THE THIRD GENERATION ROADWAY

METROPOLITAN TRANSPORT FOR THE 21ST CENTURY

ROGER DAVIDHEISER

A special thanks goes to Rosecrans Avenue, without whose development this book would not have been possible.

The dozen signal controlled intersections, 11 of which are fully sequenced, in the three miles between the surf and the 405, have been an inspiration.

The Third Generation Roadway
By Roger Davidheiser

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This work is both a stinging indictment of the system by which we drive, and—as written by an engineer—a proposal to vastly improve our lot with a new type of road—roadway that now appears both affordable and technically feasible, that would change how we use a city, how we plan a city, and how we use energy.
—*The editors*

Praise for *The Third Generation Roadway*

"Amazing in scope [the book] brings a breath of fresh air to urban gridlock [and] invites you to explore a future in which mass transit is conducted with individual vehicles, environmental sustainability, and operational safety."
—Michael A. Perovich
Director, Caltrans District 8, 2005–2008; Senior Resident Engineer of I–110 Harbor Transitway and Viaduct, 1990–1995

"A vision worthy of serious consideration in addressing America's 21st century surface transportation challenges"
—The Honorable Daniel S. Goldin
NASA's longest-serving Chief Administrator, 1992–2001

"…better urban landscapes enabled by innovation in transportation … increased personal mobility in more sustainable cities promised by emerging technology … This work relays new possibilities in the realms of land use and transportation studies."
—Meredith Dang
Land Use Transportation Coordinator, Houston-Galveston Area Council
Member of the American Institute of Certified Planners

PROLOGUE

This book envisions a transportation system for people, massive numbers of people, all traveling their unique door-to-door routes, all with their unique timing, and all in the comfort of their private vehicle. No trucks, no buses, no SUVs allowed. No stop signs, no red lights, no intersections. No transfers, no congestion. A transportation of people with time efficiency, space efficiency, and fuel efficiency. Automated, safe, pleasant to use.

The writing argues that each of the transportation systems developed to date for people is doomed to failure. Doomed to failure when measured against the criteria demanded: speed, convenience, safety, capacity to serve many, freedom from congestion, ecological soundness, and cost. Systems included are the urban surface street, the urban freeway, and the "public" modes of bus, train, and subway. What we have today can be improved.

While saluting the automobile and the automobile-based society, triumphs of the 20th Century enabling unparalleled mobility and freedom for the individual, the text will lament their obvious limitations. The automobile, so amazing in the 20th Century compared to the horse and buggy of the 19th, is so pathetic in the 21st when fettered by urban roadway and then compared to advances which other machines have brought in the 21st. The automobile-based society is rightly accused of promoting urban sprawl, and of being incapable of supporting dense, livable urban communities. Freeways, consuming space and destroying neighborhoods, are clearly incompatible with a compact metropolitan landscape. Yet, worldwide, the automobile is on a path to quadruple in number by 2050.

Surface streets and highways are categorized as 1st generation roadway largely built with modern techniques from 1900 to 1950. Freeways built with controlled access and interchanges to replace intersections are categorized as 2nd generation and were largely built between 1950 to 2000. While these roadways continue to be built in areas into which cities and suburbs continue to expand, virtually no new construction continues in existing cities. The era in which they symbolized progress is over.

Proposed is a 3rd generation of roadway for existing cities and suburbs; superimposed upon existing infrastructure, and using existing right-of-way. Small structures, supporting vehicles weighing only four times that of a human being, replace the huge elevated structures of the 2nd generation, built for vehicles weighing 400 times their most common user, the average human. Full, high capacity interchanges, also tiny in size by comparison to those of the 2nd generation, are to be built above the footprint of ordinary street intersections, and thus allow ubiquitous penetration of the urban interior. All traffic flows without interruption. Reliable computer networks, redundant sensors, electric motors, and speed-of-light communications assume control from human drivers—those marvelously adaptive and versatile creatures also exhibiting variable, error prone behavior, with wandering attention and reaction times approaching a full second. The computer drives the new roadway; the individual drives the local streets.

As the 2nd generation freeway is additive to the 1st generation street, the proposed system coexists with the 1st and 2nd generation structures. But with electronically controlled spacings, uninterrupted traffic flow, and very short Cars, the 3rd Generation Roadway can move roughly 50 times the number of vehicles that a city street can when configured to fit on the small city street, and by a similar margin of 50, for a given width, compared to that of a freeway when configured for high speed. Door-to-door transit times will be roughly half that of today's typical surface street trip, or of a mixed surface street/freeway trip. Parking density for a 'public' garage will be 10 times today's, and allow convenient parking for all commuters to, say, New York's Manhattan Island. Nationally, replacing roughly a quarter of all surface travel, the new Roadway's control will save roughly seven thousand lives and half a million injuries a year. Compared to today's U.S. fleet average of 21 mpg, fuel economy for the "car" fleet will be approximately 200 mpg when slip-streaming at high speed within a "train" on the new Roadway, and approximately 100 mpg on city streets. Propulsion by an electrified Roadway will constitute a much desired distribution network, and empower electric vehicles with modest, inexpensive battery packs. The new Roadway motivates the driver to buy a small vehicle, and then isolates them both for protection.

Thus, the 3rd Generation Roadway will enable a car-based society to support larger cities with increased population densities and allow them to properly function with convenient transportation. Larger cities will be free to safely evolve without traffic congestion, with transportation for their very mobile citizens consuming only 2% of today's U.S. per-capita total energy budget. Fast, convenient transportation will allow citizens to truly incorporate large metropolitan areas as their neighborhood.

Presented is a vision. But only a vision. While sufficient detail is given to communicate this vision to the university academic, the transportation professional, the politician, the enthusiast, and to the average Joe stuck at

a traffic light, each will read the book differently. To the academic it is a proof of principle or notional design. To the urban planner it is an idea to be measured against various proposals for future urban scenes. The politician or sociologist may see a daunting challenge with potentially massive impact. But to a local or regional transportation department the detail is utterly, totally inadequate. More than a dream, less than a plan. Perhaps the average Joe should simply ask, "When?" and "How much?"

Formatted to engage the reader by illustrating societal impact, technical feasibility, and overall affordability, the proposed approach, although buttressed here with sound logic, will need further critique and study. The writing's tone is that of an observant citizen, a veteran of the wars; a citizen who can't do the politics, but can do the math. It is half commentary on a society wrestling with a difficult problem, half focused on first principles like a poor man's Feynman physics lecture. Intended as an easy read, at least for the numerically literate—better yet for the numerically facile and empathetic—the writing guides the reader to see what the numbers mean, feel the driver's plight, hear the din of the ensuing traffic jam, and then, to understand the changes the 3rd Generation Roadway would bring. It is neither an engineering text nor a scholar's book, but comes without footnotes, generates simple models, and attempts to engender critical thought using traceable calculations derived from easily verifiable data.

Harbor no doubts, the approach is futuristic. In evaluating impact on individuals, communities, and nations, many technologies and operational approaches are assumed at full flower. Paradigms need disruption. And paradigms do not fall easily. But the book details elementary examples of the necessary components and highlights a number of maturing technologies now emerging in use. How such a system would be operated is clearly outlined. Thus all but the most cynical of readers will find plausibility—and wonder, "Why not?"

The dream is not new. Many mull similar thoughts. But though many a bored fourth grader, staring at the map on the schoolroom wall, cleverly concluded Africa and South America must once have been a single land mass, success for the Theory of Continental Drift came only with an understanding of its fundamental mechanisms, its profound effects, and the ability to see it happening today on the ocean's floor. So too for the 3rd Generation Roadway. The trick is to understand its potential, to engineer it, make it real, to make it happen.

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U.S. TRANSPORTATION STATISTICS AND THE MODELS TO BE USED HERE

Many U.S. national traffic statistics and several models generated in this book will be used to compare the performance of 1st, 2nd, and 3rd generation roadways. This is a good time to summarize the more important. Numbers will be rounded for simplicity but they roughly equal published Bureau of Transportation Statistics (BTS) values, National Household Traffic Survey results conducted by the BTS, and U.S. Census data. The models likewise will use round numbers.

To good approximation, we are a nation of 300 million citizens, 250 million automobiles, and 200 million licensed drivers, each of whom drives 14,000 miles/year. Adding in a smidgen of truck travel (a smidgen like 200 billion miles per year!) and smaller smidgens for buses, motorcycles and the like, sums to vehicles traveling 3 trillion miles/year on U.S. roadway. People driving to work are almost always alone (0.14 passengers). But most people driving for personal reasons—shopping, school, visits, church, dining, recreation, i.e. life—often have someone with them (0.8 passengers). Thus the average car is occupied by 1.65 people, and on average each of our 300 million citizens travels on the road just over 15,000 miles/year. On average every soul takes 4 trips/day and thus the average trip must be 10.6 miles, so as to add to 15,000. Forty-two miles each, every day! In large metropolitan areas average speed is 29 mph.

