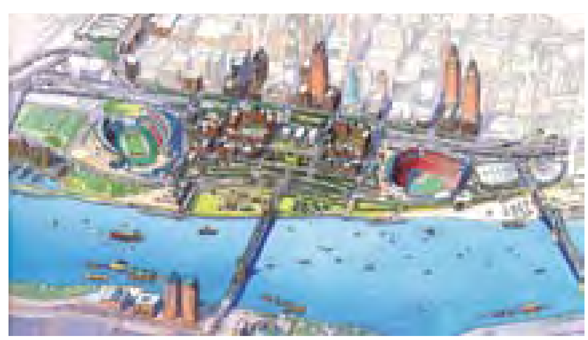
At two miles long, the Vine Street Expressway (I--676) is depressed below ground level in a walled trench and skirts the northern fringe of Philadelphia's central business district.

1. Entrenching

The first step going underground is placing the urban expressway in a trench approximately 22 feet deep—16 feet for clearance above the roadway and 6 feet for the thickness of cross street bridging. This allows cross street bridges to be flat and reduces the noise and visual impact of expressway traffic as compared to a surface or elevated design. More capable drainage pumps and advances in retaining wall construction have increased the feasibility of entrenching expressways. Mechanically stabilized earth wall (MSEW) construction enables walls to be built of quite light facing panels. Traditional retaining walls depend on the mass of the wall to hold back side loads, so they involve very heavy and expensive construction. MSEW walls are held back by 10 or 12 foot strip ties of corrosion-protected steel that are laid in the backfill and attached to the light weight (vertical) facing panels. If there is space, the trench can be made with a cheaper natural sloped embankment, but in a tight urban environment this is increasingly rare.

Entrenched expressways are quite common. A typical example is the Vine Street Expressway (I-676) in downtown Philadelphia, which links the Ben Franklin Bridge and the Schuylkill Expressway (I-76) and provides excellent access and egress at three points in the central city area. The Vine Street Expressway is utilitarian, but to many it seems bleak. A more imaginative, recent entrenched expressway is Fort Washington Way (I-71) a 0.9 mile downtown connector paralleling the riverfront in Cincinnati. A late 1990s rebuild of a 1954-vintage near-surface expressway, the new entrenched roadway has eight travel lanes, modern ramps at the ends rather than midway, and architect-designed bridges and accoutrements. It is built to allow for later "lidding" or decks to be built over it by the city or developers. It cost $320 million and was built in less than three years.

Fort Washington Way.



Plan for eventual lidding of Fort Washington Way. It was rebuilt in 1996-2000 to allow this by eliminating multiple downtown ramps.

2. Tunneling

The United States has many examples of underground highways for a short distance including: Colonial Parkway in Colonial Williamsburg, I-395 under the Mall in front of the Capitol, I-66 by the Watergate complex in Washington, the E Street Expressway in Washington, I-10 at Margaret Hance Park in Phoenix, I-95 Penn's Landing Philadelphia, I-71 under Lytle Park in Cincinatti, I-35 (four tunnels) in downtown Duluth, I-5 under Freeway Park downtown Seattle, and I-90 under the Mt. Baker neighborhood of east Seattle. Atlantic City got a tunnel as part of the Brigantine Connector, which opened in August 2001. A cut-and-cover tunnel 1,957 feet long of four lanes, it avoided the need to acquire properties and encroach on the local streets of an established community. It has a canal-front park on top. In the Dallas area, the North Texas Tollway Authority built a toll tunnel under the Addison municipal airport to improve east-west connectivity. During the reconstruction of the LBJ Freeway (I-635), also in Dallas, twin managed-lane tunnels of three lanes each are planned to avoid the need to acquire extra right of way.

Thomas B. Gray has written of the positive potential of putting highways underground. Of the Duluth I-35 project he writes: "The moral of the Duluth freeway story is that the urban freeway does not have to be a destructive influence on the inner city. In fact, it can have the exact opposite effect." He quotes the I-35 Citizens Advisory Panel member Bill Abalan as saying the I-35 project in downtown Duluth "led to a renaissance of Duluth's downtown. This is because the city and its citizens took the opportunity to turn something potentially destructive into something that added value to and improved the quality of life of the entire community."[23]

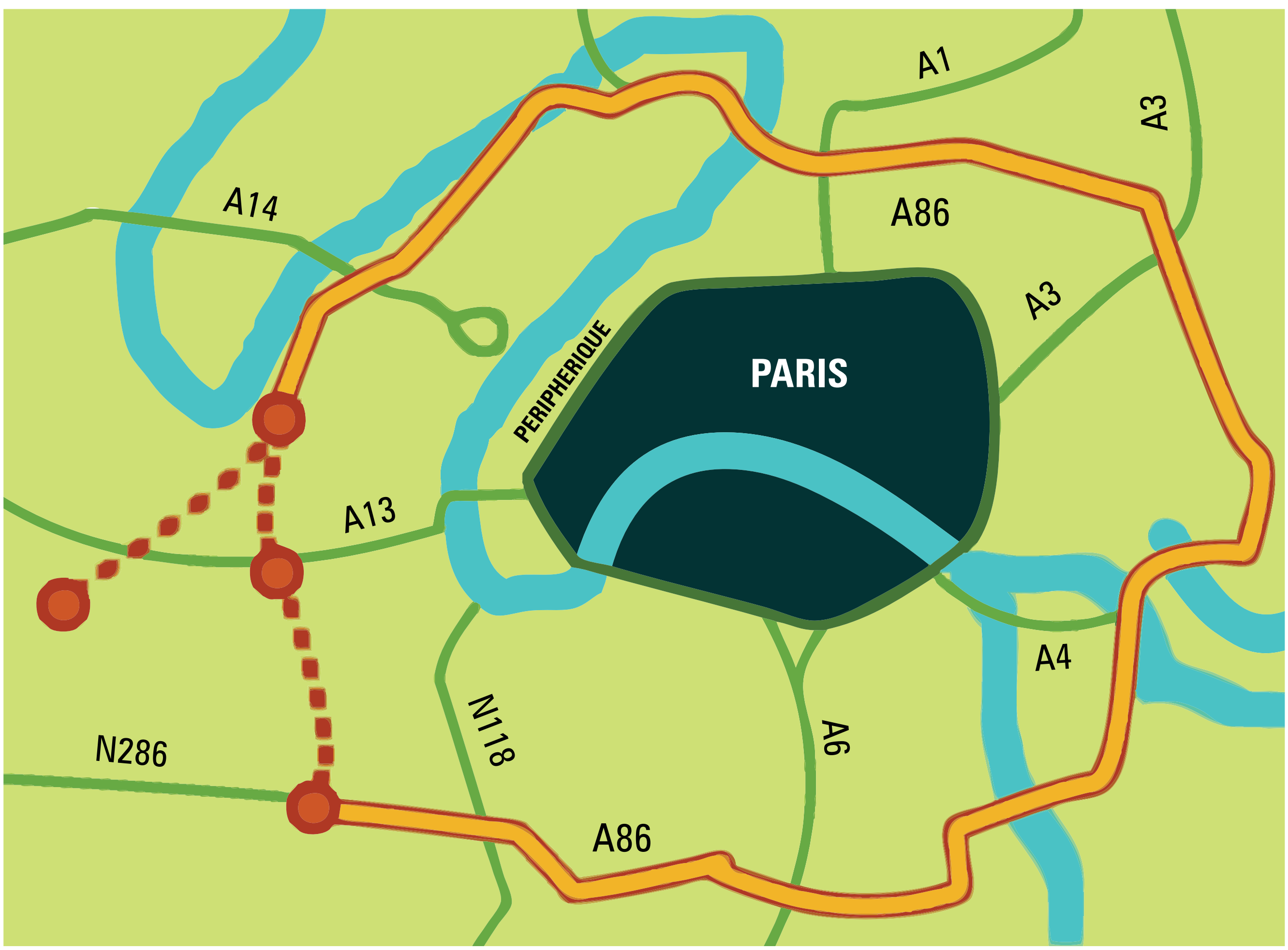
New expressway construction in Japanese cities is increasingly underground. Tokyo has several complex and expensive subsurface projects like Boston's Big Dig. The Japanese capital probably has the world's largest program for underground highway construction, including most of the seven-mile long Shinjuku section of the Central Circular Expressway and two-miles of the Oji section. The Trans-Kawasaki and Omiya expressways within the Japanese capital also have substantial undergrounding planned.

In Europe, Asia, and Australia there are some spectacular examples of urban tunnel highways being built where there is strong objection to land acquisition and construction of surface roads.

Versailles near Paris

Near Versailles west of Paris there has long been a missing link in the outer A86 ring motorway because of the sensitive nature of an area of historic estates, villages, public woods and grand palaces. For 30 years efforts to design a conventional highway link through the area failed. Traffic clogged quaint country lanes and villages because of the lack of a proper through road.

The investor-owned toll company Cofiroute proposed a pair of toll tunnelways that constitute a project called in French l'A86 a l'Ouest, or A86-West. The first, tunnelway from Rueil-Malmaison to Pont Colbert, now under construction, involves a bored tunnel 6.3 miles long with two decks inside. Midway it will rise nearly to ground level to send off ramp tubes which will be an underground interchange with the A13 motorway. This tunnelway will permit only low vehicles of up to 6 foot 7 inches height with 8 foot 4 inch headroom and in 10 foot wide lanes. But this allows four lanes of traffic and breakdown lanes along with separate fresh and exhaust air ducts to be accommodated in the interior of a 34 foot diameter tube built by a tunnel-boring machine. Over 90 percent of the potential traffic will fit in this tunnel. Its tight dimensions mesh with a planned 43 mph speed limit. Tolls will be varied to prevent excessive traffic and assure free flow at this moderate speed.



The A86 tunnelways will complete a missing link in the A86 outer beltway around Paris. The low-vehicles doubledeck tunnel now under construction is 6 miles long, and the 4.7 mile long all-vehicles tunnel heading off to the west is to be built later. Map from Cofiroute.

The same tunnel-boring machine will be used to build a second westerly tunnel, Rueil Malmaison to Bailly, 4.7 miles long for mixed traffic with headroom for full-height tractor-trailers. The project involves no public funds.

On a long tunnel in very poor soil conditions a tunnel-boring machine is best. In many ground conditions it is unnecessary. Advances in geotechnical engineering and tunneling methods offer many options. Road header machines with a maneuverable grinding head can now be set to grind out rock and send it out a chute onto a haul truck in place of the old drill, blast and shovel of rock mining. 'Boomer' machines can install stabilizing rock bolts and pressure-pumped concrete or "shotcrete" is applied over reinforcing bar caging where the natural rock is unstable. Ground freezing can be used to stabilize the surrounding ground around until manufactured supports are in place. Such flexible techniques allow an elliptical section deep tunnel to be built—more suited to the road than the circular section.

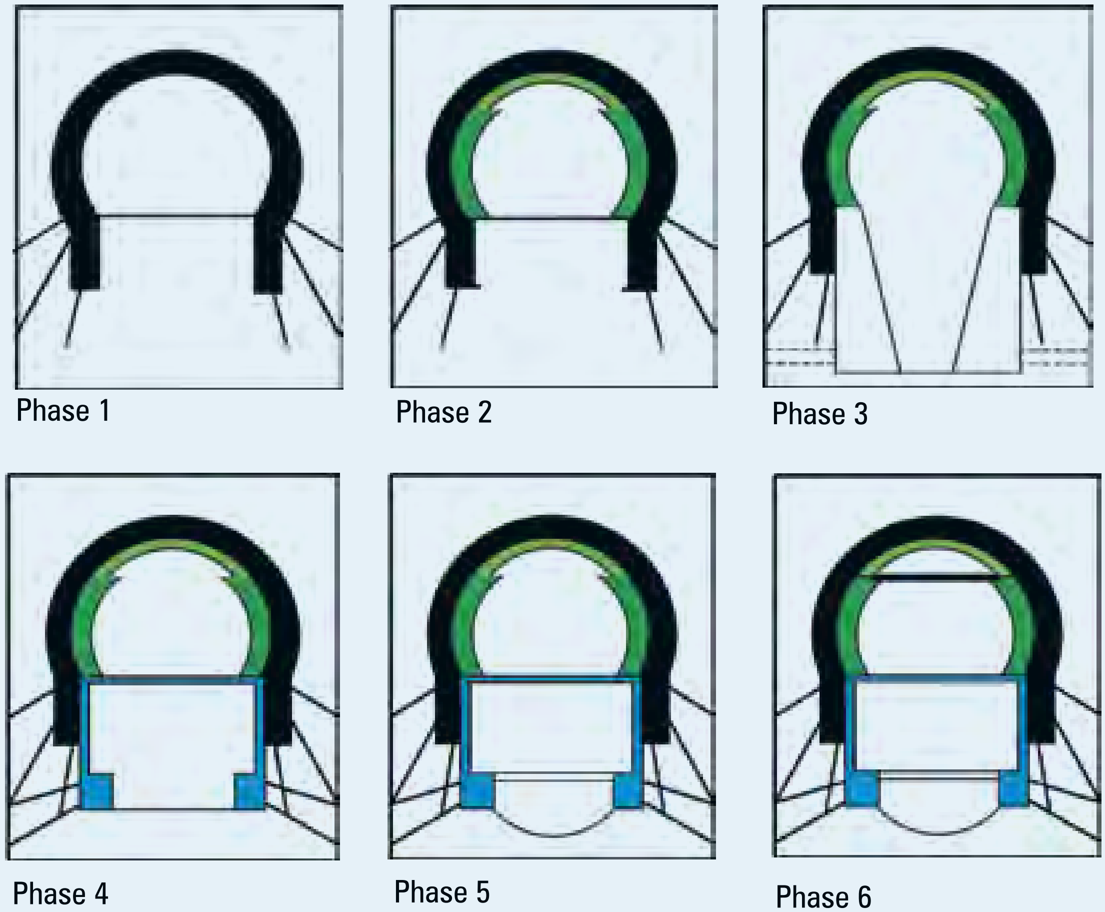
Other French Tunnels

The A14 tollroad that opened in 1996 and connects central Paris at the Defense complex of high office with the suburbs to the west has a 2.5 mile long tunnel (four lanes) in the vicinity of St. Germain en Laye. The toll operator uses a peak/off-peak differential in toll rates—during peak hours 6 AM to 10 AM and 4 PM to 8 PM, the toll is E5.95 vs. E3.95 at other times. This helps persuade some motorists to use the road outside of the rush hour and extracts the largest toll when the benefits to motorists are greatest. An older undergrounding protects the city park Bois de Boulogne in Paris. The Boulevard Peripherique, the inner beltway of 6 lanes, constructed in the 1960s, has a tunnel just under one mile long by the park. Also the A13/E5 motorway meeting the Peripherique from the west has a tunnel about half that length under the Bois de Boulogne.

A tunnel under developed areas enabled a radial motorway, the A14, to be built west out of Paris. It was financed by a toll concession granted to SAPN (Societe des Auto-routes Paris-Normandie). With only 2x2 lanes, the tunnel toll is raised in peak periods to encourage some traffic to travel off-peak, maintining free flow. Picture from SAPN.

France's third city, Lyons, has four mile-long, twin two-lane tunnels running east-west under the historic district, part of a six-mile Boulevard Peripherique Nord de Lyon built as a toll concession, but later taken over by the city. It opened in 1997.

Another interesting underground road is the Tunnel du Prado Carenage in the old French port city of Marseilles. A toll concessionaire bought the rights to a little-used 1.5-mile railroad tunnel, rebuilt it and made it into a double-deck road tunnel with two 10 foot wide lanes on each level for cars (maximum height 10.5 feet). It provides a congestion-free route to the central business district from the north. Some 40,000 vehicles per day use the tunnel, generating a good return for the investors. Most



A toll concessionaire in Marseille, France bought a littled-used 2-line rail tunnel, excavated the tunnel floor and built another level to the tunnel allowing 2 lanes atop 2 lanes. Diagram shows construction by stages. Picture by Société Marseillaise de Tunnel Prado Carnenage.

downtown Marseilles hotels and other businesses give directions to visitors via the tunnel because it is the simplest and quickest route.[24]

Other European Tunnels

A new western bypass motorway in the Swiss city of Zurich is being put substantially underground in order to avoid disturbing communities and the landscape on the eastern side of Lake Zurich. For over 30 years there had been arguments over the route. Only plans involving substantial tunneling gained acceptance. Nearly 80 percent of the motorway's 6.6 miles is underground. Now under construction are four tunnels, the longest of which (the Uetliberg Tunnel) will be 2.7 miles long and twin tubes with a roadway width of 33 feet. Expected to carry 70,000 vehicles per day, it will cost an estimated $670 million. (www.uetlibergtunnel.ch) A three-mile tunnel is planned to the immediate southwest of the western portal of the Uetliberg Tunnel as part of a project to complete a direct Zurich-Luzern-Italy motorway (N4).

The Swiss are also studying the feasibility of a Lake Tunnel (Seetunnel) to provide a motorway link on the eastern side of Zurich. A highway along the waterfront itself has always been regarded as environmentally unacceptable. Lake Zurich is quite deep so it will likely be a submerged tube within the waters of the lake. A bridge is ruled out by the depth of the lake and aesthetic considerations.

In Basel a North Tangent Motorway (N2) is under construction linking the French and Swiss motorway systems. The two-mile city center project involves a new double-deck bridge over the Rhine River and a tunnelway (1,480 feet long) that carries traffic underneath a surface city street. The developer is using a cut-and-cover and top-down construction approach that keeps half the surface street open at all times. Cost of the tunnel is $40 million.