This book will model the average metropolitan driver as one who travels on 1st generation surface streets for 3 trips/day on somewhat shorter trips, 6 miles each, at what becomes slightly fewer than 7,000 miles a year, spending 365 hours/year to do so by enduring a miserable 18 mph average speed. Almost once per day the metro driver will hop on the city legs of a 2nd generation freeway to take a longer trip, travel 5,000 miles/year, and, averaging 50 mph in heavy traffic, spend 100 hours/year to do so. Finally, once in a blue moon the average metro driver will take a long country trip at a full 60 mph for 2,000 miles/year, spending 33 hours more. Adding the three types of modeled travel, the licensed metro driver navigates 14,000 miles/year, spends 500 hours or roughly

10 hours/week to do so, and averages a somewhat better, but still miserable, modeled 28 mph. It's good that drivers only spend 100 of their 500 hours on the freeway, since we'll soon learn freeway networks barely have capacity for that. But given that freeways are indeed usually jammed at full capacity, please take this as evidence that drivers do indeed spend those 100 hours!

The initial goal for the 3rd Generation Roadway is to double today's average metropolitan speeds. Thus, local average speeds are to be doubled from 18 mph to 36 mph and freeway averages of 50 mph doubled to 100 mph. Allowing small Rail Cars to cruise at 40 mph above city streets, slowing occasionally to 25 mph at interchanges, will produce quiet operation, amazingly small interchanges, relatively relaxed Rail requirements, and meet the goal of 36 mph. One hundred (100) mph is a speed obtainable by small vehicles with very small engines shielded from head winds in a train's configuration.

Although the U.S. Census Bureau lists roughly 80% of Americans as living in urban areas and 60% in metropolitan areas of over 200,000, the book assumes the 3rd Generation Roadway will be built to service metropolitan areas with the most pronounced problems, modeled as those areas with exactly 50% of the driving population. Thus 100 million drivers will have access to 3rd Generation Roadway for 12,000 miles of their travel. Seventy-five (75) million of them will buy a Rail Car and use it for 10,000 miles, needing the seating capacity or trunk space of an automobile for the other 2,000 miles. Thus 750 billion miles/year will be traveled by Rail Car, or roughly ¼ of the total national highway miles will occur on the Rails. As noted in the chapter on cost, it is assumed that half of all Rail Car buyers will save money selling one of their automobiles, and that Cars will last 12 years, the Roadway 30.

Obviously, Roadway alignments will be determined at a local level, with some smaller towns getting Roadway and some larger cities not. Grid density for the Roadway might vary substantially from that which is modeled. But the model establishes a baseline, from which decisions can be made and discussions can be conducted.

1 AN INTRODUCTION

What's wrong with what we've got? Whenever one contemplates efforts to develop something new, it's worthwhile to look at the problems presented by that which is. What has failed? What would one want to improve? Obviously, it is also prudent to remember the merits of what already exists. To these ends, this introductory chapter will focus on society's current use of technology to transport people — not freight, or people lugging around substantial stuff — but people.

In addition when developing something new it is obviously useful to look at what others are doing. Thus the introduction will also examine present efforts in developing novel types of road and transport. Novel roadway is only part of this latter discussion, and in later chapters entitled, "The Rail Car" and "Automated Traffic Control" complementary developments by today's automobile industry will come into play. The novel Car and the novel Roadway are to work together.

The second chapter will examine, in largely numerical terms, the principal features that constrain our streets and freeways. Why do they induce such low average speeds? Why do our roadways have such low vehicular capacity? The historical ability of our streets to function well in smaller towns and with fewer vehicles will be made clear. Their present failure could have been predicted. Looking forward with concern, the continuing growth of cities and the increasing number of vehicles in use is also evident. Where will we be in year 2050?

But most of the book's discussion will argue the merits of a very different transportation system, complete with a description of its features, design parameters and resultant capabilities. Charts and street data will make the comparisons with today's existing modes of transportation. Drawings will illustrate possible constructions of the system's elements. In some ways the 3rd Generation Roadway system is a hybrid, an evolution if you will, of several of today's modes of transportation and attempts to capture the best features of each. Hybrid though it may be, the 3rd Generation Roadway will be found to possess key performance values for speed of transit, vehicular capacity, and safety — that are far superior. Values that are game changers.

This book's discussion will start by reflecting upon how far from ideal our urban transportation systems have become. It will illustrate why our leading modes of transportation are hopelessly doomed to failure seen in contrast to the continuous and dramatic gains we have grown to expect from the fruits of our other modern technologies. It will note that urban transportation improves, if at all, at an agonizingly slow pace. Meanwhile, an expanding world is continuing to embrace the automobile, spreading a less than acceptable technology. In what ways does the automobile fail? Why, then, is it the dominant choice?

Transport of people within the world's many greater metropolitan areas, urban transport if you will, fails for many reasons. Automobile transportation networks have difficulty dealing with the large number of people who want transport. Seen by an individual, transport is slow. It is dangerous. It is expensive. Presented with "public" transportation, the individual sees inconvenience. One must make accommodations in routing, in scheduling, and in toting baggage or briefcase. And, too, public transportation is slow, typically even slower than the automobile with urban constraints.

Given today's approaches, providers of transportation find it difficult to make improvements. They find it difficult to obtain right-of-way. They find existing infrastructure inhibiting. Our approaches destroy pre-existing infrastructure, and destroy or divide complete neighborhoods. Providers thus find existing communities resistant. Adding layers to existing cities is not easy, and with all of a city's constraints, providers find it expensive.

At the same time we are attempting to transport massive numbers of people. We are attempting to satisfy users with individualistic, diverse, and sometimes conflicting requirements. And so it is not surprising that when minimal improvements can be implemented, they fail in terms of passenger capacity, average speed of transit, convenience, cost, or cargo capacity. This introduction will examine how each of today's modes intrinsically fails in one or more of these qualities desired. Included modes are surface streets, freeways, buses, light rail, subways, and futuristic modes of each.

Systems we have today are either weak in catering to the needs of individuals who need transport from their present location to another of their choosing, at the time of their choosing, or weak in catering to the massive number who wish for transport. Not one of today's modes of transportation can do both. Public lines are not near me, nor go exactly where I want, when I want. Automobile roads are too congested when traffic is heavy.

And both are slow, slow, slow. I want to go from point A to point B, and I want to go now. Quickly.

Stated in quasi-mathematical terms, each system is intrinsically weak in what could be called personal vectoring—individual journeys going from point A to B at a time each individual chooses, despite the fact that each individual path from A to B will cross many other paths given a two dimensional infrastructure. Public transport doesn't go to my A and B. Or there's too much stop-and-go on the streets.

In contrast, the 3rd Generation Roadway can take an individual from A to B with the same convenience as today's automobile when operating in light traffic, and without ever meeting an intersection. Additionally, when compared to today's roadway, it can do so with superior safety, fuel economy, and speed. At the same time, the new Roadway has a staggering capacity to transport large numbers of people. Unlike any of today's modes of transportation, the 3rd Generation Roadway can do both: cater to the individual, and operate efficiently with massive numbers of users.

WHERE WE ARE TODAY

Step back for a moment. Way back. Imagine for a moment that you are from the planet Mars. Or maybe a time traveler. Or just a young guy living in the far north woods, land of the long snowy winter. Your summer sport is paddling an old white birch bark canoe, made with a centuries old design. You love the feeling of smoothly cruising on open water, the oldest highway known to man. Slow, but steady, dependable, and relaxing. You know little of the urban world to the south.

You have an offer. An offer from a visiting friend to see the world and experience firsthand the wonders of civilization and its technology. Come critique what mankind has achieved. See what you think! You accept.

You fly away at 600 mph. Like the canoe in the water the plane in the air cruises at the speed for which it was designed. Ah, the wonders inside! Air—modified and conditioned. Plastic—from which everything is molded in quantity with incredible efficiency. Light—from LEDs, from fluorescing gaseous ions, and halogen encased incandescent wires. Light—on flat glass from a million spots looks—alive! Football! Facebook! Google!—type "CANOE", and twenty million printed articles appear in 0.26 seconds.

Now you look outside. You see buildings one hundred times taller than yours. Container ships carrying 50,000 tons. Giant dams holding water for all to use. Millions of mansion-like homes! Machines are everywhere down there. Looms, laser cutters, and sewing machines make garments in a wink of an eye. Robots weld steel with articulation, uniformity, and speed to amaze. Information is transmitted around the world in fractions of a second. In Woodbridge, one building owned by Robert Mondavi has machinery to fill and cork a million bottles of wine in a day. In Fairfield, Jelly Bellies are made by the tens of millions.

An electronic book tells you civilization has adopted a philosophy based on rational thought. That man has gone to the moon with engines of unimaginable power and landed with engines of unimaginable finesse. Your wonder grows when you read that the earth has a crust; it moves and erodes; and that all plants and animals have evolved. That each atom of entire live animals can be mapped one at a time. That parts of each atom, mobile electrons, can be harnessed and their power controlled. That all the stars visible are suns like ours, and these are but one cluster of suns among billions of such clusters. And all of this was once smaller than a fly speck …

You land.

Your friend shows you a 20 lb. machine with two wheels from the luggage rack. You see how it can roll at 20 mph—twice as fast as your canoe—both propelled by a man with 1/3 the power that a horse is said to have. He shows you a machine with four wheels. Under the front compartment he says there is a small box with the power of 600 men or 200 horses. This machine can go 136 mph. An instrument in its plush passengers' cabin makes maps and shows where you will go next.

Your friend lives 30 miles across Los Angeles. Excited to be in his new machine, you bet him the trip will take 14 minutes. Hey, cruising at 136 mph, 30 miles will take less than 14 minutes. You murmur, “I wanna see what this baby can do.” The engine purrs!

You start. Another type of light. This one shining red and hanging over a very broad street. All the four-wheeled machines stop in front of this light. A second light, this one shaped like an arrow, turns green, but the one apparently assigned to you stays red. Cars move across your path. Cars beep angrily. Your friend drives past six buildings, another light, many cars, many different sets of cars move before your light turns green. The two-wheeled machines pass.

Finally, your 4-wheeler reaches what your friend calls a freeway. It is huge! The people on it, for which it was built, are so tiny by comparison, and so sparsely scattered. Not at all like the sardines in the airplane. Your friend says it cost $40,000 per foot to build—your father once offered to sell his village for $40,000! Traffic slows. Traffic stops. You sit behind the next 4-wheeler. It moves. So you move. It stops. You stop. For a moment, the road clears, the car accelerates, and the beauty of his machine is marvelously demonstrated. Wow! You gotta love it. You get off the freeway. More lights, more waiting.

At last, you reach his house. A meter under his steering handle reads that you have averaged 28 mph on your journey. One hour and 5 minutes for 30 miles. Only somewhat faster than your bark skinned canoe! Two hundred horses and only slightly faster than achieved with the 1/3 horse you can provide. How can this be?!

Your friend sighs and says, “Some time back at a conference, the Silicon Valley guys laughed at the Detroit guys for the product they made. But the Bay Aryans had it wrong. To crudely paraphrase political consultant James Carville, ‘It’s not the car, stupid; it’s the road’. And somewhat more forgivable, not the car but the driver, hesitant to move quickly in such close quarters.” In shock, you grunt, “I’ve never seen so many try to go down one path”. Yes, the technology on which we have spent upwards 20% of the GDP, all things included, now moves us around, on average, at 20-something miles per hour.

They say that those who experience the long winters in the north woods have a 100 words for snow. Words for snow—both good and bad. Compare your vocabulary for traffic, and listen to your own visceral reaction to the words:

stop-and-go	**nasty**	**bumper-to-bumper**
a parking lot	**terrible**	**crazy**
grid locked	**slowed**	**hectic**
fast	**slow**	**congested**
heavy	**light**	**flowing**
easy	**raging**	**clogged**

I’m stuck in traffic.
The lights were just terrible!
Let’s not go during rush hour.
I’ll go in early.
Let me telecommute.
I’ll go in late.

Can you believe it took me an hour?
Why don’t they build another lane?
I couldn’t find a place to park!

And listen to your impression of other drivers. How variable they are.

That guy cut me off!
She’s on a cell phone!
Cut right in front of me.
Look at that guy weaving.
He must be drunk.

Passing on the right!
He’s going too fast.
They must be doing 90!
Changed four lanes in one swoop.

Look out where you’re going!
Texting while driving #@§æ!
Use your blinker, buddy!

He must be asleep at the wheel.

Changed lanes without looking.
They’re playing tag on the freeway!
Slow, old fogie.
Get that boat off the road.

Look at that monster pickup with attitude.
Why do Range Rovers drive like they own the road?
Road rage!

Let's ignore the emotion. Please examine the problem in terms of three quantities highly valued by all of us. Each has received greatly increased attention in the last century: our time, our safety, and our planet. Each can be translated to a fourth quantity: money.

OUR TIME

The average American is busy. He or she works roughly 40 hours a week, sleeps 56, plays 32, and spends the remaining 42 supporting the first three habits. Those 42 include eating, cooking, dressing, cleaning, changing diapers, repairing the home, shopping … and driving. And driving takes 10.

Time is money. Arguably the average American driver earns $45,000 per year. Yes, this value is one's piece of the Gross Domestic Product (GDP) pie; although a share of the nation's Personal Income is only $40,000, and one's take home pay even less. But arguably a typical driver earns more—remember children, the retired, and the off network folk neither earn nor drive as much. What's more, we won't be counting the value of any passenger's time, so we'll stick with $45,000 a year. Remember the average driver is busy full time and depends on those 40 hours of work; that is to say his or her time in traffic is worth the same as in the office—$24/hr. Thus those 10 hours are worth $240 per week, $12,500 a year. At this rate the nation spends $2.5 trillion in lost time on the road. $2.5 trillion that's not in anyone's budget. $2.5 trillion that's just part of life.

As much as gasoline costs, as much as gasoline upsets our national trade balance, at $4 a gallon it is still cheaper than our time. At $4 a gallon and 24 mpg, a vehicle going 60 mph is burning $10 an hour.

Only in a taxi, with meter running, is proper accounting practiced in the cost of driving. Yes, the cabbie's meter allocates for profit, the dispatcher in the office, and the sturdy old sedan, but the principal cost is that for a man working to eke out a living. Next time you're clutching a twenty watching that meter tick away, sneak a peek at the proximate drivers, amateur cabbies all. Imagine 12 million of your meters ticking away, 24/7. And yes, on a 24-hour average, that's the number of drivers on American roads at all times. On a 40-hour-a-week basis, that's a 50 million employee workforce—whose salary is not an expense to be ignored.

And what are we getting for your time? 18 miles for an hour, in most of your driving. That's an optimistic number for urban/suburban surface

street traffic. Yes, when you get on a freeway—and time your trip so as not to get in a traffic jam—things are better. But if you live in a big metropolitan area, even with all those freeways and your occasional rural vacation, overall you'll get 29 miles for your hour of time.

Don't believe these average speeds for your driving? Try it! Remember, when you sit at a traffic light, you're going zero. And if it takes 6 minutes on your slow mile to get to a fast mile at 60 mph, you've averaged 17 mph. If you drive 60 down a highway but have to start and then stop at the ends of a several mile stretch, you haven't averaged 60. Now if you're lucky enough to drive a late-model luxury car, it will more than likely have recorded the car's average speed since delivery. It does so by simply dividing the odometer reading by the number of hours the engine has been running—displayed right there on the console. Such an incredibly slow average speed for a vehicle capable of so much more.

The 3rd Generation Roadway proposed in this book will increase local traffic speeds by at least a factor of two—to about 36 mph. And increase cross town lines to speeds of 80 to 100 mph. The change will save the average driver 240 hours a year and an equivalent of $5,800 in effort. Without costing in the gas, if all drivers took advantage of this faster transport, nationally $1.16 trillion of equivalent effort would be saved. Some 8% of the GDP.

OUR SAFETY

The State of Montana records almost one traffic fatality a day, about 22 a month. Traffic in Montana is to a good approximation rural. Locals fall asleep and drift off the road in the summer. Tourists slide off the icy roads in the winter. Untimely death has become, while not accepted, a part of life. "Poor Johnny, hit a deer up on the old road, didn't see it coming." "Those kids, been dragging every Friday night, ran an intersection." "I told Frank he'd been drinking too much." 22 a month, 260 a year, if one lives 80 years that's 20,800, in a state of 950,000. That's 1 in 45.