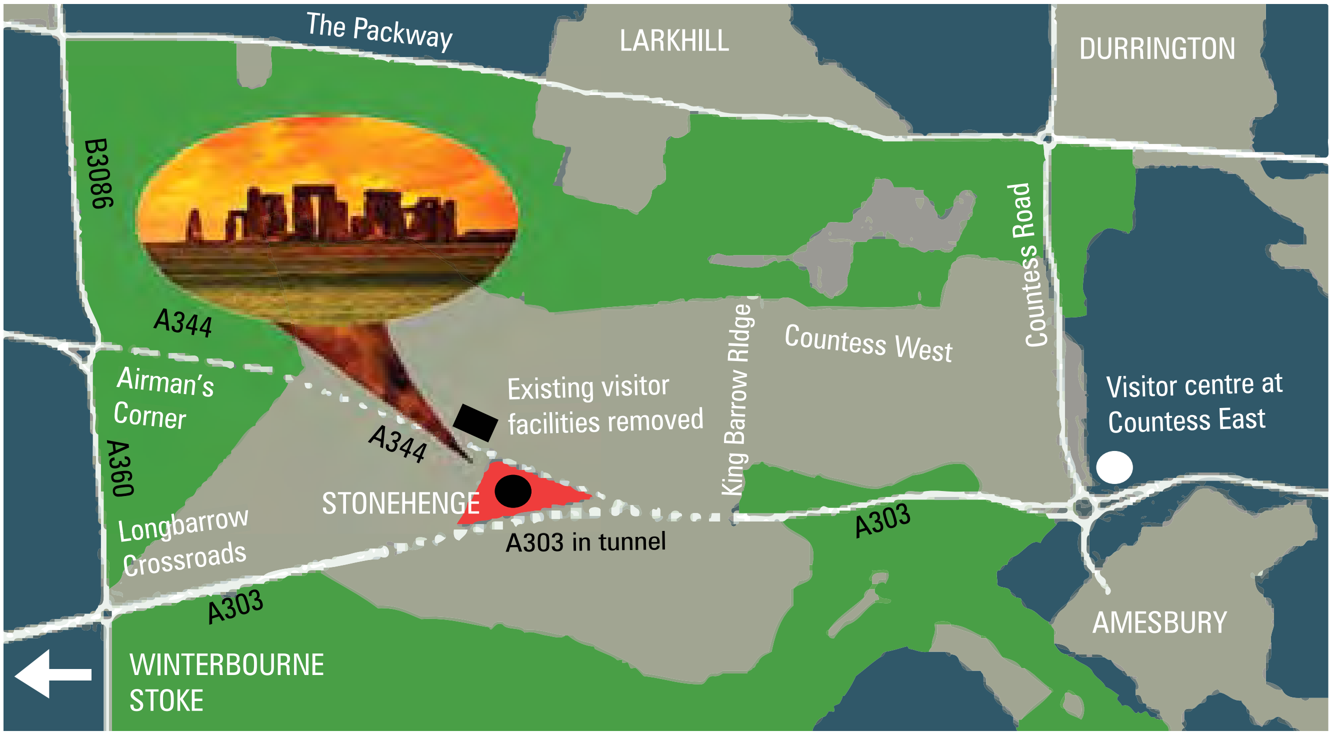
In the north of the Austrian city of Graz, plans for the A9 motorway as a surface facility ran into overwhelming political resistance in the late 1970s. The Plabutsch tunnel, six miles long, was built instead by the Asfinag toll company. At that time it was only able to finance a single tube, one lane each direction. Tunnelers broke through on a second tube in 2001, and it was completed in 2004 along with a full motorway segment, four lanes divided. Meanwhile in Liefering in the north of Saltzburg a short third of a mile connector road of six lanes at about ground level is being enclosed in a cast-in-place tunnel and will have earth mounded over it to minimize impacts on nearby housing.

Tunnels have also been built in Stockholm, Oslo, and Prague.

UK Tunnels

In the Wapping/Limehouse docklands area, the London Docklands Development Corporation devised a scheme to preserve the historic character of this gritty area of old London while providing a new level of mobility to support its economic redevelopment. The key to realizing the potential of the area lay in relieving it of crawling through-traffic. In 1981 local government looked at surface road alternatives, but rejected them. The solution was found below the ground. To minimize the amount of demolition in a residential area, a serpentine route under Limehouse Basin, linking a number of parcels of derelict, underused and cleared land, was selected. This in turn would link with the road corridor across the top of the Isle of Dogs and on through Leamouth to the A13. The 1.2-mile Limehouse Link tunnel opened in 1993. It was designed, planned and built in seven years. The complexity of the engineering and construction made the Limehouse Link, at the time, the second biggest engineering project in Europe after the Channel Tunnel.[25]

There have been impassioned arguments over plans for a 1.3 mile tunnel to isolate Stonehenge in fields in the south of England from traffic on a couple of busy arterial routes



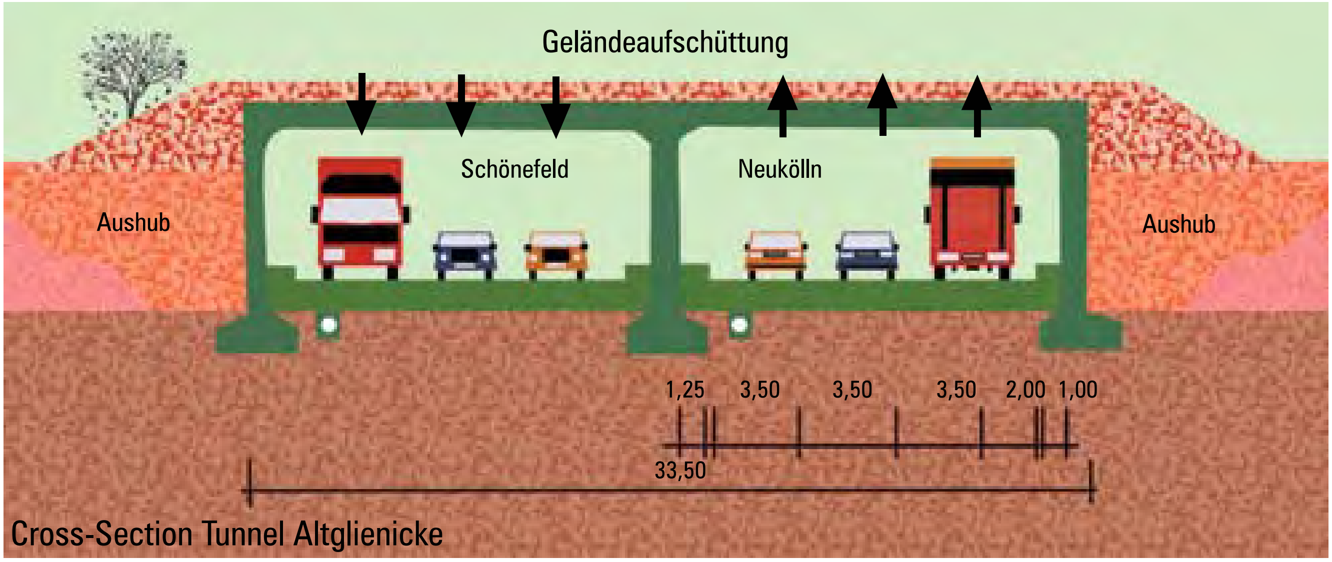
Map of the proposed Stonehenge Tunnel from the Stonehenge Project.

that go right by the ancient monument. The arguments revolve around the appropriate route and length of the tunnel, as well as financing issues. Many charge the costs have gotten out of hand, but there is widespread support for the tunnel concept. The National Trust which administers the site says: "A road tunnel will break the current stranglehold of traffic thundering past the stones on the busy A303 and A344."[26]

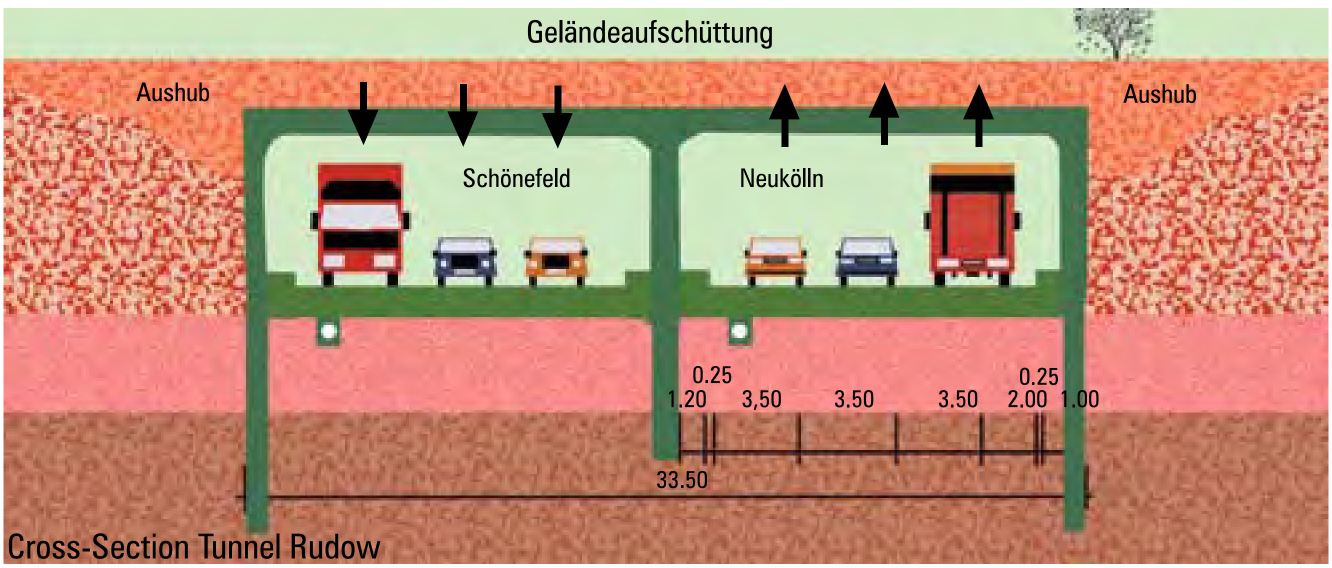
Germany's Unterbahn

In Germany, where the Greens are strong politically, there are several important examples of undergrounding of difficult highways.[27] In Berlin, the capital, the Cold War division of the city left important links in the urban autobahn system unbuilt until the collapse of communism and reunification. One of the most important East Berlin-West Berlin links was the BAB A100 motorway from Tempelhof to Neukölln, the centerpiece of which is a 2x3-

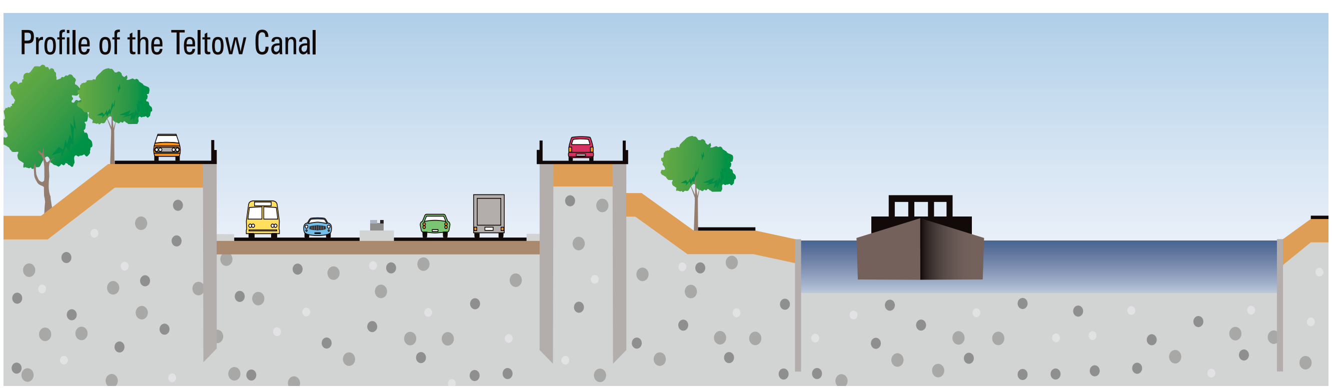
Berlin's three highways with tunnels.



Section showing A113 tunnel in berm.



The second A113 tunnel is a more conventional cut and cover in a trench.



Part of the A113 alongside a scenic canal is open but the canal is isolated from traffic noise by walling and earth.

lane tunnel 1.1 miles long opened in July 2000. Designed to cater to an expected 170,000 vehicles a day by 2015, it links the West Berlin inner-ring motorway to a new A113, part of the national network and also a route to the future Berlin-Brandenburg Airport. Cost is put at $277m (based on 1.18 $/E and E235m).[28]

A113, another 2x3 lane motorway to the immediate southeast of the center of Berlin is being built with two tunnels—solely to mitigate impacts and improve the ambiance of the surrounds.

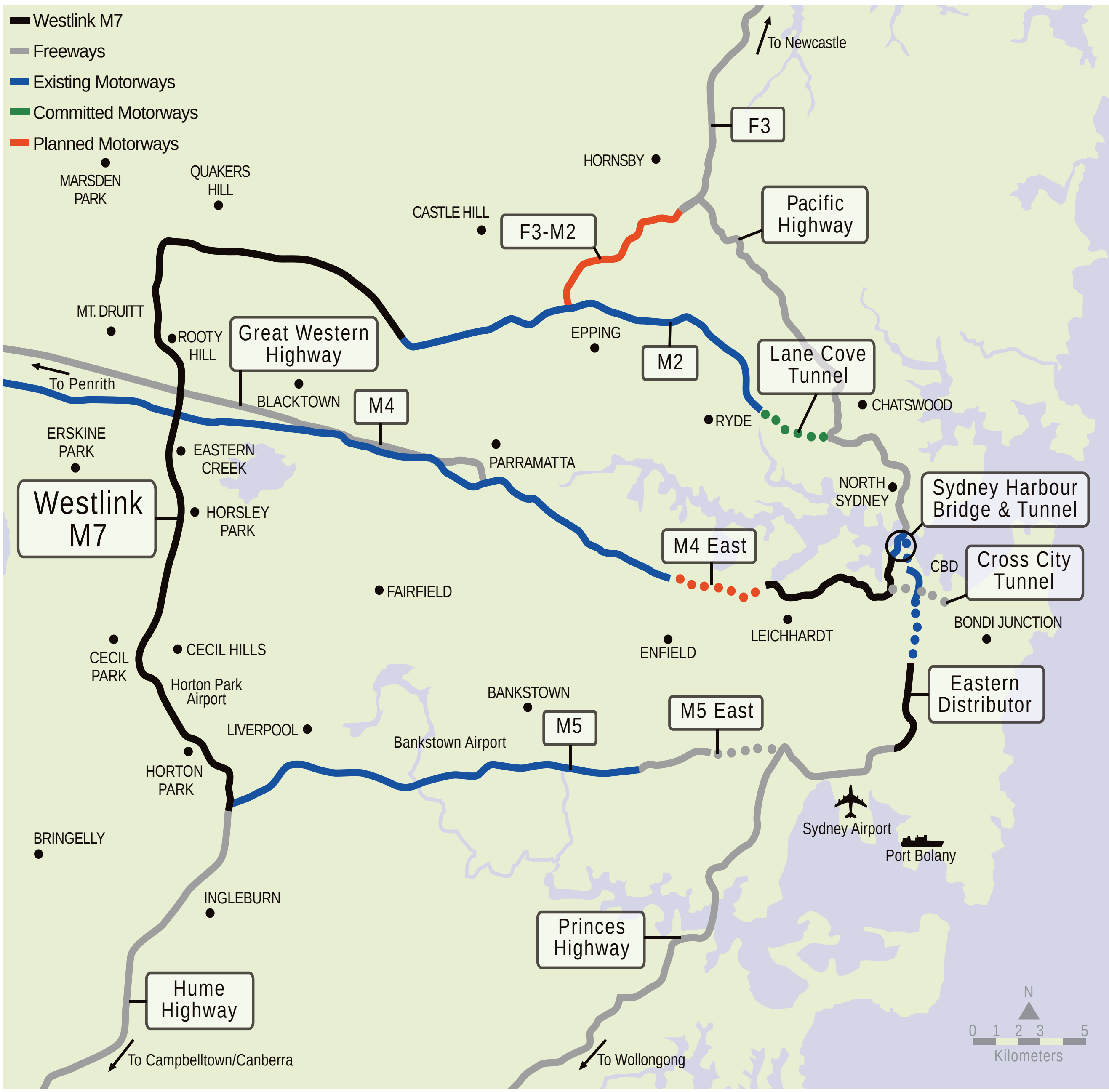
The A113 is located along the line of the former Wall between east and west, so involves little by way of property acquisitions and demolition. (The Wall had strips of cleared land on both sides for patrols to deter escapes.) The A113 is also parallel to an attractive canal. Planned for 140,000 vehicles per day, it is 6.3 miles in length and has three-quarters of a mile (3,940 feet) of tunnel in two segments—called Tunnel Rudow and Tunnel Altglienicke. Both were built by cut and cover. The second is built close to natural ground level and the earth is mounded over the double box structure, the idea being to provide a stretch of open ground without the barrier effect of a surface highway. Beyond the buried segments, the banks of the canal are separated from the highway by walled earth banks, allowing it to be enjoyed free of traffic noise by boaters, walkers and cyclists. Total project costs of $850m (E720m) are listed for the whole project, which is due to open by the end of 2007.

A third Berlin tunnel project is the Tunnel Tiergarten Spreebogen carrying federal road B96, an arterial road, one level down from an autobahn. The existing B96 goes through the famous Tiergarten Park. With the overall project length being 1.8 miles long, the tunnel portion under the park is 1.5 miles in length and consists of 2x2 lanes. Built for 50,000 vehicles per day it will take traffic out of the gardens allowing enhancements, make the area more pedestrian-friendly, and shield future parliament buildings, embassies and offices from traffic noise. The works are fitted into a tightly developed prestige area alongside the basements of new buildings. Special measures have been taken to minimize transmission of vibration. Construction began in 1995 and is taking 11 years, due for completion in the spring of 2006. Cost is put at $460m (E390m).

Australian Tunnels

The transit-not-roads movement got an early start in Australia and blocked the kind of surface urban expressway construction that was common in the United States in the 1960s and 1970s. In Sydney, the country's most populous (4.4 million) city, surface arterials were developed in the 1970s with coordinated signals and fiercely policed restrictions on curbside parking and turns to carry near-expressway volumes of traffic. However business along these corridors died early on because access was impossible for long hours each day. Plenty of transit alternatives were developed but the surface arterials were eventually overwhelmed. Average speeds dropped into the single digits. The specter of Bangkok-style congestion loomed.