To a good approximation, the traffic in Los Angeles County is urban. Locals fall asleep and drift off the road. Tourists freak out. "Poor Johnny, hit a muffler in the fast lane, spun out, and the semi behind him took out six cars." "Those kids, been dragging every Friday night, jumped a curb and killed eight pedestrians." And Frank drinks here, too. The County of Los Angeles records two traffic fatalities a day. About 760 fatalities a year are recorded in a population of 10,000,000. One in 164 for your lifetime. Much better, yes, and better than the national average of 1 in 87.

> The National Highway Safety Administration lists highway fatalities by both location and cause. While huge differences result from very different driving conditions—with 10 times the population in effectively 1% of the area, L.A.'s population density is 1,000 times that of the State of Montana—many statistical similarities persist. In both Montana and L.A. 36% of fatalities involve speeding. In both areas about 10% die after being hit by a big truck. Surprisingly, fatalities involving single vehicle crashes are similar (65% Montana vs. 57% L.A.). DUI fatalities are somewhat higher in Montana (40%, 28%). The most shocking difference between the two areas is the overall ratio of death—3.6 times higher in Montana. Montanans suffer far more from accidents the NHTSA somewhat sweetly states as involving "roadway departure" (65%, 34%), and rollovers (65%, 17%). Angelenos suffer far higher relative rates of pedestrian fatalities (5%, 26%) and fully 30% of fatalities involve intersections (13%, 30%). The intersection may be the most dangerous place in L.A.

For every 100,000 Americans born, the automobile takes 1,170. Nationally, that's 42,000 a year. Between the ages of one and 35 the car accounts for 4% of all deaths. The automobile is the most common cause of death between the ages of one and 39. Cars are responsible for more death than falls, suicides, homicides, firearms, and poisoning combined.

More shockingly, since the automobile was invented, for the US, you can add war to that list and still be correct! And the car's time includes WWI, WWII, the Korean war, the Vietnam war, and two Iraqi wars. If you like war as a metric, Iraq, wracked by sectarian violence, an insurgency, suicide bombers and IEDs, all witnessed by a horrified world, in just under five violent years after the U.S. invasion, suffered 85,694 Iraqi civilians, military and police killed (one does have to believe the Iraqi Human Rights Ministry data as reported by the AP and the WSJ). That horrific bloodshed is only 4½ times our death rate driving to the grocery store.

Since the 1920s roughly 40,000 Americans per year have died in an automobile. Given the huge increase in total yearly distance traveled, roughly a factor of 50, a level yearly death rate actually speaks volumes for the safety

efforts of road engineer, automobile industry, and driver alike. Only during World War II did deaths dip to 20,000, and in the 1970s increase to about 55,000. Ironically, the collateral benefit of rationing gasoline saved fully half as many lives as were lost in defeating Japan. In 2009, with jobs scarce and total driving down, the death rate also dropped to about 34,000.

But in the U.S. we spend an estimated $3 billion per year to equip cars with air bags and reduce the carnage by 5%. The performance of automobile safety devices is measured in the percentage reduction of anticipated death rate. Where else would you accept a safety device that achieved its goal one of two times (the three point harness)? Or one out of five (The air bag and two point harness)? ABS brakes don't seem to help at all. The GFI in your bathroom, the rock climber's 9 mm dynamic nylon rope, those are safety devices! They almost always save your life.

Again, for every 100,000 births, the two biggest killers in the U.S. are cancer which takes 14,700, and heart disease which takes 17,300. (The annual death toll among 300 million Americans is 42,000, 560,000 and 660,000 for the three causes.) But the automobile killing machine that takes one in 45 in Montana and one in 87 in the U.S. is more likely to kill the young. Until you reach the age of forty the automobile is more likely to kill you than cancer or your heart. Not to minimize the awful effect of cancer and heart disease—the two most common causes of death by far—but cancer and heart disease most commonly affect the elderly. When they take a life, they take fewer years. This book will certainly not dare to compare the value of a year of life at 16 versus a year at 75—it assumes the same—but a life taken at 16 has certainly lost more. Using Actuarial Society data, Table 1–1 lists the frequency of death versus age for these three causes for the United States as a whole.

	1-4	5-14	15-25	23-35	35-45	45-55	55-65	65-75	75-85	84+
vehicle	4	4	26	18	15	15	14	16	24.5	26
heart	5	0.6	2.5	10	29	111	219	541	1506	4896
cancer	2.5	2.5	4.1	9.1	33.4	119	333	755	1280	1652
% still living	99.2	99.1	98.7	97.8	96.5	94	88	76	54	38
life expectancy	76	68.5	60	49	40	31	22.5	15	9	6

TABLE 1–1 The Automobile as Killing Machine displays the frequency of death for three major causes vs the age of the victim. Numbers are in Deaths per Year per 100,000 Births vs Age and Cause taken from US Actuarial society data.

People are not good at assessing risk, mortal risk anyway. We fear the spectacular, the scary, the razor blade in the Halloween apple, the subway terrorist with a bottle of anthrax, and, gasp, black mold. We fear, and the press reports, what others might do to us—the government conspiracy, the alien spaceship, the Mayan calendar—rather than what we might do to ourselves. So we fear the e. coli that might be ground into our hamburger, and by law eat it literally cooked to death in tasteless, overcooked, fast food burgers, when we're far more likely to die by choking ourselves to death on a steak eaten with a glass of wine. (About 60 in this country die of e. coli poisoning every year. About 2,500 die with a "cafe coronary," that is, choking on food. 90% of those choke on steak usually facilitated with alcohol or bad teeth, although President George W. Bush almost managed it with a pretzel in 2002.) The fear is expressed in our legal system. Witness product liability law. Thus the 2010 congressional uproar that Mr. Toyoda's product defects probably killed 20 to 50 people. Never notice that 20 to 50 thousand killed themselves driving Toyotas during the same period.

With the common, boring risk we grow blasé. "I do it all the time, and I haven't died yet." A 10-year review of search and rescue data in Yosemite National Park compiled fatality statistics within Park boundaries. Three major categories were: rock climbing—those spectacularly frightening acts of hanging by chalked finger tips and chicken wings thousands of feet above the valley floor; walking in the woods; and cruising open roads in the park with a 35 mph speed limit. Respectively, the numbers are 29, 36, and 19. And, of course, "I drive all the time." Little wonder Allstate, the auto insurance company, runs an ad headlined, "If 12 fully loaded jumbo jets crashed every year, something would be done about it. Every year, more than 4,000 teens die in car crashes." (Please note that new state laws have recently reduced teen deaths.)

As much as safety has improved, consider this: vehicles are still controlled with the same mechanisms the inventors used for their initial guidance, a wheel and several pedals. The very name, automobile, means an autonomous mobile machine. What an incredibly scary concept! Do you think your liability lawyers would let such a scheme get off the ground today? As at the time of its invention, the automobile is still driven by a human being, a marvelously adaptive creature, but one who exhibits huge variance—from moment to moment and from specimen to specimen. Where else can we be thoughtless for a moment and suffer "roadway departure"? And all human beings exhibit reaction times, intrinsic to a biological

thinking process, on the order of the better part of a full second. The driver, who has passed two 20 minute tests down at the DMV, is expected to handle how many dangerous situations?! Do you think Karl Benz really would let his daughter, Mercedes, drive down today's freeways?

In a cold calculus, the Federal Highway Administration assigns a value, a negative value that is, to each death. And a value to each of the 2.3 million automobile injuries per year in this country. Extrapolating older values it's roughly $5 million per death, and very roughly, depending on the average severity, $50,000 per injury. Totaled, that's $320 billion per year. Two percent of the GDP. Oddly, since the auto insurance biz on average collects $825 a year from you and all the other 200 million drivers in this country, their gross direct premiums in 2008 were only $165 billion. I guess dead men don't collect.

OUR PLANET

Your Footprint. Your Carbon Footprint. Such a 21st century usage for an old word. What effect do you personally have on the planet just by being here? Or more precisely, by being here, AND living the way you were taught to live and want to live. Let's just look at your carbon footprint and let the rest lie, shall we?

A group in Basel, Switzerland is named for what it promotes: The 2,000 W Society. Members propose that any responsible citizen of the world live, and live comfortably, by using no more than 2,000 W as a continuous average (Stated in other words, that's 48 kWhr per day). The Society lists U.S. consumption at 12,000 W, as smoothly reported in *The New Yorker*. Lawrence Livermore National Lab studies, funded by the Department of Energy, conclude the average American uses 11,000 W. That usage is derived by knowing this country consumes energy at a rate of a little over 1×10^{20} J/year. An amount that is about 20% of the world's total consumption. Of America's use, about 33% is Industrial, 17% Commercial, 21% Residential, and 28% is for Transportation. Of that for Transportation, 70% is for automobiles, 13% for trucks, and 12% is for aviation. Thus 20% of our total energy usage is for automobiles. (Although on a subject beyond the scope of this writing, the reader should note, within the categories of Industrial, Commercial, and Residential, a huge 40% of our overall consumption is for lighting and climate control within our buildings.)