Gradually the power of environmentalists and NIMBYs (Not In My Back Yard) to block road improvements was worn down, governments were elected pledging to tackle the problem, and the field was opened to investors to build modern highways with toll franchises. They started where it was cheaper and easier to build with three major radial toll roads in the outer and middle suburbs—surface expressways (M4, M5, M2). All three are successful financially and are subsequently being expanded. The M4 has done major widening and another, the M2, is starting a widening. Then a new four-lane harbor tunnel was built to complement the eight lanes of the famous 73-year old steel arch harbor bridge.



Map of Sydney tunnels (dashed) and tollroads (dark blue) as of March 2005. From Kim Edwards, presentation " Tollroads: Managing Complexity," USB Conference, March 2005.

The next major problem tackled was an expressway connection between downtown and the airport. Called the M1 Eastern Distributor, it was completed by a concessionaire in time for the Olympic Games in August 2000. This toll facility provides a fast, free-flow road trip between Sydney's main airport and the city center that previously involved 19 traffic signals, and could take anywhere between 15 and 45 minutes to travel just five miles. It also connects the northern third of the metropolitan area via the Harbour Bridge and Harbour Tunnel to the airport. Key to gaining acceptance of the Eastern Distributor roadway was a 1.1-mile long "piggyback" tunnel of three lanes atop three lanes driven deep under a densely developed area called Taylor Square immediately southeast of the central business district. The motorway to the airport continues for some distance in a deep-trenched and partially lidded section below ground level. The planners worked with local groups to foster agreement on a major scheme for making local surface streets more pedestrian-friendly with handsome street furnishings, landscaping, and new pedestrian, bicycle, and bus lanes.

The success of the Eastern Distributor led to the state financing a non-toll tunnelway called the M-5/East located west of the main airport. The project—which includes four-lane tunnels of 2.5-miles length, and 1,804-foot long under-river tunnel, and 3.4 miles of roadway below or at the surface, plus seven interchanges—cost $450 million. (All monetary figures are U.S. dollars based on exchange rates on the date cited.)[29]

In August 2005 a fourth tunnel opened, this one as another toll franchise project. The Cross City Tunnel is an east-west facility under the CBD and a congested, signalized arterial named William Street. It is 1.3 miles long east-west and of twin two-lane tubes, but also includes a set of underground ramp tunnels connecting to the Eastern Distributor and to surface streets midway as well as multiple ramps at each end. Cost to investors was $540 million.[30]

Number five presently under construction is the Lane Cove Tunnel, a connector between the M1 Hills Motorway and the expressway coming off the Harbour Bridge. Basically four lanes, it has a long third auxiliary lane and is 2.1 miles in length. It, too, is being financed by investors, at a cost of about $1,400 million (A$1,700m). Like the other tunnelways it will offer a fast alternative to a congested, signalized arterial.

Two more Sydney tunnels to be built with investor financing are in planning:

- M4-East: an inwards extension to the CBD of the M4 radial tollway in the inner western suburbs in twin three-lane tunnels of two miles length, to be toll franchised.

- F3-Orbital Link: a link in the northern suburbs consisting of 4.7 to 5 miles of twin tube tunnels of at least 1.3 miles and 3.4 miles split in the middle by a short 1,600-foot surface segment.[31]

Melbourne, Australia's second largest city (population 3.4 million) but the country's largest port and manufacturing center, faced a major congestion problem in the early 1990s. To the immediate southeast of the central business area there is a favorite riverfront promenade, long-established city botanical gardens, and gentrifying inner suburbs, yet a pressing need for a higher quality highway link to the spreading suburbs to the far southeast. To the west and northwest of the city were freeways which had been truncated and fed into surface signalized arterial streets because of difficulties finding acceptable surface right of way.[32]

An investor group (Transurban) consisting of a large, local construction company (Transfield), and Japanese tunnelers (Obayashi) got state approval for a self-financing toll project named CityLink: 13.7 miles of six- and eight-lane roadway to the immediate west and south of the central city area linking three previously unconnected freeways and providing new access to the central business district with a combination of elevated and tunnel construction. Overall cost was $1.2 billion financed by tolls on a 34-year toll concession.

Investors built 14 miles of inner city motorway in Melbourne linking truncated segments of freeway. The West Link contained an elevated segmental box girder including the sound tube, while the South Link has two 3-lane tunnels, the longer of which is 2.1 miles. Map courtesy of Transurban, owner of the project.

There is no cash toll collection. Motorists either have a windshield-mounted toll transponder and an account or they call in, give their license plate number and buy a day pass with a credit/debit card. Cameras on the roadway check vehicles without a transponder and sort out those with day passes and those who are toll evaders.

Two tunnelways have been built in the most sensitive southeast area, each of three lanes. The shorter Domain tunnel, one mile long, goes under the gardens, the river and riverfront, and connects with an existing riverfront road which becomes a westbound roadway. A longer tunnelway to the north, the Burnley Tunnel, runs 2.1 miles under not only the gardens and river area but under an inner suburb of renovated 19th century houses. It carries three lanes eastbound.

Time from the southeast to the airport in the northwest is now 39 minutes on CityLink compared to 87 minutes on free surface arterials. For that 48-minute time saving, together with the more relaxing driving experience on a free-flow road, nearly 200,000 motorists a day are paying tolls, and the project is profitable for the investors. No tax money was needed.

Australia's third city, Brisbane, has requested proposals from investors to build a north-south bypass tunnelway to supplement the capacity of a city bridge and provide a bypass of downtown city streets for through traffic.[33] Campbell Newman, the present mayor of Brisbane, was elected promising to get tunnels built to improve mobility. Others are planned.

Asian Tunnels

Hong Kong has three major undersea road tunnels linking the island of Hong Kong with Kowloon on the mainland and now three under-land tunnels like Sydney's with more in planning. They too are concession-financed. Singapore is building one stretch of new expressway underground.

U.S. Experience

America's recent experience with tunneling has been discouraging. The Big Dig in Boston was a nicely conceived project, but it was poorly managed and costs spiraled out of control —from $3 billion to an estimated $14.6 billion. Arguably the major reason for that was the perverse incentives of cost-plus project management, and an apparently bottomless pit of federal and state handouts to pay for the cost over-runs. Although managed in its later years by the Massachusetts Turnpike Commission, it is not a toll project (except for its affiliated Ted Williams Tunnel to Logan Airport) so it had little of the budgetary discipline toll financing entails.

Being studied are several major U.S. tunnels:

- Riverside-Orange county connection under Cleveland National Forest, California;
- Coronado tunnel to San Diego Naval Base;
- Missing link tunnel for I-710 through South Pasadena, California;
- Glendale to Palmdale tunnel under the San Gabriel Mountains, California;
- Hampton Roads, Virginia Third Crossing;
- Port of Miami Tunnel, Florida; and
- Undergrounding of the elevated Gowanus Expressway (I-278), Brooklyn, New York.

Promising tunnels which have been suggested but are not currently under study include:

- Daly City to the Golden Gate Bridge to take SR 1 traffic off 19th Avenue, the only part of SR 1 with signals;
- Golden Gate Bridge to U.S. 101 in downtown San Francisco as bypass of Lombard Street and Van Ness Avenue for through-traffic; and
- I-70 eastern extension from Security Blvd. at Baltimore city line to the downtown and the port of Baltimore.

The high cost of truck delays is likely to make some truck-only facilities viable for tunneling where other designs are unacceptable.[34] This is especially the case in New York City where many expressways ("parkways") exclude trucks. Especially troubling is the lack of modern tractor trailer (14-foot, 53-foot trailer) access to lower and midtown Manhattan and the poor truck routes between New Jersey's ports and distribution centers and Brooklyn, Queens, and Long Island—an area with a population of 7 million. Truck routes to Kennedy Airport are appalling, equally for the truckers who must drive them and for the communities through which the trucks must pass.

3. Air Rights Above Highways

There are also places where the air rights above expressways—the right to build structures over the roads—have been used for buildings: on the Cross Manhattan Expressway which links the George Washington Bridge to the Cross Bronx Expressway, on the FDR Drive on the upper east side of Manhattan, on the Georgia 400 in Atlanta; on I-394 at its eastern end near downtown Minneapolis, and on I-66 in Arlington, Virginia. Such examples are rare, however. One of the great missed opportunities to use air rights was the mismanaged Big Dig project in Boston. No serious attempt was made to find the highest value use for the land freed up by putting this massive expressway underground. Instead most of the space was used for urban pedestrian squares and parks, which civic designers have said are unnecessary while also being expensive to maintain. Had this land been made available for commercial development, the proceeds might have paid for a considerable portion of the Big Dig project.

State departments of transportation have difficulty realizing the potential of air rights. Many do not have legislative authority. Others would not benefit financially, under current laws. Most see air rights as an unnecessary complication. The economics of air rights depends on the cost of land versus the extra cost of building over a highway, but some analysts think there is major potential for this, especially where a surface expressway is put underground. Certainly putting the traffic out of sight is one way to overcome the aesthetic objection to an open highway in an urban area.[35]

C. Neglected Rights of Way

Lack of right of way in cities is the most common objection raised to adding new links to the urban expressway network. Yet legal constraints and mental blocks often inhibit making use of certain urban corridors for highway purposes, notably railroad rights of way and powerline easements. If we could overcome the legal and mind-set obstacles, some of these urban rights of way could provide important new routes for much-needed highway capacity.

1. Underused Railroads

Railroading has been transformed by competition and technology changes. It excels in transport of bulk commodities (coal, grains, gravel), with unit trains loaded with large quantities of goods going from one single location to another. Rail is also king in transcontinental movement of containers, for example from west coast ports to Chicago.

The railroad network as reflected in railroad rights of way dates back to an earlier era when the railroads were general freight carriers with vast networks of routes organized in a hierarchy of track from main lines down through secondary lines, short haul spurs, and sidings onto the properties of individual customers. The main lines are thriving because of the new specialization of the railroads in long-distance and cross-country traffic, but the rest of the old networks are either unused or scarcely used.[36] Even some previous main lines are redundant because of consolidation of railroad companies and the unification of operations.

Turning over old railroad corridors to higher value use is often hindered by different forms of title—some is fee simple ownership, but most is in the form of an easement which may or may not be transferable. In order to avoid the costs of litigation, railroads sometimes in fact abandon track without formal route abandonment (which must be sanctioned by the federal Surface Transportation Board, a successor agency to the Interstate Commerce Commission).

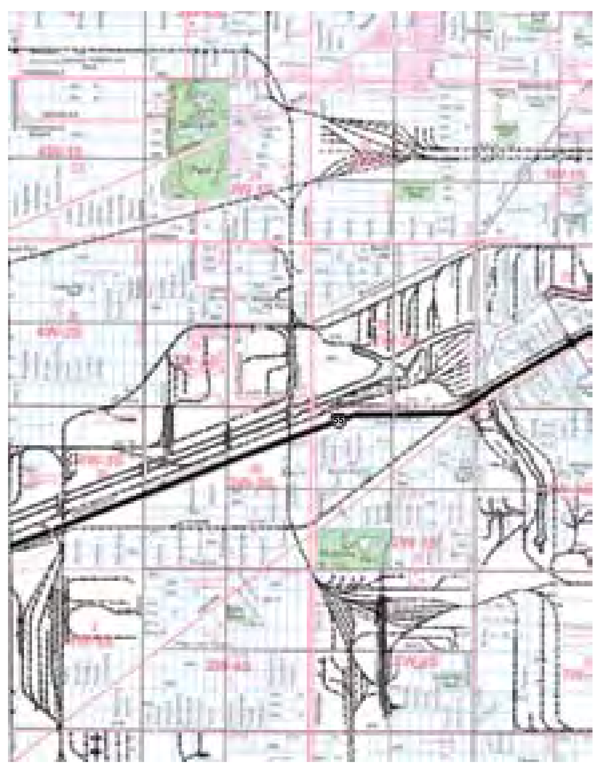
Another problem is that present laws and policies on abandonment of railroad routes favor their use by rail transit or recreational trails, rather than for use as roads. Trails do encourage healthful exercise and are a recreational resource, but they are not a serious transportation facility. Similarly new rail transit lines will rarely move numbers of people or goods comparable with a new road. Governments that wish to improve urban mobility need to take a harder look at allowing the use of underutilized railroad rights of way for new roads.

There are a number of precedents for rail-to-road conversion. The earliest of the cross-state expressways, the Pennsylvania Turnpike, was built during 1938-1940 in the right of way of the South Pennsylvania Railroad, even using the former rail tunnels and embankments to reduce its construction costs.[37] One of the most successful toll roads in Texas, the Dallas North Tollway, was built in the mid-1960s in the right of way of the St. Louis Southwestern Railway (also known as the Cotton Belt Railway) after it consolidated its operations onto a Southern Pacific line.[38] More recently, in Houston the Harris County Toll Road Authority built the Westpark Tollway in railroad right of way acquired initially from a railroad by Houston Metro, the local transit agency. Houston Metro had in mind constructing an exclusive busway. However the local toll authority persuaded Metro to sell it the right of way for a toll road, in exchange for granting transit buses the right to free use of the toll road under guaranteed free-flow conditions (thanks to variable pricing). The buses now operate on the toll road financed on the basis of car driver's tolls in what was previously wasted land.

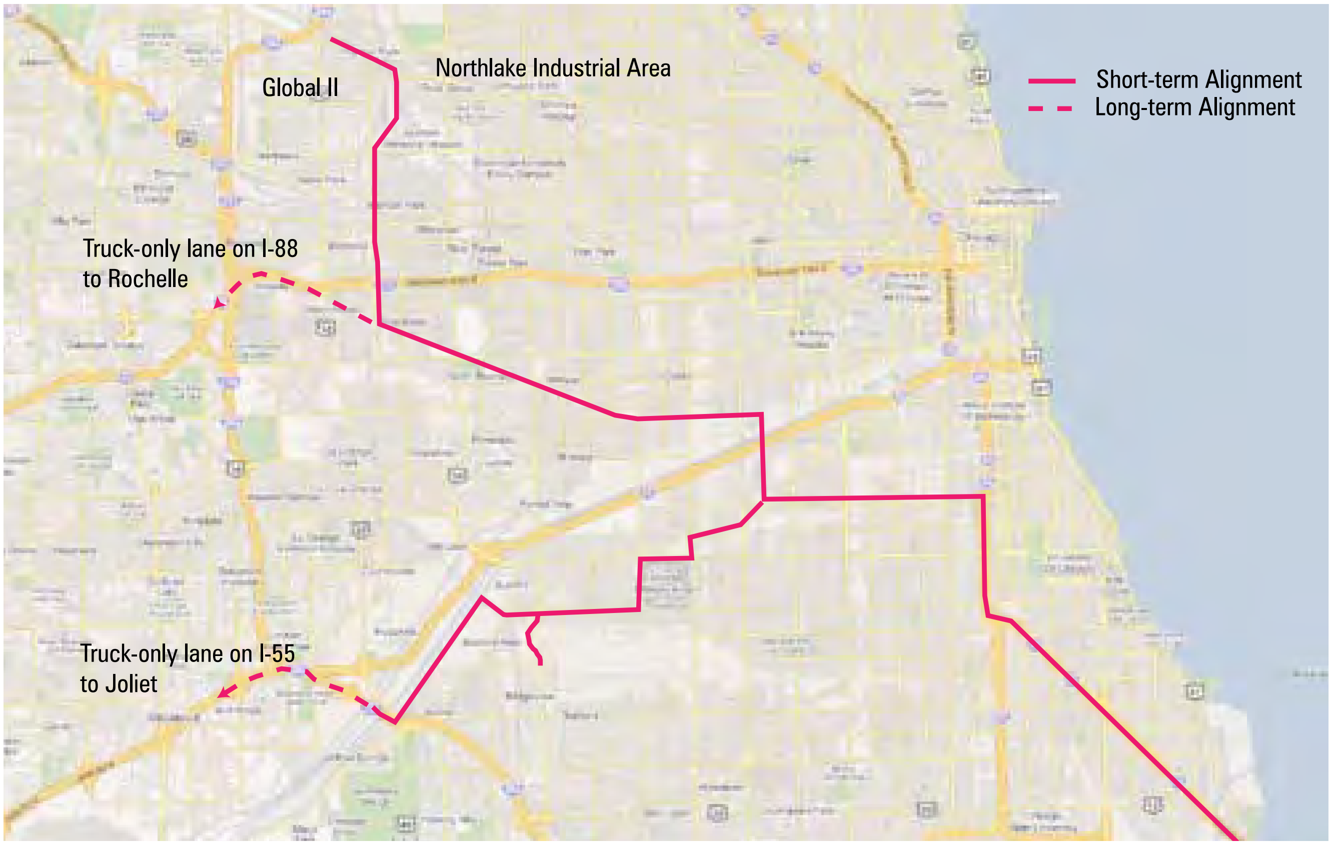
A number of important urban roadways have been proposed for under-used railroad right of way:

Chicago

Railroad rights of way abound in what has always been the premier railroad hub of the nation, now with the biggest concentration of intermodal (rail on/off truck) facilities. The four state tollways handle truck traffic to the outer areas but trucks are less well catered for within the city of Chicago. There is also an interest in some new bus rapid transit in the region. A major deficiency is the lack of a high-quality, north-south route about midway between the Dan Ryan Expressway and the Tristate Tollway, which are 10 to 14 miles apart. Various proposals to remedy this have focused on the Cicero



A common Rand McNally Road Atlas plots the maze of rail lines in the west side of Chicago. Many have wide, unused right of way. Some are completely unused.



Steven Shladover, an expert in vehicle automation at the Institute of Transportation Studies (University of California, Berkeley) studied potential rights of way for truckways that would serve freight nodes in Chicago and came up with this plan.

Avenue (State Route 50) corridor. The city government is currently studying a Mid-City Transitway/Truckway and Cicero Avenue is the location of interest. There is railroad right of way along much of the corridor. Also there have been proposals for improved east-west movement across the south side and east side of the Loop.[39]

Brooklyn, NY

Brooklyn, Queens, and Long Island are seriously lacking in roadways for trucks. Many major grade-separated highways in the area were designed as "parkways" which ban trucks. Major expressways tunnels and bridges have low overhead clearances, making standard 14-foot high trailers impossible to use. Narrow lanes and sharp curves mean that standard modern 102-inch wide, 53-foot long trailers can't be handled on most of the area's major highways, with those of Brooklyn completely inhospitable. Deliveries have to be made by specialized but smaller trucks, which are more expensive to buy (per unit of payload) and carry smaller loads. As a result freight rates are significantly higher east of the East River than elsewhere in the United States, and trucks passing through are forced to use local avenues and boulevards.

Old railroad rights-of-way like those pictured here traverse Brooklyn.

Map of the old Bay Ridge and Manhattan Beach rail lines - now largely abandoned. Along these lines, 50 to 100 feet of right-of-way lies largely unused.

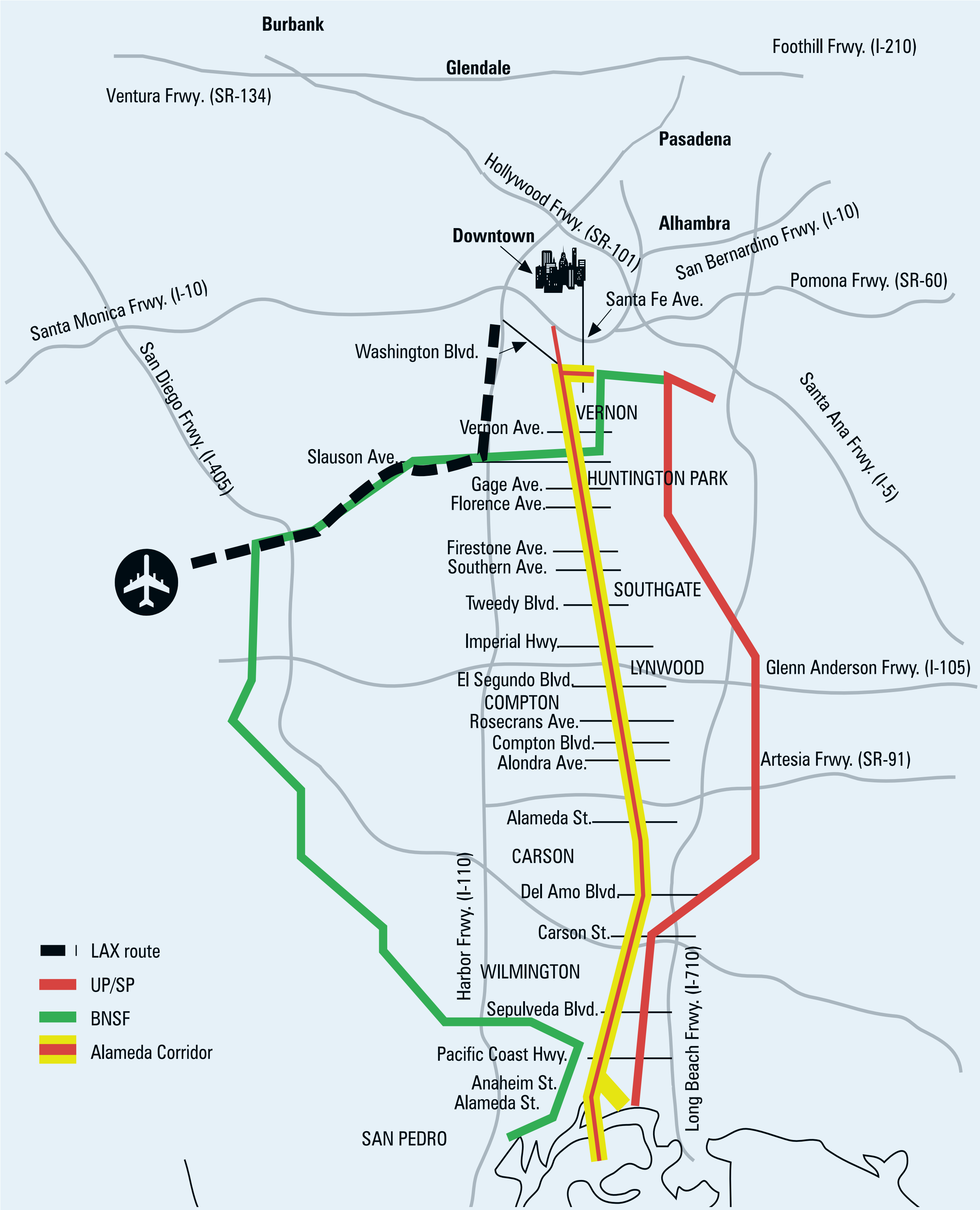
Map from *Regional Plan Association News* May 1964 shows a Cross Brooklyn Expressway. A full expressway would have required a corridor wider than the rail right of way, but a dedicated trucks-only road would fit in.

Yet right by the approaches to the Verrazano Narrows Bridge near 65th Street, curving in a graceful arc through the center of Brooklyn to Queens, is the Bay Ridge Branch line of the Long Island Railroad. It had as many as four tracks originally and is fully grade-separated from local streets with bridges. It has only a single working track remaining and is used for only several short trains of freight cars each week.

Rail enthusiasts want to use the line as a connection to a $7 billion Cross Harbor [rail] Freight Tunnel from Brooklyn to New Jersey, a project which would have to be funded over 90 percent with taxpayer money or surcharges on truck tolls on competing crossings. The Bay Ridge Branch corridor has attracted interest as a truck/transit route. With trucks it could work as a stand-alone project by providing a high-quality connection between the harborside of Brooklyn plus vehicles coming off the Verrazano Narrows Bridge going to locations deeper within Brooklyn, on to Queens, the Long Island Expressway, or Kennedy Airport. At present these trucks have to traverse scores of signalized intersections on Brooklyn's boulevards and avenues. Such a Bay Ridge Truckway might warrant connection to a new, cross-harbor truck tunnel to the New Jersey Turnpike.

Los Angeles International Airport (LAX) lacks any direct connection to downtown Los Angeles and communities to its north like Burbank, Glendale, Hollywood, Pasadena and Alhambra. People at LAX wanting to go those places have to go due east on the I-105 Century Freeway, then due north on the I-110 Harbor Freeway or the I-710 Long Beach Freeway. Yet following the opening of the Alameda Corridor railroad line, a BNSF rail line from the south side of downtown Los Angeles to LAX has been largely abandoned. That route from LAX to downtown is just 10 miles versus nearly 15 miles by the I-105/I-110 route. Managed with a variable toll rate for free flow, it would offer time savings of 10 to 30 minutes. The BNSF right of way could be used to provide a premium service link to the airport for cabs, buses, delivery vehicles and private cars—no large trucks—willing to pay a high toll for a quick ride. The old railroad track has at-grade crossings throughout, so any modern facility would need to be grade-separated—probably entrenched and partially capped. The time savings for high-income persons using the airport would provide the revenue stream to finance some serious construction, including undergrounding.

Pricing can play into the design. At low toll rates there might be demand for eight lanes in peak hours because of the advantages of this direct route and its avoidance of major interchanges. However, a general-purpose highway would require at least 140 feet right-of-way (eight 12 foot travel lanes, plus four 10 foot shoulder lanes, and median divider). Railroad rights of way are typically 50 feet to 100 feet wide. Within that space it is possible to fit four to six lanes. Purchase of extra right of way is possible but only at a high price, monetarily and in terms of community opposition. Bridge spans and tunnels have diseconomies of scale in the sense that the per foot cost of a bridge span or tunnel arch increases more than proportionately with size. There are major cost advantages in keeping the scale small and the cross-section tight. By the same token, the higher the toll the less will be the traffic. Any design should be around the crossover point where the cost of extra roadway capacity will just be supported by willingness to pay for that extra capacity in tolls. In dense, developed areas with high real estate costs like Los Angeles it is likely that compact, specialized facilities at high toll rates will work best. An LAX-downtown LA roadway would likely work best as a premium service facility charging $5 to $10 per vehicle trip (50c to $1.00 per mile). It might be only two lanes each direction. It might exclude heavy trucks, while supporting buses, pick-up and delivery vehicles, vans and cars. A detailed study of alternate designs, their costs and willingness to pay would be needed to arrive at the optimum design.



BNSF line (green) made redundant by the Alameda Corridor rail line (red in yellow) is almost perfectly located for a premium service route between Los Angeles International Airport (LAX) and downtown LA. The final couple of miles would follow the Harbor Freeway, I-110.

2. Drainage Channels

An example of a possible use of a storm water drainage channel is the so-called Central County Corridor in Orange County, California, an extension southward of the SR 57 or Orange Freeway. The freeway currently ends at I-5 and the SR 22 or Garden Grove Freeway at a complex interchange known as the Orange Crush. The Santa Ana River, usually a tiny stream in the middle of a wide, concrete-paved drainage channel, leads from the interchange south 7.5 miles to the San Diego Freeway (I-405) in Fountain Valley. A group of investors were awarded a toll concession to build the project as a six-lane elevated toll road in 1991, but the project made little progress without local support and was eventually dropped. Now there is local support. The Orange County Transportation Authority believes the project needs to be revived and has begun studies under the name Central County Corridor—analyzing alternatives, doing public outreach, and conducting traffic studies. They consider the ugly river channel as the prime opportunity for a major highway.[41]

Clearly use of such a flood control channel would necessitate elevated construction with piers that would not inhibit the channel's functioning for flood prevention. The U.S. Army Corps of Engineers has jurisdiction to regulate such design. An elevated structure need not preclude beautification of the channel. Indeed it could be designed as part of a larger scheme to add interest and amenity to the drainage channel.

Precisely this is being done to the immediate west of downtown Dallas where the Trinity Parkway toll road is being built in a collaborative effort between the Dallas, the North Texas Tollway Authority, Texas Department of Transportation, and the Army Corps of Engineers in the Trinity River flood plain. The six-lane toll road will form flood levee walls on the eastern bank, and its design will be integrated with new playing fields, walking trails, lakes and wild areas.[42]

Trinity River Project plans to use the floodway of the Trinity River alongside Dallas' central business district to locate a new tollway reliever route.

3. Power Line Corridors

Use of a long power line reservation in Maryland has been suggested as providing right of way for an extension of I-95 inside the Capital Beltway five miles to the District of Columbia line. From there it is proposed to go underground for about a mile to the Metro Red Line, which it would parallel as far as New York Avenue where it would link to the existing I-395 spur built under the Mall in front of the Capitol Building. I-95 was originally planned to extend through the District in the 1960s, but unfortunately planners adopted an arrogant bulldoze-homes approach . Using powers of eminent domain they calculated that it would be cheaper to condemn whole blocks of houses than to purchase right of way from a railroad and an electric company. This created vast political turmoil. The I-95-inside-the-Beltway project was therefore defeated. But that area of Maryland and the District have suffered economically ever since from the lack of good highway connections to the northeast.

D. Costs of Land and Construction for Innovative Alternatives

Costs of different forms of construction will vary greatly from city to city. Generally speaking, land has become increasingly expensive relative to construction in many cities in the past decade. Sometimes urban highways can still be widened without buying extra land, or by buying relatively small slivers of land. But a review of a number of recent urban highway projects where the complete right of way is being bought finds land costs in the range of $2 million to $10 million per lane-mile. Costs of design and construction (for surface roadway) per lane-mile are in the range of $5 million to $15 million, the cost influenced by the number and type of over or under bridges and the amount of walling needed. Walls are used both for retaining a roadway on fill at higher or lower elevation and for sound protection. The cost per lane-mile is greatly affected, too, by how much shoulder is built, and whether adjacent lanes are reconstructed. Many widening projects in fact use some of the supposed widening money for improvements to existing lanes. With those qualifications, surface construction costs seem to be in the range of $5 million to $15 million per lane-mile.

With similar qualifications, elevated construction seems to range between $10 million and $20 million per lane-mile. So, if extra land has to be bought for surface construction where land is not needed to do elevated construction, then elevated construction may be no more expensive, and perhaps even less expensive in some circumstances. Of course, that is not to say it will always be acceptable. It will often not be. In that case underground will need to be considered.

Trenched construction requires expensive utility relocations, retaining walls and usually pumps for drainage. Full undergrounding near the surface is done by cut-and-cover construction. It also involves major disruption to local streets, along with utility relocation, and cannot generally be done under buildings.[43] Deeper construction by mining techniques (such as tunnel-boring machines) can leave surface streets and utilities in place. If deep enough it can go under buildings. But the greater the depth, the longer the approach ramps needed. Tunnels require fans to maintain fresh air and to provide some control over smoke in case of fire—which also increases requirements for sensing and surveilling incidents and major water pipes to douse any blaze. Tragedies in older, single-tube tunnels in Europe in the past decade have emphasized the value of building a second tube with crossovers, normally used for the opposite direction of traffic, but also invaluable as an escape route and safe base for firefighting and rescue.

Tunnels Table: Costs of Land Construction

Name	Place	Lanes	Length	Lane-miles	Cost	Lane-mile cost	Construction method
A100	Berlin, Germany	2x3	1.1 miles	6.6	$217m	$33m	Cut & cover
B96	Berlin, Germany	2x2	1.5 miles	6	$460m	$77m	Cut & Cover
A86 West	Paris, France	2x3 lanes	6.2 miles	37.2	$1300m	$35m	Tunnel-boring machine
Central Artery/ Tunnel	Boston, MA	2x5 lanes & 2x2 lanes	7.5 miles totalled	161 (Half is bridge)	$14.6 billion	$91m	Cut&Cover, immersed tube, jacked
Westerschelde	Holland	2x2 lanes	4.1 miles	16.5	$910m	$55m	Tunnel-boring machine
A71 Rennsteig	Thuringen Forest Germany	2x2 lanes	5 miles	20	$300m	$15m	Mined
Eastern Distributor	Sydney	2x2 & 2x3 lanes	1 mile	5	$160m	$33m	Mined
Boulevard Periph-erique Nord de Lyon	Lyon, France	2x2 lanes	2.3, 0.7, 0.7, 0.4 miles	13	$900m	$69m	Mined
Dublin Port Tunnel (u/c)	Dublin, Ireland	2x2 lanes	2.9 miles	11.4	$530m	$46m	Mined, cut and cover
CityLink	Melbourne, Australia	2x3 lanes	2.1, 1.4 miles	58 (includes bridging)	$1560m	$27m	Mined
Prado Carenage	Marseille, France	2x2 lanes	1.5 miles	6.0	$196m	$33m	Deepening old railroad tunnel
Cross City Tunnel	Sydney, Aus-tralia	2x2 lanes	1.4 miles	6.7 (incl ramps)	$545m	$81m	Mined
Herrentunnel	Lubeck, Ger-many	2x2 lanes	0.65 miles	2.6	$201m	$77m	Tunnel-boring machine
LBJ I-635 Managed Lanes Tunnel (esti-mated)	Dallas, Texas	2x3 lanes	2.1 miles	12.6	$588m (incl some surface work)	$47m	Mined
Addison Airport Tunnel	Dallas, Texas	2 lanes	0.3 miles	0.7	$15m	$21m	Mined
Lane Cove Tunnel (u/c)	Sydney, Aus-tralia	2 + 3 lanes	2.25 miles	11.3	$1.3 billion	$115m	Mined

Cautionary note: We have tried to get total project cost and divide that by travel lane-miles. It is usually impossible to isolate tunnel costs from other costs associated with the tunnel, such as approach roads. Some projects with tunnels include substantial additional costs on associated surface roads and even some bridging, while others are mostly tunnel. Tunnels vary in the extent to which breakdown shoulder is provided, which adds greatly to cost per travel lane-mile. The tunnels above have been built at different times and no attempt has been made to account for different year costs. Costs will vary according to soil conditions, and the extent of fit-out with safety systems. The table gives an indication of the range of costs likely to be incurred.

Most urban tunnels seem to cost in the range of $30 million to $80 million per lane-mile. The mean cost of a random sample surveyed is $54 million/lane-mile (see Tunnels Table on previous page). This makes them a last resort cost-wise, though there may be exceptions to that. For example, on the project to complete the missing link on I-710 in South Pasadena, California, the project manager has said land costs are now so high that surface construction would save little over tunnels even if surface construction were acceptable—which it isn't. In general, however, tunnels will only be used where surface or elevated construction isn't feasible.

Costs alone should not rule out any form of construction. The question is whether the benefits of the project outweigh the costs. Not building roads and denying mobility has heavy costs too. It limits the jobs people can get, the educational, social and recreational facilities they can reach, and denies employers specialized labor and services. Motorists are willing to pay very high toll charges in some cases to get a quick, reliable and hassle-free journey. Highways are being put underground many places now precisely because the benefits outweigh costs, high though those costs may be.

Part 3

Rethinking Traditional Design Standards

A. Overview

Many of the innovative highway design ideas discussed in Part 2 resulted from designers thinking outside the manual—for example fitting two decks of roadway into a tunnel that could accommodate only one deck (and half as many lanes), or designing some routes exclusively for trucks. The U.S. highway design standards of the 20th century have generally served us well. But by standardizing all limited-access highways on amply dimensioned general-purpose (GP) lanes suited for all kinds of vehicles and all sorts of drivers, they have seriously constrained our ability to add needed capacity to the urban expressway network. In this section, we will look more closely at design standards and suggest increased flexibility.

Design standards for expressways are rather well established, and their performance is well understood. The first 160-mile section of the Pennsylvania Turnpike, which opened between Harrisburg and Pittsburgh in 1940, set the initial standards for expressways in terms of 12-foot lane widths, a median divider for the two directions of traffic, full access control, and consistent interchange design, sight distances, grades, and engineered camber. It set a design speed as a performance standard.[44] In the past 65 years the details of expressway design have been refined in a gradual evolutionary process.