Every Joule of energy, only a single Watt for a single second, produced by burning gasoline in our oxygen-rich atmosphere, creates a 4 mm bubble of CO_2. Every tablespoon of gas burned fills a 12-inch balloon. Every mile in a Honda 8 balloons. The IMF predicts 2.6 billion cars worldwide in 2050. At 10,000 miles/year each, can we predict 26 trillion miles driven? 200 trillion balloons? The earth still clings to a volume of air effectively only 5 miles thick over its surface area of 200 million square miles. A volume only a million times greater than all those balloons. Thus 26 trillion miles of automobile travel translates to 1 ppm of atmospheric CO_2 in a year. Translates to 100 ppm of CO_2 in a century. And climatologists can translate 100 ppm of CO_2 to some level of catastrophe.

Since this book promotes replacing a good deal of your usage of a car with a far more efficient vehicle, let's explore further. Instead of the 14,000 miles a year you now travel at the U.S. fleet average of 22 miles per gallon, and assuming a fully implemented 3rd Generation Roadway in your neighborhood, you will travel the new Roadway for 10,000 of those miles using about a gallon for every 200 miles traveled. Instead of 450 gallons for those 10,000 miles you would use 50, thus saving 400 gallons—more than half of what you normally would have used for all your travel. If half of all drivers do the same, the nation saves 40 billion gallons and roughly $80 billion in the trade balance. And you save a thousand or two!

Every one of your 400 gallons has saved 21 pounds of CO_2 from entering the atmosphere. Over the year your waste CO_2 is down 4 tons! With the one change toward using an energy efficient Rail Car you have reduced your 11,000 W to 9,300 W—one small step for mankind! If you still feel guilty while riding the Rails, realize that rather than using 20% of your energy needs as with an automobile, travel is now only 2%.

The world of mankind presently struggles to translate all this to a value in money. What's the price of a CO_2 credit? Where do we set the cap which will determine market value? What price our present climate? What price a runaway atmosphere? Suddenly a global discussion replaces those local debates for clean air, an endangered species, a lost landscape.

But … enough. Soon, in the next chapter, "The Intersection as Villain", we will discuss why our difficulties are intrinsic, why we should expect traffic to be slow, congested and dangerous. And why over time we should expect traffic to get worse. But first, here in the introduction, we should now briefly recall roadway's history, and recount in some detail research efforts ongoing today to improve our lot. Research efforts which are both complementary and precursors to the proposal to come within this book.

A BRIEF HISTORY OF ROADWAY

Most animals, enjoying what plants cannot, make and use paths to ease their travels and find their homes. Ever since mankind invented the wheel, smoothing the path has had positive benefits. The discovery of two wheels and an axle, which provides stability and eases the burden of pulling a heavy load, made widening the path to a road a priority. Much later, the rutted and muddy dirt roads of early civilizations yielded to the marvelous stone roadways of the Imperial Romans. The Appian Way is famous for a reason.

The mid-19th Century reinvention of high-quality concrete, a recipe lost for 1,400 years, and the first use of asphaltic petroleum as heavy tar to embed small stones changed the road. Spread on a thick bed of compacted, broken rock, these new materials brought maturity to the street and highway, the 1st generation of roadway.

In the mid-20th Century the advent of more and much faster vehicles brought about many needs. Seeking to save lives and streamline traffic flow, designers controlled access to the road, set rules to qualify vehicles, divided the highway, and standardized designs. Architects conceived amazing multi-level structures such that traffic never crossed paths. So distinctive were these new roadways that new terms—think Turnpike, Freeway, Expressway—were coined to identify this new and 2nd generation of roadway.

Oddly in many senses, but clearly by necessity, the architects of the new roadways, having configured so much to aid the driver, also continued to allow all sizes of vehicles on the roadway and designed the structure to accommodate the largest. The smallest human was still mixed with the largest semi-trailer truck. And the structure's scale and strength grew to be appropriate for the Peterbilt's size and weight. See Figure 1-1.

With no hope or even concept of using today's sensors, computers, and many other technologies, the architects left the driver in full control of the vehicle, using a wheel and several floor pedals as designed by the original inventors. Not surprisingly, drivers continued to possess the same reaction times and demand the same spacing between vehicles.

Today, in the 21st Century, this 2nd generation of roadway fails to carry the immense traffic flows imposed by ever more numerous individual travelers, and the driver's task is now complicated by the guy in front of him. The roadway's immense appetite for real estate makes it nearly impossible to build in previously developed areas. Fortunes are spent to add a mile.

FIGURE 1-1. A truck out on the highway.

No one alive today was born before the age of the automobile. No one has lived the ideal of the narrow cobblestone street as the active model for the urban world. Not the broad six lane street with the mini-mall behind its parking lot, but the narrow human scale walkway swarmed by pedestrians between shops and houses. Gone is the model used by cities for thousands of years, a relic appealing to tourists as quaint, enjoyable, and yes, livable if transportation were only possible. Only an impossible dream for giant metropolitan populations.

SOME PLANS FOR TOMORROW

THE INTELLIGENT HIGHWAY

If cars could tailgate, each snuggled up behind the next, couldn't we increase freeway and city street capacity? And if cars could be guided down the road, virtually but securely attached to the center of their lane, and a computer assigned to avoid collisions, couldn't we improve safety? The answer is yes. As proposed, the concept of the so called Intelligent Highway promises to achieve both. Below, let's discuss some of the required technology and how highway capacity and automobile safety can be improved.

The next generation of cruise control automates the act of following another car. The idea is to have a technology to automatically adjust your vehicle's speed so as to maintain an appropriate distance behind the vehicle ahead. Appropriate, that is, for the lightning fast responses of the electronics employed. Following a vehicle by a mere 0.1 seconds may be appropriate for electronics, while 1.5 seconds is the rule for the average driver. The electronics use various sensors to detect obstacles ahead, determine the obstacle's distance, determine how fast that distance is changing, and then change your vehicle's speed as needed. For safety purposes, several automobile manufacturers are aggressively developing similar technology. Volvo calls its system "city safe". Daimler-Benz engineers use the term,"virtual safety cage". As the potential for an accident approaches, if you don't apply the brakes, the machine will.

A series of elements embedded in the roadway can define a path. The car's task is to follow the path. Thus the highway keeps the car on the road and keeps the car centered in its lane. One goal of the Intelligent Highway is to tell the "intelligent" car exactly where to be. GPS systems can provide redundant information and be used to improve reliability. Likewise the highway's embedded elements can potentially augment cruise control technology by telling your car when the previous vehicle passed. Several readings will determine whether your car is gaining on that previous vehicle.

Automatic parallel parking is an amazing act to watch. Its technological cousin, a system to warn drivers about to change lanes, is also in active development. Today, a little light in your side-view mirror or other warning signal gives you a heads-up. GM, for one, wants to combine this warning system with its adaptive cruise control to automate lane changes. If there's an opening, and if no other vehicle is rapidly closing into it, your auto can hop lanes. GM says all this will be ready by 2015. Not only will this technology help you from smacking another car in the next lane, but it will warn drivers about to veer off the road.

Taken together the trio of approaches above offers an exciting scenario. Platooned vehicles will move as efficient small trains using robust adaptive cruise control. Vehicles will move like slot cars virtually captivated by the markers at lane center. Vehicles will switch lanes, and do so swiftly while remaining in tight formation as dictated by advanced algorithms. Lane change control, adapted from automated parallel parking and lane change warning technology, will switch vehicles from lane to lane to smooth traffic flow and allow traffic to merge and exit. Thus, platooned vehicles in massive numbers will greatly increase highway capacity. The Intelligent Highway has assumed control from the driver.

This is a good time to introduce the concept of headway. Headway is a term used by transportation experts to denote the time it takes a single vehicle to cross a line behind the preceding car. That is, how long after a vehicle crosses an imaginary line will it be before the next crosses that line. The more quickly vehicles can pass a gate, the more that can get through. This concept will be central to much of this book's discussion of congestion, a highway's capacity for numerous vehicles, and the upper limit of a livable population density supported by the automobile.