Highway designers now avoid closely spaced on- and off-ramps, whether from interchanges being less than about a mile from one another or the early “cloverleaf” design, because such designs create weaving conflicts as entering and exiting vehicles have to cross one another’s paths. Such weaving is a major source of bottlenecks in expressways. Usually to fix the problem, one of the loops is replaced by a direct connector ramp so that exiting traffic exits ahead of entering traffic. Less use is made of loops (turning 270 degrees or three quarters of a full circle) and more of long, sweeping left-turn ramps (with just a 90 degree turn). That adds to the expense and visual impacts of the interchange, however, since the ramps are longer and higher, usually at a third or fourth level. With current GP-lane clearances, each level is at least 22 feet. That is the 16 feet for safe truck clearance and 6 feet for the structure thickness—so that with a 3 percent grade limit, a ramp about 725 feet long per level is ideally required.

Compromising and accepting that trucks will be slowed on the ramp sometimes permits 500 feet per level. However a four-level stack interchange will require some approach ramps at least 1,500 feet, and for better performance over 2,100 feet long.

Other standard improvements on the original expressways are a continuous crash barrier in the median to prevent crossover accidents and rumble strips along the roadway edges to wake up the dozy driver who might otherwise careen off the road from inattention to the driving task. Run-off-the-road accidents are the most common cause of death on rural expressways. Sadly there is an unpleasant tradeoff between safety and a parkland setting along highways, since substantial trees represent a fatal hazard for run-off-the-road drivers. As a result trees are being banished from medians, and quite wide clear zones on the roadsides are being maintained.

Future urban-friendly roadways will need to be built with lane widths, sight distances, camber, and curvatures designed to reinforce speed limits rather than relying solely on posted limits and enforcement to discourage excessive speed. Many of the autos-only parkways of New York and Connecticut are examples of how tight roadway design can keep speeds down compared to later expressways.

B. Breakdown Lanes

We now build a continuous breakdown shoulder on at least the right side wherever it can be done without exorbitant cost. If there are more than about three lanes per direction there is often a left-side breakdown shoulder as well. Their principal purpose is to provide a margin of pavement for disabled vehicles or vehicles damaged in collisions. If built to full depth and strength, these shoulders can also be used as temporary travel lanes when there's repaving work to be done on the regular lanes. That way roadwork as a major source of congestion can be reduced or eliminated.

However, it needs to be acknowledged that under normal operating conditions, full-time breakdown lanes add to the width and expense or reduce the capacity of a roadway. It has been standard practice to build all but the shortest tunnels without breakdown lanes because the extra expense is held not to warrant it. In a two-lane tube it adds about 50 percent more to build the tunnel with that third lane. Bridges on expressways used to be built without breakdown shoulders for the same reason, but that has changed, and most new bridges have breakdown shoulders.

It may be possible in the future to implement systems that safely close a lane to traffic only when there is a disabled vehicle or obstacle ahead, thereby allowing the whole roadway —all lanes—to be used in normal conditions. Attempts are being made now to implement this in road tunnels.

- Sydney's 1.3-mile long Cross City Tunnel, which opened in 2005, like the many other urban expressway tunnel systems in Australia has twin tubes which are 23 feet wall to wall. Those are lanes of 11.5-feet width and there is no offset or shoulder.[45] The Cross City tubes have a network of vehicle detector loops in the roadway that allow vehicle speeds to be constantly estimated and a stopped vehicle is quickly registered. Video surveillance cameras covering all portions of the tunnel also come into play. The control center can communicate with motorists via an extensive system of electronically controlled signs for warnings—546 variable message signs in about four miles of tunnels, or about one sign every 40 feet. And there are boom gates controlled from the operations center that can be lowered to block entry at the portals.[46]

- On the A86 West autos-only tunnelway under construction near Paris, developer Cofiroute is installing an automatic incident detection system based on a variety of vehicle detectors supported by some 350 video cameras. The system has been tested at the operational Les Halles Tunnel over three years and was rated as effective in 99.8 percent of incidents. It looks for anomalies in traffic flow, alerting operators within 10 seconds to call up the relevant camera picture.[47]

Another approach is for a shoulder lane to be signed so it can be called into use in peak periods or emergencies. The thinking is that in dense traffic vehicles will be forced to travel at moderate speeds, so use of the shoulder is safer.[48]

The widespread use of breakdown shoulders for peak-hour traffic will probably have to wait on the availability of "in-vehicle signing"—a way for the roadway managers to communicate to drivers via a display in the vehicle—rather than just via the present signs mounted over the roadway. In-vehicle signing and other advanced safety warning systems are dependent on adoption of the next generation 5.9GHz transponder system and factory installation in new cars.[49] That could happen on a wide scale from about the 2010 model year onwards if the motor vehicle manufacturers implement a joint program being promoted as Vehicle Infrastructure Integration, using the kind of wireless data communications being used for toll collection for a range of safety applications.[50]

A variant is to squeeze extra capacity with variably striped lanes using fiber-optic lighting rather than paint stripes. The idea, again, is that in dense traffic motorists are comfortable traveling closer together than when the road is open.[51]

C. Lane Widths

The actual width of lanes on our roads varies a great deal. Ten feet was a well-established lane width in the early days of the automobile. Through the first half of the 20th century there was a slow widening until the Pennsylvania Turnpike established 12 feet as the gold standard in 1940, and soon afterwards it was embraced by AASHTO, the association of state departments of transportation.

The Holland Tunnel opened in New York City in 1927 and has 20-foot wide roadways with 10-foot lanes. Similarly, the 1928 Goethals Bridge (which carries I-278 linking the New Jersey Turnpike to the Staten Island Expressway) has a 42-foot roadway carrying four expressway lanes of 10.25 feet each. Since then there has been a gradual expansion of lane widths on major facilities. The Lincoln Tunnel, the busiest U.S. tunnel, has three tubes all of 21.5 foot width, or 10.75 feet per lane. The George Washington Bridge, the world's busiest bridge with 300,000 vehicles per day, has eight lanes on 90 feet on its upper deck—or 11.25 feet per lane—as part of a 1946 widening. The lower level deck of six lanes is similar.

It is testimony to the flexibility of the automobile/roadway system that many of these early facilities remain in heavy use. The Goethals Bridge, despite its 10.25 foot lanes, is a major truck route between New Jersey and New York. That 10.25 feet is widely regarded as uncomfortable and unsafe at speed, especially with trucks. Trucks have gotten wider and faster since the days of 10-foot lanes. Today 8.5-foot wide trucks are allowed in the United States—and that doesn't include mirrors—so these narrow lanes provide barely a foot clearance to the lane stripes on either side. Europe's maximum vehicle width of 8.37 feet is very similar to the U.S. rules.[52]

Cars are not only narrower but have not been growing in size like trucks. The best-selling car in the United States, the Toyota Camry, is 5.9 feet wide, and one of the widest SUVs, the Ford Excursion, is 6.7 feet.[53] American light vehicles—cars, pickups, vans and SUVs—will fit in 10-foot lanes, and 11-foot lanes are more than adequate. The New Jersey Turnpike adopted 11-foot lanes as standard for its no-trucks southern segment of the Garden State Parkway including the new 15-lanes Driscoll Bridge over the Raritan River. Eleven feet is also a common striping standard for many lanes on freeways in the Los Angeles area. On the A86 West toll tunnelway in France, the French are building a double-deck, cars-only roadway in an internal diameter of 34 feet, leaving space for three lanes of about 10 feet each. There will be an overhead clearance of only 8.4 feet, ensuring that only low vehicles can enter.[54]

D. Car-Truck Separation

Federal aid highway policy (via the Federal Highway Administration) has been to only support mixed-traffic (GP) facilities for the almost 50 years since it came heavily on the scene with the beginnings of the Interstate system in 1956.[55] That put a stop to the further development of cars-only "parkways" that had developed around New York, in Connecticut, around the Washington DC area, and (one only) in California. If these federal constraints can be loosened, it should be possible to develop new cars-only parkways, so long as separate provision is made for trucks.[56] As well as being more pleasant and safe for car drivers, parkways can be built with narrower lanes and lower overhead clearance at underpasses. Without the pounding of heavy trucks they can be built with lighter pavement and will last longer. Cars have a better power/weight ratio so they can accelerate faster and can brake in shorter distance than heavy trucks. That allows an all-cars road to be designed with more forgiving standards for sight distances, curvature, grades and ramp design. The reservation has to be entered here that many of the early parkways took this to an extreme.[57]

Even with more modern standards than the early ones, parkways can be fitted into an urban environment more easily than an all-vehicles expressway. Many of the early parkways blended into the course of a river or creek and great attention was paid to melding them into the natural landscape by employing top landscape architects. The emphasis was on making the roadway fit the landscape. As a result, parkways like the Sawmill or the Hutchinson River in Westchester County, New York meander pleasantly, making their way around natural obstacles. There has been some effort to revive aspects of this early landscape approach in recent years under the rubric of “context-sensitive design.”[58] One aspect of this is a serious effort to incorporate a local aesthetic into the detailing of the highway project. A number of projects have been made better projects and gained community acceptance they might not have been able to obtain without it.[59]

E. Truckways

Another alternative to building four or more continuous lanes in each direction is to split the expressway into four roadways, two for trucks, two for light vehicles.[60] This is the preferred solution proposed for 325 miles of the I-81 corridor in Virginia. There are major safety benefits from separating trucks and cars. Their huge differences in weight and length give them very different handling characteristics. The weight mismatch between a tractor-trailer (up to 100,000 pounds) versus a car (3,500 pounds) makes many collisions fatal to car occupants. Some 5,000 Americans die each year in truck-car collisions, so where feasible, separation will save lives. Separate truckways like this cost more to build because they need separate entries and exits, more breakdown shoulder, and service facilities. Separating heavy trucks from cars may only make financial sense if regulations allow truckers to operate short triple-trailer or long double-trailer rigs—called Longer Combination Vehicles or LCVs in the regulatory jargon.[61] The idea is that each driver/tractor can haul up to 50 to 100 percent more payload, a major gain in productivity.

Truckways may be developed within the right of way of existing expressways. Or they may be developed along other corridor-type rights of way such as are occupied by high-voltage electricity lines or railroads. They may be built on the surface, isolated where necessary with sound walls, or depressed below ground level, open or lidded over, or in a bored tunnel, depending on the local context and relative costs.

STAR Solutions, a group of investors, is proposing widening I-81 from 4 to 8 lanes with trucks operating separately as shown in this visualization. From STAR Solutions, Richmond, Virginia.

F. Overwide Roads

Too often roadways are being widened with so many contiguous lanes that lane changing becomes disruptive and dangerous. Combined with interchanges at less than a mile apart, this causes complex weaving patterns that interfere with traffic flow. Roadways should generally not have more than four contiguous lanes, and a maximum of three is better. The New Jersey Turnpike in its central section splits seven lanes per direction into roadways of three and four lanes, each in what is sometimes called a dual-dual or four roadway configuration. The downside of this is the need for extremely complicated interchanges including flyovers for right-turn movements as well as lefts. A parallel highway separated by several miles would usually be preferable.

In areas where there are frequent, short on-and-off trips on an expressway, the planners often try, when reconstructing, to reduce the number of interchanges to discourage the short-hop trips. This is appropriate where the surface arterial network is sufficiently developed. Otherwise it just makes journeys more circuitous and increases local congestion.

Another solution is to run separated roadways connected by slip ramp openings at controlled points. The outer roadways are called collector distributors and the inner roadways the through or express lanes.

Texas is unique in the extent to which is uses a variant of this—frontage roads. They serve the collector-distributor function and also provide access to local properties, usually businesses. Collector-distributor roadways are grade-separated from the cross streets just like the main through lanes. Texas-style frontage roads, by contrast, meet the cross-streets at grade, normally at signalized intersections.

Both solutions provide a way of handling short trips without adding to the traffic on the main lanes. They both require wide right of way because of the need for space for slip ramps and shoulder or offset space on either side of dividing barriers—unless some kind of doubledecking is done.

Part 4

Improving Urban Arterials

A. The Role of Arterials

Arterials are the next level of highway down from expressways, the major distinction being that the arterials lack the access control and grade separation that characterizes expressways.[62] In urban areas arterials comprise some 57,200 centerline miles so they are much more widespread than urban Interstates (14,700 miles) and other urban expressways (9,230 miles). The arterials in urban areas see substantial vehicle-miles traveled (VMT)—about the same as urban Interstates and about two-thirds the VMT of all urban expressways. Of total VMT in urban areas 35 percent is done on expressways and 23.5 percent on arterials.

The importance of arterials varies quite a bit from state to state. They are rather less important (13.3 percent of travel) in Minneapolis-St Paul, in New York City (17.8 percent of total VMT) and Atlanta (17.9 percent) because each of those areas has a major expressway system and relatively weak arterials. Detroit, Chicago, Philadelphia, and the urban areas of New Jersey and Tennessee, by contrast, rely disproportionately on arterials.[63]

Though less data are collected on them than expressways, arterial congestion seems to be growing along with expressway congestion. Herbert Levinson notes that early cities were often laid out with arterials at half-mile intervals—the near city areas of Chicago, Los Angeles, and Miami are examples—but in the age of expressways it has become the norm to have arterials only on a one-mile grid in the suburbs, and many of these lack continuity. He makes a rather persuasive argument that the suburbs have changed dramatically since the traffic calculations that set down one-mile spacing. Car ownership has extended to almost all adults of driving age, suburban densities have increased in many places, and workplaces have dispersed to the suburbs, all generating levels of traffic best handled by arterials on a half-mile grid.

Arterials have far less capacity than expressways. Average speed begins to drop on an expressway at about 14,000 vehicles/day/lane whereas the corresponding figure for an arterial is 5,500 vehicles/day/lane.[65] Free flow speeds are 60 mph on urban expressways and

35 mph on the arterials. Obviously the general environment of an arterial is less conducive to high volume movement, what with frequent traffic signals and constant entering and departing traffic at almost random points along the way, as well as entries and exits which involve sharp angle turns and require very slow speeds.

Arterials are also very dangerous compared to urban expressways. Though they see substantially less travel than expressways, arterials had 4,925 fatalities compared with 3,888 on expressways in 2003, the last year for which there are statistics by functional class. Urban expressways had 6.09 fatalities per billion vehicle-miles traveled compared to 11.48 per billion vehicle-miles on urban arterials. Thus, arterials are 1.89 times as dangerous as expressways. One of the most effective road safety measures that can be taken is to convert a road from an arterial to an expressway. If the arterials were as safe as expressways (as measured by fatalities per billion miles traveled), then only 2,613 people would have been killed on them compared to the actual number of 4,925, a saving of 2,312 lives in 2003.[66] That's not very different from averting a 9/11 attack each year.

Clearly both congestion relief and saving lives in urban areas will be served by road improvements that focus on making arterials more like expressways. In many cases the aim should be straightforward: to upgrade arterials to expressways by adding full access control and grade separation. Alternatively, expressways can be built to take all but local traffic off the arterial.

Needless to say there are limits to such conversions. Arterials in their nature provide a considerable amount of local access that an expressway cannot provide—unless it is built Texas-style with frontage roads. That requires a wide right of way to provide expressway-style lanes for through traffic and others for local access. Levinson argues for what he calls parallel "strategic arterials" wherever real expressways are more than five miles apart. These would be limited access and four or six lanes divided with grade separation or interchanges at other strategic arterials, but surface intersections elsewhere. (The Silicon Valley has a number of such facilities, called "expressways" there to distinguish them from full-fledged "freeways.") He also argues that if arterials or at least collector roads could be made continuous on a half-mile grid, then many of the horrendous congestion problems of arterials on a one-mile grid could be avoided.

A grid of continuous arterials and collectors at a half-mile spacing reduces the volume of left turns at each intersection by two-thirds to three-quarters as compared with such a grid at one mile, according to the modeling reviewed by Levinson. To the extent such a denser arterial grid can be developed, there will be less need for expensive intersection improvements.

Handling left turns is the bane of arterials. That is where the worst accidents occur, but steps to improve safety heavily constrain throughput. Beyond 100 vehicles/hour and on-coming traffic at speeds of more than 35mph, traffic engineers argue persuasively for storing left-turners with a red signal and giving them a protected phase to make their turn safely. This leads to the need for extra left-turn storage lanes and wide flaring of the pavement at intersections, while requiring four phases to each signal cycle.

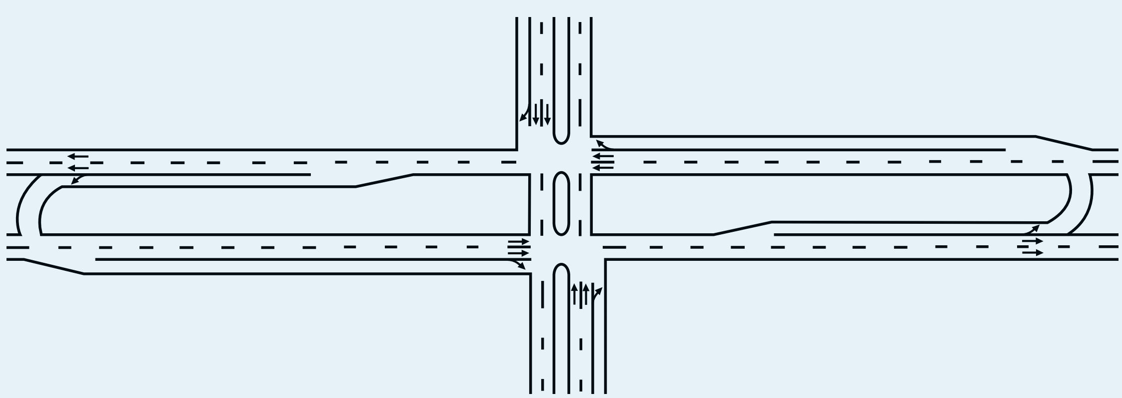
Most of the attempts at innovation on surface arterials are, at root, an effort to mitigate the left-turn problem. These includes one-way streets, split intersections, superstreets or boulevards, median-U turns, continuous flow intersections, the split intersection, roundabouts, bowties, jersey jughandles, as well as various forms of partial grade separation or bridging. Most of these involve transferring some of the movements away from the intersection in order to simplify it, reducing conflict points and the number of signal phases needed.