To foreshadow the book's arguments, headways for various scenarios differ by three orders of magnitude. Freight trains, commuter trains and airplanes during takeoff operate with over a full minute of headway. In similar fashion, low speed, prototype, computer-controlled Personal Rapid Transit (PRT) vehicles on prototype guideways under construction today leave headways of 2.5 seconds. All operate under the controlling paradigm that if the preceding vehicle hits the proverbial brick wall, the subsequent vehicle can safely brake to a stop. The airplane of course also waits for a turbulent wake to dissipate. And all of course proceed with the knowledge that the limited number of vehicles involved allows successful use of such a paradigm in practice.

Headways for automobiles vary from a high of 4 seconds when drivers follow others one-by-one through a single stop sign, to 3 seconds for cars flowing on a small city street, to 1.8 seconds for cars moving on an open highway. The paradigm here assumes that the trailing driver will immediately see brake lights but needs some time to react appropriately. Obviously, if the first driver hits the proverbial brick wall, this paradigm leads to ugly results. Drivers who tailgate or lag due to inattention change individual times, but well-behaved traffic flowing smoothly on a good roadway proceeds with times very close to these values.

Automobiles on intelligent highway test tracks have demonstrated headways of 0.28 seconds. That's the time associated with a line of 15-foot-long vehicles allowing 9 feet of clearance while going 60 mph. The 7-foot-long Rail Cars characterized in this book when coupled into solid trains at high speed, 140 feet/s (95 mph), will achieve 0.05 seconds. The paradigm here is that computer control will "instantly" achieve sufficiently identical performance from each vehicle for "completely" safe operation.

Operating under these very different assumptions, our various headways result in very different numbers of vehicles passing the imaginary gate. In the seven scenarios, the respective numbers of vehicles per hour passing the imaginary gate are: less than 60, 1,440, 900, 1,200, 2,000, 12,672, and 72,000. But we get ahead of ourselves.

The government has had a very active role developing the Intelligent Highway. In 1998 near San Diego, the U.S. Department of Transportation conducted key tests of the concept. Outfitting cars with a suite of experimental sensors including radar, lasers, and optical cameras, the test achieved control of a set of vehicles by commanding the brakes, the steering wheel, and the gas pedal, thereby wresting control from the now passive drivers. See the photograph of Figure 1-2. The NASCAR race-like formation is composed of cars with 9-foot separations going 60 mph. Each car's computer is controlling the minimum spacing.

FIGURE 1–2. An experiment in platooning with lateral control and 6 meters of headway between cars at 60 mph.

DARPA (the US-DOD Defense Advanced Research Projects Agency) has achieved a noteworthy milestone in autonomous vehicle control with its race-across-the-desert contest. To win $1 million in DARPA's Autonomous All-Terrain Vehicle Challenge, a vehicle needed to navigate off-road—in the dirt—from Barstow, California to Las Vegas, Nevada, a distance of 132 miles, without a human driver. The winner was Stanley, a VW Toureg modified by VW's Electronic Research Lab and Stanford University students. Stanford and Google, now working on a project using artificial intelligence and a suite of sensors, have several Prius automobiles equipped to autonomously prowl—with a human on standby—the streets of Palo Alto. The automobiles have driven thousands of miles recognizing and reacting to road conditions, stop signs, traffic lights, other cars, etc. with only occasional human intervention.

The FCC (the Federal Communications Commission) has allocated a frequency band centered at 5.9 GHz to allow cars to "talk" to each other. Presumably knowledge of all neighboring vehicle—their positions and velocity for example—will reduce accidents. Pedestrians and bicyclists can be added to the conversation. Such a system could provide redundant information defining allowable moves and speeds.

It should be noted that in the San Diego test, success was celebrated when the equipment performed as planned. Unfortunately, the drivers did not perform as planned. Drivers experienced severe discomfort as their command of the vehicle was relinquished. The human interface was deemed a failure. So realize you're not alone if you have trouble relinquishing your life's safety to a machine.

Do you tense as the airplane begins its runway takeoff, the automated subway or train slows to a stop, or the ski-gondola approaches the platform? You're not alone if you watched with concern the great 2010 recall of Toyota's "fly by wire" technology—an approach to replace purely mechanical controls operated by your hands and feet with electronic equivalents. After all, to err is human, to really screw up takes a computer. On the other hand, remember auto-pilots land the airplanes we all fly, traffic lights are trusted to be red for all paths except one, and even century-old Otis elevators stop at the right floor. You are safe; if the computerized system doesn't fail, you won't die. And do you really trust your own driving? Trust the cell phone user driving next to you? Or the harried Mom with kids screaming in the back seat? Or the DUI dude in the pickup, or the anger-challenged meth addict. Or the perfectly decent 16-year-old boy who's just been dumped by his first love 10 minutes ago?

But the human reaction to the loss of control is a warning to designers of the 3rd Generation Roadway. The 3rd Generation Roadway proposes control by automation. Rail Cars will tailgate and then slowly move up to touch and then couple bumpers—all at high speed—by using sensor range and range rate data, differential GPS, and coded markers embedded in the Rail. Rail Cars will turn corners as if on a roller coaster ride, the sequence initiated by computer instructions to a mechanical element. Now imagine Rail Cars coming in from a different line, about to merge onto your line, a thrill for all occupants. A computer will take communications between those lines, open a slot where needed between Cars, and properly time the entering vehicle(s). But do you trust it? Proposed for the 3rd Generation Roadway are rapid—maybe gut wrenching—sequences of maneuvers. The terror will be reduced only by the knowledge that the path is defined and simple. Like a tame roller coaster for an 8-year-old, exciting for an adult the first time, totally cool after that.

The Intelligent Highway can solve the capacity problem of our freeway system. The technology may well solve congestion on our surface streets. The Intelligent Highway can improve safety. But achieving these goals is clearly a difficult problem. It's difficult because the Intelligent Highway presupposes to control today's many different vehicle types—vehicles with very different handling characteristics. As well, today's roads present a wide variety of different scenarios, all of which must be considered. Perhaps worse, the Intelligent Highway solves only part of the problem. It does little to alleviate the burden and much of the delay imposed by the intersection. And we will see in the next chapter what a villain the intersection is. Nor will the Intelligent Highway, as it services many vehicle types both big and small, greatly reduce the massive size of freeway structures so destructive to urban neighborhoods.

The reader should take from this section a note that the Intelligent Highway develops many of the key elements needed for the 3rd Generation Roadway. Most importantly, development includes artificial intelligence, adaptive control of vehicle positions, redundant sensors, and "conversation" between vehicles. But the reader should note that the 3rd Generation Roadway, with a single vehicle type and a Rail providing well defined scenarios, has an easier control problem. It also promises a more complete solution. It promises small Roadway structures and easy right-of-way access. The Intelligent Highway does not. It can build small interchanges in the urban core to eliminate intersections. The Intelligent Highway cannot. The

3rd Generation Roadway greatly facilitates vehicle parking, the Intelligent Highway does not.

PERSONAL RAPID TRANSIT (PRT)

The concept closest to the 3rd Generation Roadway is one for which many who study and develop the idea use the term: “Personal Rapid Transit” or PRT. Personal Rapid Transit and Group Rapid Transit proposals have many variants but all include a vehicle and some guiding path that routes the vehicles and separates them from street traffic. The specialized vehicle is sometimes called a “podcar”. Podcars are public property, wait for customers, and are rented for personal use. Sorta-like a robotic taxi ready 24/7 when you are.

The rail or path is traditionally called a guideway, and thus many, including the U.S. Department of Transportation, refer to PRT as Automated Guideway Transit. Most guideways are elevated support structures which like a monorail support the vehicle from below or suspend the vehicle from a rail above. Guideways vary from line and looped systems to drawings of area wide urban systems. Most podcars simply use a tracking device to guide the driver-less vehicle down the center of a path like guideway.

PRT lines are presently conceived to service heavy-use facilities and connect them to other destinations. Think airports, train stations, ballparks connected with parking lots, or rental car locations. Think small, flexible paths to deliver passengers “the last mile” from the subway station to their office or to the shopping center. For example, London’s Heathrow airport has installed a PRT system, named for and built by ULTra, as a people mover between terminals and from the parking lots around the airport. The 3.8km, £25m system is said to be ready to carry 500,000 passengers per year in 4-passenger electric vehicles. Podcar vehicles are public, individual rides are purchased, and as public vehicles they allow wheelchair access. They typically seat four to eight people.