B. One-Way Streets

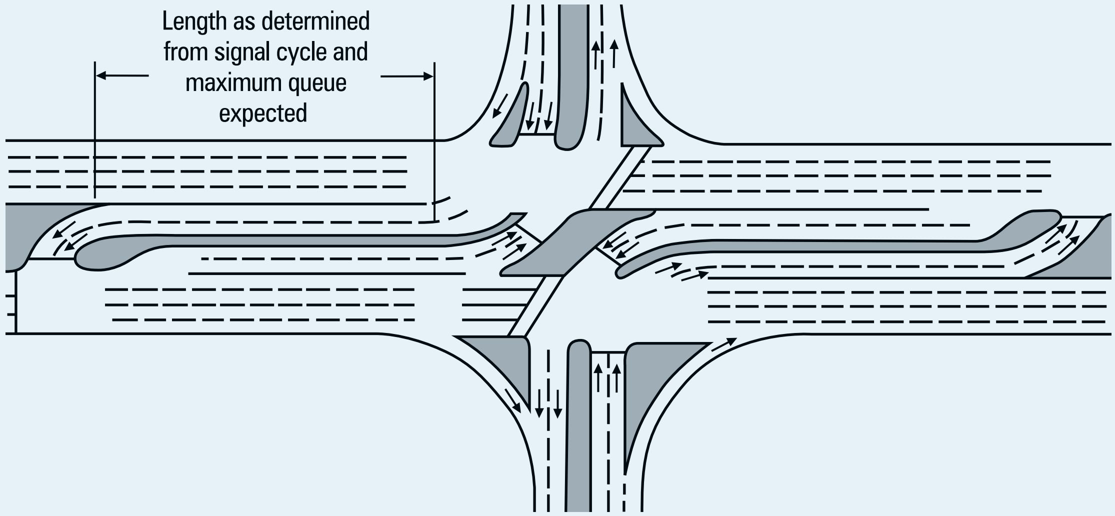
One-way streets were an early adaptation to growing traffic and the complexity of left turns across opposing traffic. They, in effect, put the opposing direction of traffic on a separate road a block away. This simplifies the intersection and makes left turns just a matter of merging with the cross traffic. Without the need for protected turns, the signals can be simple two-phase, and it is easier to organize for progression of signals to move traffic in platoons, minimizing stops. Throughput and safety are improved considerably. [67]

As with most such schemes there are tradeoffs. One-way street networks involve more circuitous routes and, on, average, slightly longer trips. They are more difficult to navigate, especially for strangers to the area.

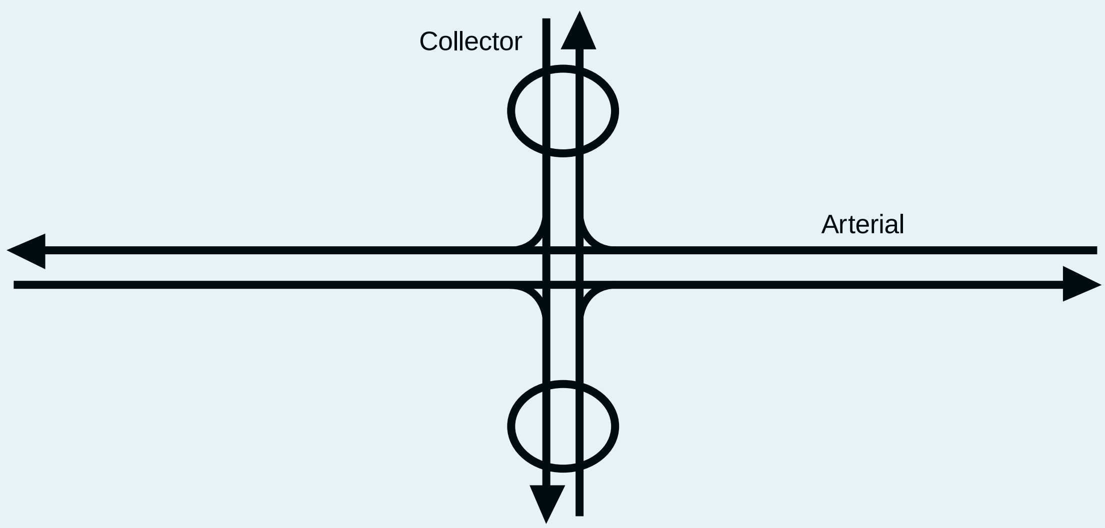
A variant of one-way streets is a split intersection, in which the direction of traffic is splayed out on the approaches to the intersection. Similarly, superstreets or boulevards provide for a



The Michigan superstreet has left-turning traffic go beyond the intersection to do a U-turn, then weave across and turn right. Drawing from Joseph Hummer and Jonathan D. Reid.



A more extreme form of the superstreet eliminates direct cross-traffic by directing it to the right and to a U-turn.



The bow-tie or dog-bone intersection only allows straight-through traffic at the main intersection and sends all turning traffic to the right to go through two roundabouts. We doubt this one will find favor! Drawing from Joseph Hummer and Jonathan D. Reid.

very wide median in the center of the arterial, separating the two directions of traffic by 80 or 100 feet. This allows left-turning traffic to be merged with cross traffic before crossing the line of opposing traffic. Lavish real estate in the median is the biggest cost since to store just a tractor-trailer requires some 70 feet.

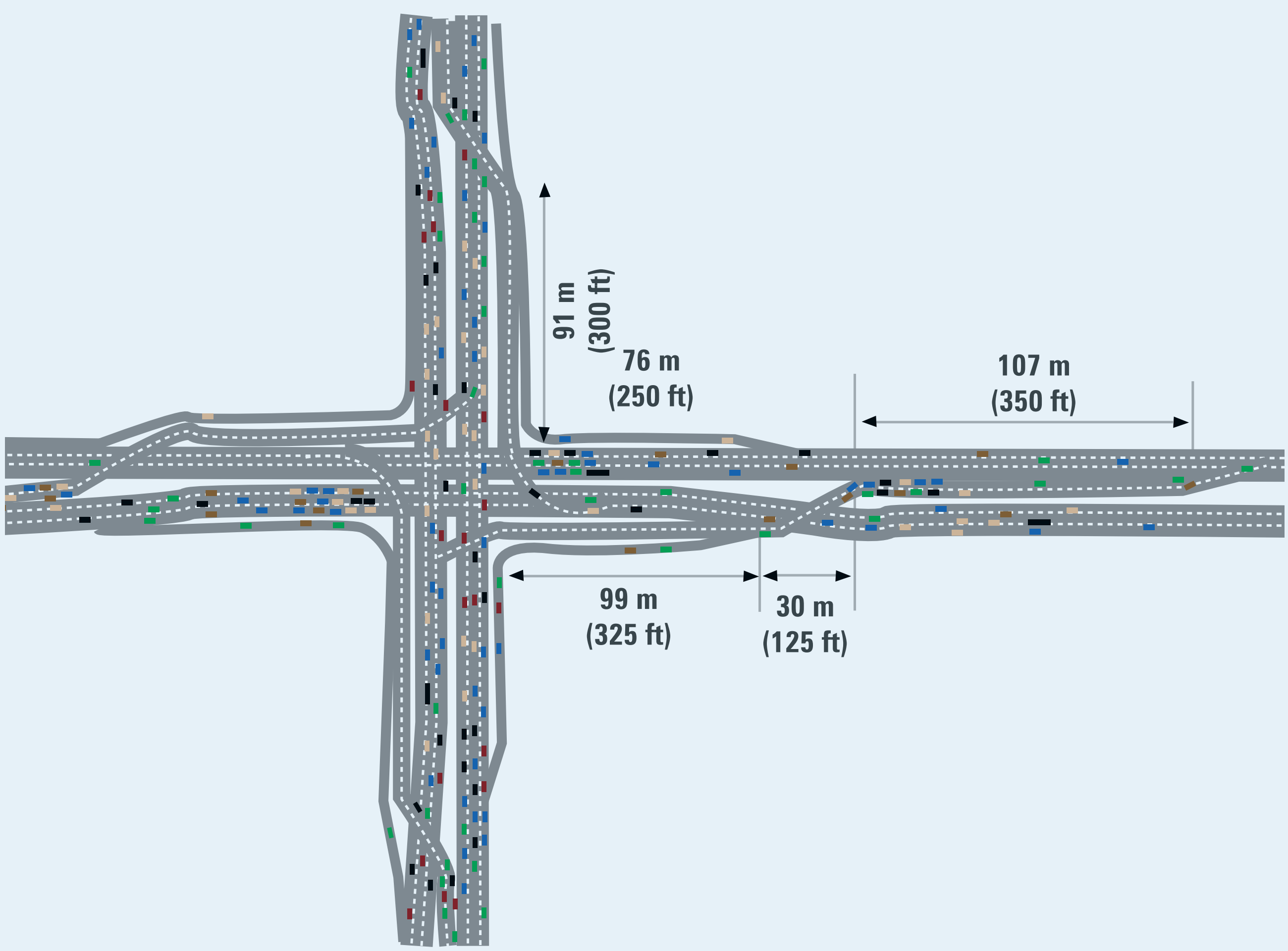
Michigan has a variety of superstreets in which left-turners go beyond the intersection several hundred feet and do a U-turn into the opposite direction of traffic and then complete the maneuver with a right turn. More circuitous routing, occasional mistakes by unfamiliar motorists, and extra weaving movements or lane changes are the price paid for simpler 2-phase signals and the elimination of left turns.

A design called a bowtie has roundabouts on the cross street on either side of the arterial. Left-turners on the arterial have to exit right, go 180 degrees around the roundabout and return to cross the arterial with the cross traffic.

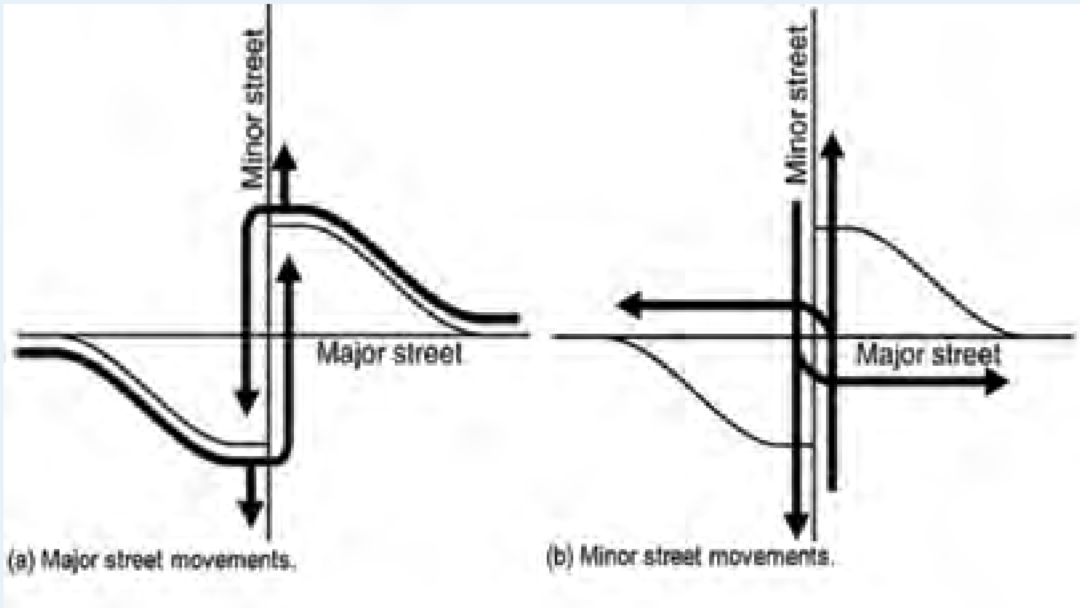
C. Redesigned Intersections

1. Continuous Flow Intersection

One of the most radical intersection designs involves an advanced left turn in a design which is called the Continuous Flow Intersection (CFI). Designed by engineer Francisco Mier, the CFI takes the left-turners across the opposing flow of traffic several hundred feet before the intersection, simplifying movements at the intersection itself. The CFI is an improvement on the operations of a four-phase signalized intersection. There are only two constructed in the United States but there are many in Mexico. Their downside is the requirement for three roadways to run parallel in the approach to the intersection, complicating frontage access and requiring extra real estate.



A detailed drawing of the Continuous Flow Intersection (CFI), designed by engineer Francisco Mier.



These diagrams of the Jersey Jughandle show that left turns from the arterial go right first and join cross traffic (left diagram), while cross traffic can turn left directly into the arterial (right diagram). A variation of this Jersey Jughandle is where, instead of turning right ahead of the intersection, the left turner on the arterial goes through the intersection and does a right hand loop to arrive on the cross street. Drawings by Joseph Hummer and Jonathan D Reid

One of the oldest alternatives to central left turns is the Jersey Jughandle in which left-turning traffic is directed to the right instead of into a left side turn storage lane. On the right it joins cross traffic—either by a direct ramp or by a loop. With turning traffic presenting itself to the main traffic direction as cross traffic, signal phases can be reduced to two or three.

Jughandle designs with their right-side ramps and/or loops help establish the roadway footprint needed for an eventual upgrade from arterial to expressway.

2. Reduced Conflict Intersections

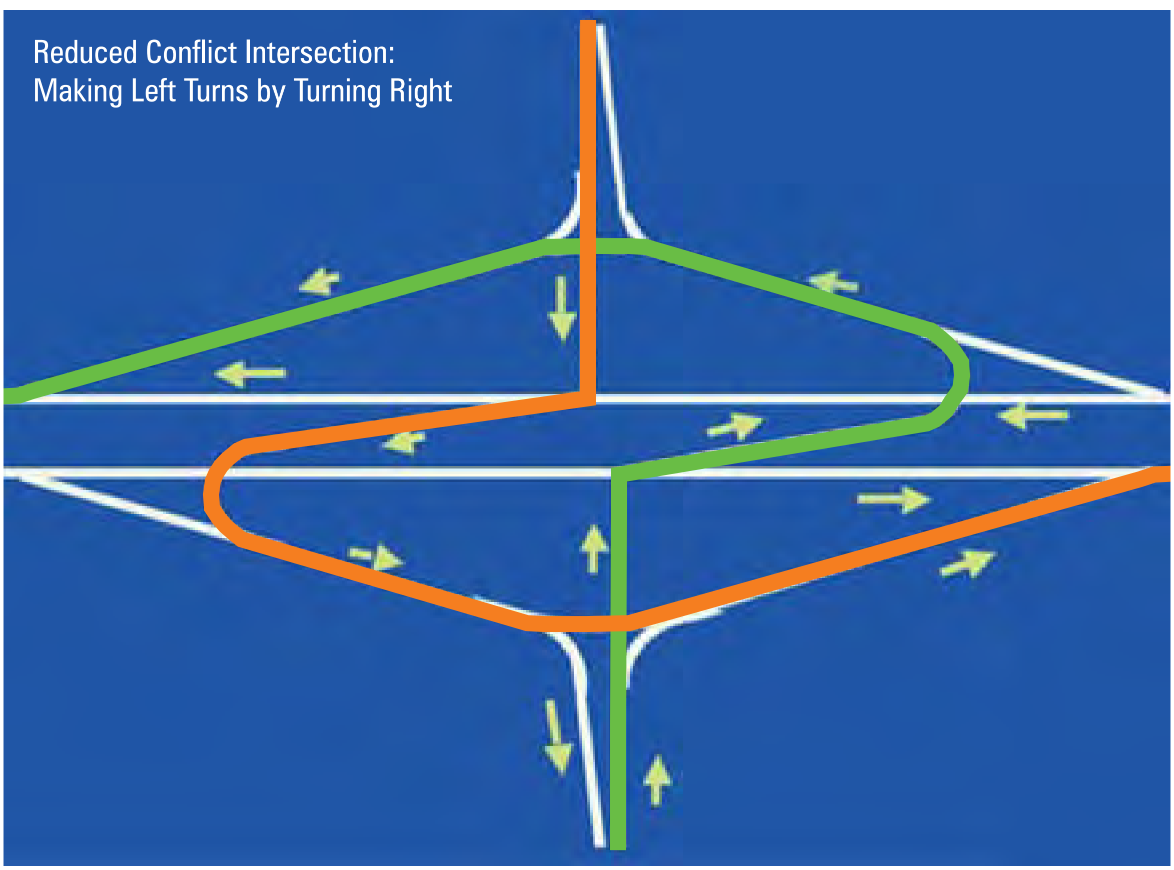
Dennis R. Eyler, senior partner in a leading Minneapolis engineering firm, has recently come up with some innovative intersection designs to improve on existing intersection treatments, drawing on the best of each and attempting to avoid the shortcomings. This synthesis of different approaches is called the Reduced Conflict Intersection.

RCIs draw on roundabouts for their value in slowing cross traffic by forcing a turn before entering the main direction of traffic. They draw on a cut-through design in giving priority and a straight run-through to the dominant traffic flow. And they draw on the traditional one-way pair of a divided surface arterial in having left turns from the main line making the intersection simpler for main-line motorists to “read.” A major breakthrough is using the longitudinal distance in the median of the divided highway for storing, not just left-turning traffic, but cross traffic as well.

Eyler has written that we should think of the RCI as "an intersection that has been channelized to allow only right turns to and from the main line and left turns from the main line. Crossing straight through traffic and left turns to the main line are to be made at a U-urn crossover which would typically located some distance from the subject intersection. The RCI design optimally combines the restricted movement main intersection with the 'U-turn' connections by combining them at one location."

RCIs scale well. Eyler has done three generic designs costing $400,000, $800,000 and $1.6 million. The minimal RCI is designed for lowest volumes, the $800,000 intermediate version can handle higher traffic volumes and can be signalized. The $1.6 million RCI is an Interchange Precursor designed to take advantage of a footprint of roughly the size which will be required when the bridging and ramps of an interchange replace the at-grade RCI. They have been modeled using standard traffic simulation software and perform well.

RCIs are interesting in that they allow an incremental approach. They can begin with Yield or Stop sign controls, move to signals, then be upgraded with grade separation. They seem



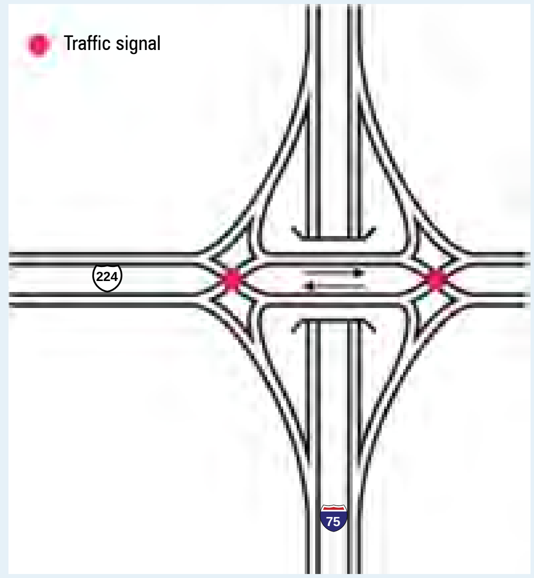
Eyler's Reduced Conflict Intersection (RCI) deals with cross traffic and left turners on the cross street by sending them to the right or downstream where they weave across one direction and only have to cross the other direction of the main line.

likely to be applicable in a number of places within developed urban areas, but may have their greatest application on the urban fringes—where two-lane roads are starting to bear the brunt of urban bypass traffic for example. The simpler versions may help in rural areas on high-speed, low-volume inter-city roads.

3. Queue Jumps

This is the new term for a self-contained flyover or overpass allowing motorists to "jump" over a queue at traffic signals.[68] Lee County, Florida has studied queue jumps and they plan one in the Fort Myers area.[69] The overpass will be built at a congested, signalized intersection and allow traffic on the most heavily trafficked arterial route to drive up and over the intersection. They plan to collect tolls from traffic using the jump via transponder or video-tolling. The toll will be varied by time of day to reflect the greater value of the structure and also to limit traffic volumes to those which flow freely. The toll also will help pay off the cost of the structure.

The first queue jump will be on Colonial Boulevard (SR 884), a six-lane arterial at the intersection with Metro parkway (SR 739), and will be one lane each direction, carrying Colonial Boulevard through traffic. Motorists who want to turn at the intersection, or don't want to pay the toll, will continue to use the surface road and the traffic signals. Detailed design is now being done, but the structure will be about 1,500 feet long in order to have a reasonable slope.



Diverging Diamond lanes. The Missouri Department of Transportation officials considered a number of plans for the downtown Front Street approach to Interstate 435. But the one they settled on appears to be a national first, costs the least and is expected to most effectively handle traffic by briefly crisscrossing lanes and putting drivers on the left, a position seldom experienced this side of the Atlantic.

This map shows the location of an effective flyover from Alton Road/63rd Street turning left onto Indian Creek Drive north of Miami Beach.

The beginning of the flyover on 63rd Street looking east. Photo by P Samuel.

The end of the flyover looking south down Indian Creek Drive. Photo by P Samuel.

Overpasses on arterials can also be used to cater to heavy left-turning traffic. Two of these exist in Miami Beach, Florida. A flyover starting on 63rd Street coming off the Alison Island Bridge takes motorists wanting to turn left onto Indian Creek Drive northbound over the top of the intersection avoiding a stop at traffic signals. Another is where the MacArthur Causeway transitions to Alton Road on the south end. There's at least one more such left turn queue jump in Miami in the hospital complex north of the SR 836 toll road.

Washington, DC has a number of quite old arterial underpasses or "queue dives" in the sense that they allow one movement of traffic to dive under the intersection—often a large traffic circle or a complex intersection where a diagonal avenue is superimposed on the grid of lettered and numbered streets. Many of these arterial underpasses are now somewhat decrepit, but they work well to speed traffic under bottleneck intersections. Connecticut Avenue, NW at Dupont Circle, 16th Street at Massachusetts Avenue, NW, K Street at 23rd Street in Foggy Bottom, and North Capitol Street at New York Avenue are examples.

Clearly underpasses are going to be more disruptive of traffic during construction than overpasses and they will have more demanding maintenance because of drainage requirements. On the other hand they will have less visual impact and may be more acceptable to neighbors.

4. Hybrid Interchange/Intersection (HICIS)

Traffic engineer Joel K. Marcuson, PE is a proponent of a hybrid interchange/intersection (HICIS). As a designer of new roads he has been frustrated by the problem that surface arterials are often limited in their capacity by multi-phase signalized intersections at grade. He writes:

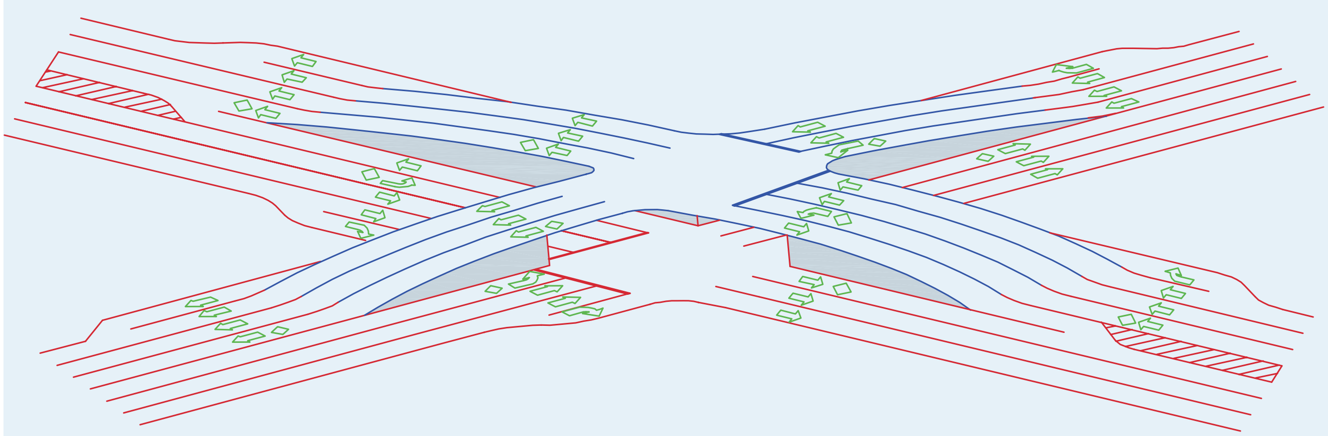
Connecticut Avenue underpass at Dupont Circle in Washington, D.C. Photograph by John Whitman.

> *The weak point of arterial design, or the linchpin (depending on your perspective), has been the arterial/arterial intersection. Extremely high volumes, both through and turning, come together at the same point at the same time, and all of these substantial traffic demands need to be served in the best manner we know how. Because of these conflicting needs, intersections have served as bottlenecks to flow on arterial roadways, providing only 30-50% of the capacity available on the arterial itself.*[70]

The HICIS splits both the arterials into two levels with an intersection at each level. The approaches on each level are one-way streets, plus turning ramps. With a one-way street approaching another one-way street at each level, you have the simplest kind of intersection to signalize. All you need is a two-phase signal.

Marcuson has proposed the HICIS as one alternative for McCarran Blvd. and Pyramid Way in Reno, Nevada. McCarran Blvd. is an arterial ring around the greater Reno area with some 13 surface signaled intersections that are failing from excessive traffic for their capacity. Marcuson modeled alternatives using projected 2012 traffic:

- signalized intersection widened with more turning-storage lanes
- grade separation for a single-point urban interchange (SPUI)
- HICIS.



In a HICIS or Hybrid Interchange/Intersection, opposing directions of traffic are grade-separated, reducing the normal complex intersection to two simple intersections. Drawing by Joel Marcuson

Any of the alternates can be made large enough to perform, but only the HICIS can do it within the existing right of way. The surface approach requires a widening from the present 90 feet to 130 feet and even then only provides level of service E (congested) conditions.[71] The popular single-point urban interchange (SPUI) design has an underpass or overpass for the main through direction of traffic and an enormous signalized intersection superimposed above or located underneath which handles all movements with a three-phase signal. The intersection works all right at level of service D (some congestion) in the Reno modeling, and the overpass provides level of service A (completely free flow). SPUIs are most suited to expressway-arterial junctions with one route clearly dominant. Both the widened surface intersection and the SPUI require widening the major arterial to three lanes each way and the SPUI requires widening at the junction to 160 feet from 90 feet.

The HICIS provides about equal performance to the various movements (LOS-C, and LOS-D). It spreads the pain! But it manages to do all that without requiring any widening of the main line, or any junction widening. The HICIS fits in the 90-foot right of way. The two-phase signal patterns at the double-decked one-way street intersections are more flexible and move the traffic faster, reducing the need for extra lanes for storing waiting traffic. By using HICIS junction treatment, it is possible to greatly increase the capacity of arterials without widening.

5. Echelon Interchange

N. Craig Miller and Joaquin E. Vargas of Miller Consulting in Florida have called a similar concept the "Echelon Interchange." In a paper in 2002 they describe a simple pair of two-phase, one-way signalized intersections offset and grade-separated from one another —a simplified version of the Marcuson HICIS.[72] Their reasoning is that conventional interchanges placed at strategic points on an arterial suffer the disadvantage that they will overload adjacent intersections and favor one traffic movement heavily over others, producing unbalanced improvements. Hence, full advantage cannot be taken of the interchange capacity and some is wasted. This is true whether the interchange is a diamond (the most common expressway interchange with four ramps, two on each side of the over-bridge or under-bridge), a single-point urban interchange (SPUI), a newly favored design which manages traffic off the main line with a single large intersection controlled by a three-phase signal, or a queue jump. Since all traffic movements on an Echelon Interchange face some red time, signals can be used to meter traffic and prevent adjacent intersections being overwhelmed.

The Echelon Interchange by Miller Consulting is very similar to the HICIS.

D. Better Signal Coordination

Better traffic signal coordination is an apple pie issue. Who can argue with it? The problem is figuring out how to do it. The low-hanging fruit was picked in the 1960s and 1970s with SCOOT[73] and SCATS,[74] two network-optimizing approaches that revolutionized signal coordination. They were devised by clever mathematician engineers in Britain and Australia, respectively. Despite major subsequent efforts in the United States, Europe, and Asia, the various upgrades and refinements of those two approaches continue to be regarded as the best designs going. But they have both proven difficult and expensive to implement in the American urban environment. The Australian approach has seemed intuitively to be more suited to U.S. conditions than the British SCOOT, though both have been implemented in a number of places around the country. SCATS was tried on a large scale in the Twin Cities in the 1990s with great hopes, generous state and federal funding, and worthwhile but limited results.[75]

These systems require a large traffic data collection system, well-maintained sensors, and considerable skilled and motivated staff. They are expensive to install and to operate. The expense may well be warranted in terms of the benefits to motorists. But there's a problem under present institutional structures in capturing some of the benefits from the beneficiaries and making it into an income stream for the service providers. Signal optimization is currently the responsibility of city or county traffic departments. They have to compete for funding and staff with schools, trash collection, police, fire and ambulance and other city hall-type activities in a competition for local taxes, as well as grants from state and federal governments.

There are a lot of demonstration projects and ribbon-cutting ceremonies opening new traffic control centers and signal optimization, but much less follow-on support. A report to the U.S. Congress recently stated that of 10 traffic management centers in the Chicago metro area, six have no staff at all to monitor traffic conditions, and another only has a part-time staffer.[76] Only three of the 10 have staff to make use of the surveillance systems in place and the traffic data being generated. Sometimes there is outright fraud.[77]

Most times the traffic management centers don't get the funds to support serious ongoing signal optimization. Traffic data collected to support optimization is spotty. The traffic centers most often revert to small incident management centers which play a useful but modest role in dispatching a service truck, a tow, or a clean-up crew in response to debris on the road, stopped vehicles, and the like. They rarely have the comprehensive surveillance or data coverage, let alone the personnel to look after the whole expressway mileage, let alone large arterial networks.

In many instances communication systems have proved inadequate to get traffic data to the control center, and sometimes the sensors themselves—electromagnetic loops in the pavement are still the most widely used—provide bad data. Usually this is a product of government budget compromises, which are inevitable when financing is done from general revenues.

Even when fully implemented and robustly maintained, signal optimization produces most of its benefits in low to moderately congested conditions. Optimization means allocating spare green time better, attempting to ensure that a green signal never beckons a roadway with no traffic in it. No amount of real-time traffic data and signal control smarts can be helpful when there's heavy traffic queuing on all approaches to major intersections—when there is no spare green time. Most optimization programs in essence give up under those conditions, because beyond a point in traffic saturation there is no help to be gotten by retiming of signals. So long as the limits of signal optimization are appreciated it is a valuable tool. There are many periods of time and places of low to moderate congestion where wasted green time can be reduced by adaptive signal systems.

The full benefits of signal optimization then depend on other measures to mitigate congestion, the most promising of which is addressing bottleneck intersections by enhancing capacity with extra lanes, some grade separation, bypass or relief routes.

Area pricing of the kind in use in central London may be appropriate in certain limited downtown or special areas, though it has less obvious application in the United States because we have few areas of the extremely narrow street networks that characterize older European and Asian cities. Moreover, the boundaries of area pricing are difficult to draw without producing economic distortions.

Part 8

Conclusion

In a recent book "The Substance of Style" Virginia Postrel focuses on the pervasive role of aesthetics in modern society.[78] The aesthetics of objects, she writes, "offers pleasure and signals meaning" since it is "personal expression and social communication." She adds that since the aesthetic character "shows rather than tells" and works in a subliminal, associative way, its impact is immediate and often emotional. This was indeed the case with one of our most famous road bridges.

John van der Zee's account of the campaign for the construction of the Golden Gate Bridge describes its final design as shaped collaboratively by Chicago engineer Charles A. Ellis and a renowned local Bay Area architect Irving Foster Morrow.[79] Ellis exploited a new understanding of ways to slim the size of towers with new mathematical approaches to sizing them for the forces they had to handle. Architect Morrow's stroke of genius was to follow through on Ellis's work to introduce the subtle stepping of the towers. The result of this was, in Van der Zee's words, to "give the finished bridge its fascinating, painterly sense of perspective, so that, seen head on, each tower seems instead a row of towers of ascending height, extending away in depth behind the first one."

Joseph Strauss, the relentless promoter of the bridge, commissioned the best local artists to do oil and water paintings of the proposed structure, which were reproduced in reports, brochures, and posters. A lantern slide show—the Powerpoint of the 1920s—was also used at many of the hundreds of presentations Strauss gave to local groups. His pitch early on had been how the bridge would open up Marin County to economic development, enhance property values and end the long lines of automobiles at the ferry terminal at Sausalito. But as time went on the visuals grew in importance. There was a huge political battle with ferry interests, and other opponents who exploited a reasonable fear that failure of the bridge might leave local taxpayers to foot an enormous bill. It went to popular ballot.

As Van der Zee describes the battle: "Against this well-organized and substantially financed opposition, the bridge proponents wielded their most powerful weapon: the bridge itself. Even in the simplified caricatures of editorial cartoons, the bridge looked slender, graceful—and strikingly original." The economic arguments were inconclusive, since both costs of construction and toll revenues were so uncertain. The engineering was risky with towers atop a major earthquake fault and within a wild channel beset by fierce tidal currents and storms. Also, the longest suspension bridge built at the time, the Manhattan Bridge in New York, was less than half the proposed span of the Golden Gate, so there was an enormous jump in scale from the proven.

Strauss however managed to turn the difficulties to the advantage of the project by presenting the bridge as a symbol of a city boldly and confidently striving for a better future. At ballot the bridge won by more than three to one in all six tax districts.

Van der Zee writes: "It was ultimately, in the privacy of the polling booth, an emotional decision, and the emotion in this case proved overwhelming… The people of the (tax) district, in an act of either mass foolhardiness or considerable courage had put themselves at risk, in service of a metaphor."

We need to build more beautiful roads, bringing back architects, landscapers, graphic artists and other designers to play a major role as they did for the 1920s and 1930s parkways of New York and Connecticut. They need to be built to respond to local aesthetic themes and sensibilities. Sometimes it is as simple as recruiting local artists. There are encouraging examples of this in the major new highways of Phoenix, where desert and native American themes are reflected in the colors, textures, motifs and landscaping of the roads. In Texas the "lone star" is cast by formwork into the piers of sweeping ramps and highlighted in distinctive coloring.

Grand bridges are already recognized as an opportunity to create something a local community can be proud of, something that expresses its character, that is recognized as a local icon, and which endures over the decades, while local personalities come and go—a "signature bridge." Architectural qualities are now taken for granted as a legitimately large part of big bridge design. All this can be overdone, of course. Some will want to create a giant piece of civic sculpture for sculpture's sake. In California in the new east span of the San Francisco-Oakland Bay Bridge and in Buffalo, New York in the case of the Peace Bridge signature styling has gotten out of hand, and the major portion of the cost is the sculpture, and the minor cost the transportation function. A good adage is that form should follow function. A long span bridge is appropriate over a deep channel where towers on either side are needed because of the cost and impracticality of in-water piers. By the same token it is ridiculous to build a long span bridge with its high towers over shallow waters.

There are economical ways of getting a signature design. Indeed some of the most distinctive designs have been achieved through the discipline of economy. The Golden Gate Bridge design started off as a complex combination of truss and suspension bridge, but the need to keep costs in check led to the substitution of the simpler and far more elegant design that we see today. Similarly the George Washington Bridge's distinctive open, box-trussed towers were designed originally to be encased in a veneer of stone masonry that was the convention of the time. Budgetary issues forced omission of the stonework. Most people liked the lacy structural trusses and an open tower became a new aesthetic.

So a call for aesthetic concern is not a call for extravagance in pursuit of artistic whimsies. It is a suggestion that within the bounds of what is financeable, aesthetic expression should be given free rein. This adds to the challenge of project management because what is beauty to some is ugly to others. Views on aesthetics can be as diverse as views on politics. But management of a project as an aesthetic expression is simply a challenge which has to be met. Just as our processes seek to reconcile differing political perspectives, they need to tackle different aesthetics.

And it shouldn't apply just to the grand bridges. Aesthetics needs to be handled at all levels of construction. It should be approached as an opportunity to create something which people will feel proud of, which can be a mark of local pride. The talk about remediation, and minimizing impacts is overly defensive. We want to do all that, of course, but we should see new projects as something an opportunity to go further and design something people want, not just something they will sullenly accept as necessary.