Worldwide development has a limited but long history with various results. Interest, number of participants, and activity has recently picked up dramatically. Recent international conferences held in the U.S. include “Podcar City IV” conducted in San Jose, California in October 2010 which follows others in Washington, D.C. in January 2009, and in Ithaca, NY in September 2008. A European conference was held in Malmo, Sweden in

conjunction with the United Nations’ 2009 summit for Climate Control. A number of city, state, and international transportation studies have returned positive recommendations. Cities considering podcar systems include San Jose, Alameda, and Santa Cruz, California; Ithaca New York; Tyson’s Corner, Virginia; Uppsala, Ostersund, Saguna, and Kiruna, Sweden; Daventry, England; Amritsar, India; and the Masdar eco-city in Abu Dhabi. Winona, Minnesota has issued an RFI and applied for a $24.9m federal grant. As in this book, longer term goals include far more ambitious schemes extending development to entire metropolitan areas. Such has been proposed for Minneapolis, Minnesota. In Opole Poland, the MISTER project is developing a citywide shuttle using suspended vehicles.

The MISTER (Metropolitan Individual System of Transportation on an Elevated Rail) goals are 21 miles of track 10 meters off the ground with vehicles at 30 mph handling about 5,000 users per hour. San Jose wants its airport connected to BART facilities. Tyson’s Corner wants to connect its office facilities with public transportation hubs. The connection will complete “the last mile” for commuters, and thereby encourage increased use of public transport, helping the area compete with Arlington, VA. Ithaca plans 7.7 miles of guideway to connect the city up the hill to Cornell University and separately to Ithaca College. Masdar conceives an eco-friendly transport system which will facilitate human-scale urban areas.

Microsoft Corporation is considering an intra-campus PRT system for its 30,000 employee Redmond, Washington headquarters. To Microsoft, according to its literature, it’s not a roadway or podcars on a guideway, but a software-controlled, packet-switched solution to the last-mile problem of personnel communications! And of course the topology allows off-line access. Its intent is much the same as Heathrow’s slightly different campus.

IBM has a substantial effort in “intelligent transportation”. For example, one effort in Singapore will predict traffic flow, predict resultant speed, and adjust the timing of some 2,000 intersection traffic lights to ameliorate expected problems in affected areas. According to the Wall Street Journal, IBM is also in discussions to build a “complete, automated transportation system that would include 3,000 remote-controlled vehicles” for a small undisclosed city.

Ventures producing hardware include Vectus, a London-incorporated subsidiary of the large South Korean steel company POSCO, RUF International in Denmark, and Cabinen Taxi in Germany.

The Vectus product lists line speeds of 60 kph, headways of 2.5s, decelerations of 0.5g, and turning radius of 5 m. Most developers are using linear induction motors with the active element as part of the guideway. Electrical current flows in the track, the vehicles react. The weights of the vehicles compared to that of an automobile are surprisingly light.

Vehicle and other hardware development is both promising and telling. Vectus' vehicle and test track in Sweden, the German Cabin Taxi, and RUF's dual mode vehicle all show progress, clever innovation, and determination. They also show how hard it is to build a modern vehicle. People know how a world class vehicle should perform. And these are presently but small companies. Automobile manufacturers know how hard it is for new companies to succeed. The U.S. has yet to have a new manufacturer succeed in, what, 80 years. RUF's experimental vehicle is reminiscent of the research vehicles developed for DARPA's Challenge and tested on the Mojave Desert to Las Vegas course: crude, problematic, promising, and awe-inspiring, all rolled into one.

Many high quality corporate websites are available to demonstrate various approaches to PRT systems and are recommended viewing for readers. Some of these corporation's best demonstrations, supplemented by simulations of imaginative individuals, are available on YouTube. One of the best examples, particularly illustrating how some of the ideas of this book and some major threads within the PRT community are converging, is the short video entitled "Bubbles and Beams II." Bubbles are the cars, the beams the roadway. The effort was funded by the Swedish Institute for Transport and Communications Analysis, SIKA, and produced by the late Hans Kylberg. Clearly conceptualized in the simulation are dual mode cars useful on the rail or the road, a round-about interchange useful at low speed, cars docking to form trains, the high speed of the trains, cars disengaging mid-train in order to exit lines, an on/off ramp, and parking. Even the constraint presented by human aversion to jerk—the rate of change of acceleration—can be visualized in the roundabout of the old lady's journey. Figure 1-3A shows four clips courtesy of SIKA. See also Figures 1-3 B-E.

A European Union study concludes that PRT complements existing public transit networks, is the first public system to truly attract automobile users and is "affordable mobility". An American study, commissioned by the New Jersey Department of Transportation, issued its report "The Feasibility of Personal Rapid Transit for New Jersey" in April 2008. Another report and supplement, "The Viability of Personal Rapid Transit in Virginia: Update" posted on the web in January 2009 is also recommended reading.

FIGURE 1–3A. A simulation of a city line, a no stop intersection, and a high speed train allowing a red car to disengage in the country.

FIGURE 1–3B. The Vectus Podcar, rail and tube beam support, and test tracks.

FIGURE 1–3C. The ULTra intra-campus people mover at London's Heathrow airport.

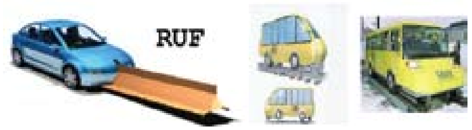


FIGURE 1–3D. Dual mode Vehicle on the left is the RUF design on a blade, on the right is a Japanese proposal.

FIGURE 1–3E. Two way PRT transport down the centerline of a boulevard is illustrated using a modern suspension type bridge support.

Minnesota has a study. A description of dual mode vehicle advantages is available on the web in a full length book, The Revolutionary Dual Mode Transportation System by Francis D. Reynolds. Following the work of Palle Jensen is also recommended.

This book will propose 3rd Generation alignments down the centerline of both boulevards and freeways. Modern bridge building techniques will also be discussed. Both are conceived in the computer simulation of a PRT line seen in Figure 1-3E, again courtesy of SIKA as generated by Hans Kylberg.

One of the most thorough developments in the understanding of personal rapid transit was implemented in a series of studies performed in the 1970s by the hardware-excluded, non-profit Aerospace Corporation in El Segundo, California. Different service models were discussed, although in all models the cars are public, supplied by the system, and stay with the rail. One model analyzed high capacity and distributed rails over an entire metropolis. Physical models on scaled tracks with small cars demonstrated what could be done. Analysis of merging schemes included synchronous and non-synchronous slots, imaginative routing switches, as well as capacity, and delay models. Of the two different control modes considered, synchronous and asynchronous slots for merging cars, asynchronous was shown as superior for heavy traffic. While this book's writing will blithely state that merging delays will reduce line capacity by small (10–20%) percentages, the Aerospace

Corp. studies, while analyzing slightly different scenarios, carefully plot and demonstrate those delays. Figure 1–3F reproduces an Aerospace Corporation's pictorial of a system illustrated for downtown Los Angeles of the 1970s. Much of the work is summarized in the seminal report published as a 1978 book, The Fundamentals of Personal Rapid Transit.

FIGURE 1-3F. An Aerospace Corporation montage.

Since 1960, the population of the U.S. has about doubled, and total U.S. vehicle miles driven has quadrupled on a total road length that has barely increased 30% (US DOT statistics). And while Aerospace Corporation researchers could have reasonably assumed 70 million Americans would benefit from a completely developed version of a 3rd Generation Roadway, and certainly could have assumed that the U.S. was the only country in the world with the wealth to build such, the assumptions for today's world are completely different. In the U.S. the number of potential users may be 150 million, and in the world that number may be well over one billion. Japan and western Europe have wealth, need, technology and insightful clever populations. And while this book will bemoan the average U.S. metropolitan speed of 20 mph, what is the average traffic speed in Mumbai, Istanbul, Mexico City, Sao Paulo, or Beijing? With sales of automobiles in China now exceeding and India soon expected to exceed those in the US, what will traffic become in those huge nations? Indeed the IMF, as reported in British journal The Economist, expects the number of cars in the world to quadruple to almost 3 billion by 2050. And for those who argue such a system would never be applicable to the emerging world, one needs only to point to the cell phone to understand how quickly a society can adapt and implement when no real alternative exists.

In the 1970s, the French launched an imaginative and futuristic set of PRT systems conceived to allow individuals in small public vehicles to choose their destinations without transfer. Two of them, VAL (Vehicule Automatique Leger) a successful development in Lille, and ARAMIS (Agencement en Rames Automatisees de Modules Independants dans les

Stations) a failure in Paris, were developed by the Aerospace giant Matra. Amazingly, without today's sensors or stepping motors, Matra demonstrated the virtual coupling of cars into small trains. Unfortunately, the ARAMIS project suffered sporadic funding, its original design evolved to satisfy many interests, and the program was canceled with the election of a conservative government in 1982.