Construction of a New Road

But important as aesthetics is, the fundamentals of design must provide sufficient roadway capacity for safe, reliable journeys at close to the speed motorists are comfortable driving—50, 60 or 70 miles per hour depending on the context of the road, including the weather. Roads are primarily for movement and the most beautiful road is tedious if viewed in frustrating stop-and-go conditions.

Which brings the argument full circle to the question of how design can make provision of extra capacity more acceptable.

In summary, this paper has suggested that just widening existing highways is not the answer because overlarge highways are part of the reason highways are unacceptable. The gargantuan scale of 10-plus lane highways is part of the reason highways are seen as ugly. Constant widening also aggravates the problem of handling the traffic coming on and off at expressway interchanges. On the surface arterials, widening beyond two lanes each direction is often necessary when such arterials are a mile or more apart. However handling the left turns becomes the major challenge. Intersections become bottlenecks because of the complexity of signal phasing needed to safely cater to the volumes of left turns.
More and smaller highways are part of the answer.

This paper has laid out various ways to make new highways acceptable:

- seeking out unused or underused railroad rights of way, co-location rights in high-voltage electricity corridors, floodways, run-down light industry strips

- elevating, trenching, capping even full undergrounding; and

- tailoring roads for certain kinds of traffic—some for cars only, some for premium service for a price, and some for trucks.

Where the capacity of existing highways has to be increased, doubledecking of general-purpose lanes tends to be hugely intrusive and expensive because of the height of structures needed. A more feasible scheme has been suggested for these mega-expressways—separating the 80 to 90 percent of light vehicles (10 feet and less) and running them on more modest height double deck while running high vehicles (tractor trailers which go to 15 feet) alongside in a separate single deck. And where arterials have to be widened beyond four lanes there are a variety of designs—from grade separation to a range of special measures for troublesome left-turning.

Everything is expensive and unlikely to be easy to implement but lesser plans that acquiesce in chronically growing congestion are unacceptable and will prove politically unsustainable.

Millau Viaduct in France. Photos from Gettyone Images © 2006.

About the Authors

Peter Samuel received his B.Comm. (Honors) majoring in economics from the University of Melbourne, Australia, where he also studied city planning. He taught economics at Monash University, then moved into journalism with the *Canberra Times* and later the newsweekly, *The Bulletin*. Based in the United States since 1980, he founded and edited *Toll Roads Newsletter*, now replaced by the comprehensive Web site, www.tollroadsnews.com. He has been a contributing editor to *World Highways and Intelligent Transportation Systems International*.

Robert W. Poole, Jr. is Director of Transportation Studies at Reason Foundation. He received his B.S. and M.S. in engineering from MIT and worked in aerospace before launching Reason Foundation in 1978. He has advised the U.S., California, and Florida departments of transportation, as well as the Reagan, Bush, Clinton, and Bush White Houses on transportation policy issues. He was a member of California's Commission on Transportation Investment in 1995-96.

Related Reason Foundation Studies

Robert W. Poole, Jr., Peter Samuel, and Brian F. Chase, *Building for the Future: Easing California's Transportation Crisis with Tolls and Public-Private Partnerships*, Policy Study No. 324, January 2005.

Robert W. Poole, Jr., and Peter Samuel, *Corridors for Toll Truckways: Suggested Locations for Pilot Projects*, Policy Study No. 316, February 2004.

Robert W. Poole, Jr. and C. Kenneth Orski, *HOT Networks: A New Plan for Congestion Relief and Better Transit*, Policy Study No. 305, February 2003.

Peter Samuel, Robert W. Poole, Jr., and Jose Holguin-Veras, *Toll Truckways: A New Path Toward Safer and More Efficient Freight Transportation*, Policy Study No. 294, June 2002.

Robert W. Poole, Jr., *Commercializing Highways*, Policy Brief #19, August 2001.

Peter Samuel, *Putting Customers in the Driver's Seat: The Case for Tolls*, Policy Study No. 274, November 2000.

Peter Samuel, *How to "Build Our Way Out of Congestion": Innovative Approaches to Expanding Urban Highway Capacity*, Policy Study No. 250, January 1999.

Endnotes

1. David Schrank and Tim Lomax, *The 2005 Urban Mobility Report, Texas Transportation Institute*, ([City]Texas A&M University, May 2005). The $63 billion number is for 2003 and for those metro areas surveyed. The national total is considerably higher.

2. "Is it wrong to love a road?" *TOLLROADSnews* 2005.11.23.

3. We follow usage in the eastern United States, the Mid-West and Texas in calling the top tier of roads expressways. They are fully grade-separated, access-controlled roads that have the FHWA Functional System classification of Interstates or Other Freeways and Expressways. Expressways may be free or tolled. In the western United States and among engineers the term expressway is often used to denote a second-tier, signalized arterial and the term freeway is used for a fully grade-separated and access-controlled road, but this creates confusion because a 'free'-way seems to preclude toll roads. The Texas Department of Transportation solution to this semantic dilemma has been to adopt the term expressway as the generic term for all the top tier roads, and we follow their lead. We use the term "surface arterial" for the second-tier road, the word "surface" indicating the lack of grade separations—intersections are at grade, or on the surface. Surface arterials have the FHWA Functional System classification Other Principal Arterials, other meaning in FHWA lingo "other than Interstates and Other Freeways and Expressways."

4. *The Aesthetic Condition of the Urban Freeway*, Thomas B. Gray, 1999, www.mindspring.com/~tbgray/prindex.htm.

5. Bureau of Transportation Statistics, *National Household Travel Survey*, 2001-2002.

6. 5,678 million bus trips were made versus 2,952 million rail trips, and 21.2 billion passenger-miles were traveled on bus to 15.4 billion by rail. See American Public Transit Association, *2002 Transportation Fact Book* (Washington, DC: 2002).

7. U.S. Department of Transportation, Bureau of Transportation Statistics, *Commodity Flow Survey 2002*, December 2004. Trucking includes parcel, USPS and courier. The balance includes multimodal in which trucking plays a part.

8. *Highway Statistics*, Bureau of Transportation Statistics (Washington, DC: 2005), table VM-1.

9. http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_highway_profile.html.

10. Lewis Mumford, *My Work and Days* (New York, NY: Harcourt, Brace Jovanovich, 1979).

11. See "The Pedestrian Mall Fad" chapter in "No Two Ways About It: One-Way Streets Are Better Than Two-Way," by Michael Cunneen and Randal O'Toole, Center for the American Dream and

Independence Institute, February 2005, http://i2i.org/articles/2-2005.pdf.

12. James A. Dunn, *Driving Forces: the Automobile, its Enemies, and the Politics of Mobility* (Washington, D.C.: Brookings Institution Press, 1998). This is the theme of his book but the phrase comes from a spin-off article he wrote in Kenneth Orski's *Innovation Briefs*, February 2001.

13. Calculations based on FHWA, Office of Highway Policy Information, Highway Statistics, Section V files hm20.xls and vm2.xls downloaded at http://www.fhwa.dot.gov/policy/ohim/hs03/re.htm.

14. Herbert S. Levinson, *Street Spacing and Scale*, TRB Circular E-C019, Urban Street Symposium, TRB December 2000. http://gulliver.trb.org/publications/circulars/ec019/ec019.pdf.

15. The coalition called Friends of the High Line wants the abandoned freight rail elevated and converted to pedestrian and urban park use, but clearly its physical presence is acceptable. The High-Line with about a two-track, 30-feet width, runs 22 blocks from 34th Street at 10th Avenue in Midtown south to the West Village at 12th Street. See www.thehighline.org/.

16. Segmental box girder construction was pioneered in Europe, but has been developed in the United States too and is now quite widely used. A leader here has been Figg Engineering Group of Tallahassee FL, see www.figgbridge.com/ On the Tampa Bridge www.tampa-xway.com.

17. The Tampa project suffered a blow April 13, 2004 when one of the piers subsided 11 feet in a matter of about two minutes, as workers scrambled from the worksite. Surveys found another pier had sunk too—only an inch but well beyond tolerance. New construction was suspended. Independent geotechnical consultants concluded a serious mistake had been made in foundation design. The designers—since dismissed—had designed the foundation shafts assuming similar soil-bearing conditions the length of the project. In fact the soil conditions were highly varied. Only 39 out of 202 foundation shafts completed at the time work was suspended met loadbearing requirements, the consultants said. The 163 inadequate foundation shafts are being given deeper 'sister' foundation shafts to bring them up to standard. Such engineering errors reflect badly on the designer and on the project management on this particular project but they don't reflect any problem with the segmental box girder-type construction as such. Under new toll authority management and with new engineers work has resumed and is expected to be complete in the fall of 2006.

18. "Innovative Sound Tube," *Toll Roads Newsletter* No. 36, February 1999.

19. The longest is a proposed greenhouse motorway in Schwamendingen in the northern part of Zurich and is 900m (2950 feet). A shorter one is in operation in Basel near the French and German borders.

20. See http://www.solarintegration.de/index.php?id=227&projekt_id=42 also http://www.pvresources.com/en/noise.php.

21. "Transparent Sound Walls Added to Woodrow Wilson Bridge," *Civil Engineering magazine*, July 2003, p29.

22. Peter Samuel, *How to Build Our Way Out of Congestion*, Policy Study No. 250 (Los Angeles: Reason Foundation, January 1999).

23. Thomas B. Gray, *The Aesthetic Condition of the Urban Freeway*, 1999, www.mindspring.com/~tbgray/prindex.htm.

24. See www.tunnelprado.com but a French-only Web site.

25. "Wapping and Limehouse," *Commission for the New Towns UK 1997*, http://www.ijpregeneration.com.

26. Http://www.nationaltrust.org.uk/main/w-global/w-special_projects/w-stonehengehistoriclandscape-stonehenge/w-stonehengehistoriclandscape-project.htm#landuse

27. See Berlin Senate Department of Urban Development, in english http://www.stadtentwicklung.berlin.de/bauen/strassenbau/index_en.shtml

28. Email from Katrin Vietzke, Senatsverwaltung fur Stadtentwicklung, Projektmanagementbereich, Strassenentwurf, Fachbereichsleitung, Berlin, January 4, 2006.

29. The NSW Roads and Traffic Authority gave an $A figure at the time which at the exchange rate then prevailing was $450m as the estimated construction cost. The project was done as a design-build project with ten years of operations and maintenance for A$794m which is $596m at present exchange rates.

30. The Cross City Tunnel at time of writing is the subject of major controversy. Its usage has fallen far short of projections—unlike other Sydney tunnels—and there is great consternation about remaining surface street congestion. Good forecasting is vital to making projects like this a success.

31. The exact length depends on interchange arrangements at the ends according to "F3 to Sydney Orbital, National Highway Link Study" *SKM*, July 2003, p15.

32. See www.transurban.com.au and www.citylink.vic.gov.au.

33. See http://www.nsbt-eis.com/ and http://www.brisbane.qld.gov.au.

34. The term tunnel as used here covers fully underground roads whether built as cut-and-cover—essentially a lidded trench—or a driven tunnel mined from an entrance portal or shaft. Cut-and-cover construction being closer to the surface is well suited to short tunnels and at the entrances to longer tunnels. Driven tunnels have the advantage they can get below utilities avoiding a major component of costs of cut-and-cover construction. They are also less disruptive during construction.

35. Bert Ely, financial adviser at Ely & Company in Alexandria, VA, is one who argues air rights have major potential—bert@ely-co.com

36. Track in use in 2002 is about 141,000 miles versus 272,000 miles in 1920 and about 3,000 miles per year are being abandoned according to Jeffrey M. Heftman, "Railroad Rights-of-Way Easements, Utility Apportionments and Shifting Technological Realities," *University of Illinois Law Review*, 4/22/2003, p. 1410. See http://home.law.uiuc.edu/lrev/publications/2000s/2002/2002_5/Heftman.pdf.

37. Dan Cupper, *The Pernnsylvania Turnpike: A History,* 3rd edition (Lancaster PA: Applied Arts Publishers, 2003), pp 6–8.

38. Jesse Sublett, *History of the Texas Turnpike Authority* (Texas: Turnpike Authority, 1993), pp. 24–26.

39. "Delivering the Goods," *The Metropolis Freight Plan Technical Report* (Chicago: Metropolis, 2020, December 2004), p. 93.

40. Truck options were arbitrarily excluded from an alternatives analysis. See http://www.crossharborstudy.com

41. Board of Directors vote was 12 to 4 in favor of studies April 25, 2005—see www.octa.net

42. See http://www.trinityrivercorridor.org/html/transportation_improvements.html

43. There are some amazing new techniques involving slurry wall and top-down construction, ground freezing and horizontal jacking of huge precast tunnels that are starting to change this.

44. Cupper, *The Pennsylvania Turnpike: A History*.

45. See www.crosscity.com.au.

46. Email from Peter Sansom, *Cross City Tunnel*, Sept. 9, 2005, who says the system has 2.6 miles (4.2km) of two-lane tunnel and 1.4 miles (2.3km) of single-lane ramp tunnel mostly at an underground interchange with the Eastern Distributor, a tunnel way that it crosses. Also http://www.crosscity.com.au/DynamicPages.asp?cid=25&navid=7.

47. see http://www.a86ouest.com/a86ouest/gb/br_3a.htm.

48. Example of this are the peak-hour use of shoulders on I-66 in northern Virginia and on I-264 in the Hampton Roads area.

49. See OmniAir Consortium at www.ominiair.org.

50. See the federal program described at http://www.its.dot.gov/vii/.

51. In the Netherlands this has been implemented.

52. See European Conference of Ministers of Transport http://www.cemt.org/topics/road/dimens.pdf.

53. Car widths available from manufacturer Web sites under specifications and dimensions.

54. They want to retain the option for running all three lanes as travel lanes, but they plan to open with two travel lanes and one breakdown lane on each level. See http://www.a86ouest.com/a86ouest/gb/.

55. The National Park Service has its own policy, which has been to deny trucks access to parkways under its control, also vigorously resisting any expansion of capacity on parkways.

56. Around New York City they made no special provision for trucks when building the area's many parkways. The predictable result was that heavy trucks clog the few all-vehicles expressways and are often forced to use boulevards, avenues and other surface streets.

57. The worst feature was the 'sudden death' entry with no space for a merge at speed. Most of these had to have a 'Stop' sign. Most have since been rebuilt with a reasonable merge lane.

58. FHWA has materials on "Context Sensitive Design" at http://www.fhwa.dot.gov/csd/

59. Joseph Passonneau, a former dean of architecture at Washington University in St Louis is a veteran in highway architecture, his outstanding work over several decades acknowledged in a Presidential Award in 2000. He was heavily involved in the designs for the Glenwood Canyon viaduct which allowed I-70 to be completed through the Rocky Mountains. A younger practitioner, Alex Krieger, professor of urban design at Harvard Design School, has been involved in many recent successfully completed "context sensitive design" projects through his firm Chan Krieger & Associates, Cambridge MA." See www.chankrieger.com.

60. "Issues in the Financing of Truck-Only Lanes" by David J. Forkenbrock and Jim March, Public Roads magazine September/October 2005, p. 9.

61. Peter Samuel, Robert W. Poole, Jr., and Jose Holguin-Veras, *Toll Truckways: A New Path Toward Safer and More Efficient Freight Transportation*, Policy Study No. 294 (Los Angeles: Reason Foundation, June 2002).

62. Urban arterials as we style them are the FHWA's "Other principal arterials" functional system designation, since somewhat confusingly FHWA defines expressways as principal arterials. Surface arterials are therefore "Other…"

63. Calculations we made from National Highway Statistics files hm20.xls and vm2.xls.

64. Herbert S. Levinson, *Street Spacing and Scale*, TRB Circular E-C019, Urban Street Symposium, TRB December 2000.

65. Shrank and Lomax, *The 2005 Urban Mobility Report*, Appendix B, Methodology.

66. Calculations from National Highway Statistics files fi20.xls and vsm2.xls.

67. Michael Cunneen and Randal O'Toole, "No Two Ways About It: One-Way Streets Are Better than Two-Way" Center for the American Dream, Issue Paper 2-2005.

68. The term "Turbo Interchange" is also used for this simple overpass.

69. *Value Priced Queue Jump Study*, CRSPE Inc in association with Cella & Associates Inc, PBS&J, Metro Transportation Group for Lee County Florida, January 31, 2003.

70. *The Hybrid Interchange, Developing the Arterial of the Future*, June 2005, not yet published.

71. LOS stands for Level Of Service—a rating of road performance which goes from A (free flow) down to F (most heavily congested).

72. www.miller-consulting.com/echelon.pdf

73. SCOOT is Split Cycle Offset Optimization Technique, the British designed system and the most widely used network optimization approach implemented outside the U.S. See www.scoot-utc.com/.

74. SCATS is Sydney Coordinated Adaptive Traffic System.

75. *Integrated Corridor Traffic Management Evaluation Report* (Booz Alen & Hamilton, April 2000).

76. *Highway Congestion: Intelligent Transportation Systems' Promise for Managing Congestion Falls Short* (U.S. Government Accountability Office, September 2005, GAO-05-943, p. 26).

77. In the run-up to the Olympic Games in Atlanta, GA there was much hoopla about an Advanced Traffic Management Center including upbeat speeches by political leaders and glowing media reports of the capabilities the traffic optimizing bought with some $70 million. It was revealed later that the basic system was not made workable until many months after the Games, and then all it provided was a bunch of video pictures on a large wall.

78. Virginia Postrel, *The Substance of Style: How the Rise of Aesthetic Value is Remaking Commerce, Culture and Consciousness* (HarperCollins Publishers, 2003).

79. John van der Zee, *The Gate: the True Story of the Design and Construction of the Golden Gate Bridge* (Simon & Schuster, 1986), pp 116–130.

Mobility Project Advisory Board

The Mobility Project Advisory Board provides overall program guidance, suggestions on research, and feedback on studies. It does not necessarily endorse the conclusions of individual studies.









Reason

Reason Foundation
3415 S. Sepulveda Blvd., Suite 400
Los Angeles, CA 90034
310/391-2245
310/391-4395 (fax)
www.reason.org