If the ideas espoused here grow out of an automobile driver's frustration at a traffic light, ARAMIS expressed the gestalt of a frustrated subway rider. Please-improve-the-subway set ARAMIS's original goals: (1) transport without transfer, (2) transport without station delays, (3) allow pre-programmed routes, and (4) give each passenger an individualized route. Small, two passenger cars allowed for individual programming. Dual track sidings allowed exiting cars to stop at destinations, and non-exiting cars to continue without stopping at non-destination stations. Over time every goal except number two was abandoned in the multi-stage disjointed program whose path will be profiled in our final chapter "Death by a Thousand Blows."

As a segue to the next section, it should be noted that as many guideways and vehicle types are in development as there are PRT developers. In contrast, if the 3rd Generation Roadway is to be a nationally or even internationally owned asset, it must service all vehicles. The Rail Cars using the system must therefor be regulated to conform in every necessary way. Every Rail Car must conform to these regulations and be "street legal". Likewise, the Roadway must be a uniformly standardized production article.

Industry wide organizations which promote standardization are, of course, standard entities. So too, are the internecine struggles between the heavy weight contenders for lucrative market share. Within electronics, the International Electronics and Electrical Engineering, the IEEE, is an organization both well established and with substantial clout. Witness, though, the IEEE's struggles to control VHS vs. Beta Max, the universal remote, GSM vs. CDMA, Blue tooth vs Wi-Fi to name a few. Reaching Roadway standards will be difficult.

This book anticipates a U.S. national requirement of 40,000 miles of 3rd Generation Roadway to be used by 75,000,000 Rail Cars consuming a staggering $2.2 trillion investment. Without standardization, Roadway utility will be as impaired a European railroads were in the early 20th Century. Incompatible national railroads resulted from mistrust, hostility, and poor planning. We have to do better in the 21st.

Within the PRT context, this book's proposal could be considered a very aggressive and geographically extensive form of high density, dual mode, personal rapid transit with emphasis on the roadway and with private ownership of the car. In comparison to the PRT hardware in actual development today, the futuristic Rail Cars of the 3rd Generation Roadway are proposed to dock into coupled trains, travel at high speeds, and undergo larger accelerations. For high capacity, they are very short. To enable slender, long span Rails, they are very light. To travel on ordinary streets, they are equipped as today's automobile.

THE 3RD GENERATION ROADWAY

We can now briefly introduce the principal properties and goals of the 3rd Generation Roadway. Many of its attractive features have commonality with the systems described above. And many of the 3rd Generation's features are distinctive—unique is too strong a word in such an active world.

The 3rd Generation Roadway is an intelligent highway. It takes complete control of the vehicle, only on a Rail. It must achieve minimum headway between vehicles. It must merge Cars as they change Rails much as the Intelligent Highway does to orchestrate lane changes. It may use many of the same range and position sensors and roadway 'markers' as the Intelligent Highway must. The expected safety and capacity advantages of the Intelligent Highway should result.

Comparatively though, the Rail should simplify control requirements. Except at interchanges, control is one dimensional. Many difficult, unexpected scenarios will not occur. Since use of a Rail allows bumper-to-bumper coupling of the Cars to be proposed, and since the Cars will be uniformly short, capacity will be 3 to 4 times greater than the Intelligent Highway. As well, by permitting only one type of light vehicle, the resulting far lighter, smaller roadway structure will greatly facilitate integration into the metropolis. But most importantly, the 3rd Generation Roadway can eliminate intersections in the dense urban core; something the Intelligent Highway cannot.

The 3rd Generation Roadway is personalized rapid transit in many senses. The Roadway resembles a mini-monorail and is elevated above the street. Individuals are transported on a public roadway which takes control of their vehicle. Computerized schemes for traffic control are used.

Switching techniques, though complicated by the dual mode design of the Rail Car, have much in common.

The distinctiveness of the 3rd Generation Roadway might be outlined by highlighting six characteristics. First, the Rail Car is bi-modal, allowing it free use of public streets as well as the Railed Roadway. Second, the Rail Car is privately owned and used on public roadway, the same approach used by our present, dominant, and very popular model. That model is, of course, the automobile, the street and the highway we know today. Third, the 3rd Generation Roadway uses existing public right-of-way, forged by our present streets and freeways, a feature in common with podcar concepts but not most light rail networks. The ready access to right-of-way is key to the Roadway's aggressive cost targets. Fourth, another key to the concept is that full interchanges can be devised to be built above ordinary street intersections, allowing full penetration of urban areas and ubiquitous metropolitan access featuring nonstop transport. The interchanges will be tiny in size compared to our present freeway approaches. Rapid switching of the Cars between Rails and large accelerations will be required at the interchanges. Fifth, because of the extremely light weight demanded of the Cars, the Rails employed will be compact, unobtrusive, and supported sparsely from the ground. Thus the 1st generation street and the 3rd Generation Roadway above it can coexist with minimal interference. Finally, in analogy to the NASCAR like formations possible on the Intelligent Highway, but without the spacings, computer assembled and coupled trains of Rail Cars will generate capacity for tremendous traffic volume.

One major capital asset of the system, the Rail Car, is to be used on the ordinary public metropolitan street. Its utility there will be equal to the ordinary automobile. Its speed and acceleration will be competitive on urban surface streets. It will carry a passenger in addition to the driver. It will carry luggage, groceries and shopping acquisitions. And indeed compared to the ordinary car, the Rail Car will have several advantages. Its short wheel base and short chassis will have the nimbleness required on crowded city streets. Its size will enable new parking schemes and fit where full highway autos cannot. The full-sized automobile compromised to operate on the open highway and accommodate five people will have difficulty competing in tighter urban spaces.

For the user, a short description of the product might best be introduced as follows.

Imagine the convenience of today's automobile in your garage. You know you love it; it's yours, it's got plush leather, a good radio, your new GPS toy, maybe hot coffee and a glazed donut. If you're not driving, it might offer today's newspaper, your Blackberry, an iPad, and that TV show you recorded last night.

Only imagine it a small, very much foreshortened SUV, like the Mercedes Smart car taken to extreme, one with a very capable computer on board. Only two seats, some luggage space behind the seats, no hood up front, no trunk back, only batteries and electric motors below. And a hook on top.

Now imagine driving down your local street—as if in a normal automobile—street legal. You have all the convenience of automobile transport—it left when you were ready, you're driving it to your precise destination, there will be no transfers or interruption, you won't leave your private cabin, it can rain; if it's cold, it's got a heater, if it's hot, it's got air, and it's taken your stuff. It's just not the family car. That sits in the two-car garage as a second to be used for the occasional family vacation, the lumber yard trip, and Saturday's soccer match. Your neighbor simply rents a full 5-seat model for vacations. Your twenty-something daughter has a sporty 2-seater and a cell phone—no automobile or land line needed.

But several blocks from your house, just as traffic builds, something remarkable happens. As you drive into a mini-on-ramp the little hook on your roof connects to a slender Rail. Your Car leaves the ground, and follows this Rail which takes you down the center of the street, only above traffic, let's say 10 feet off the ground. Your computer moves you up until you couple to the Car in front—bumper to bumper you accelerate—extracting energy from the Rail. You and others form a train, hiding behind each other, like a peloton of bicycles.

At each major intersection a miniature, but fully functional, interchange appears. No stopping, no signal light. Whizzing around the interchange at full speed with 1g of transverse acceleration—yes, your Car swings out at 45 degrees as if on a roller coaster—your car is whisked into a right turn, a mile later into a left turn, then straight, over a crossing Roadway without delay. All this takes place well within the footprint of the streets below.

Reaching more open spaces—say down the center median of your local Freeway—your train of Cars accelerates to high speed. The single five-foot-wide train carries over three times the vehicles as the rest of the freeway! Counting trains whizzing past you in the other direction, the median supports seven times the freeway's entire traffic.

Near to your destination, the computer decouples you from the train, routes you to a smaller line, and then 'spits' you out to drive onto a normal street several blocks from your goal. You drive those short blocks. You park and get out.

2

THE INTERSECTION AS VILLAIN

Individual decisions in a process may be rational and optimal, but the end result can be nonsense … especially solutions for a problem that has evolved.

TODAY'S INTERSECTION

AN INTERSECTION EVOLVES

Consider the ideal intersection depicted in Fig 2-1A. Two paths simply cross. No control, no worry. If one vehicle travels each path every day, well, the chance of collision given completely oblivious drivers is about four in a million. And OK, if that's too high or if a couple of cars pass per day, look down the other road both ways to see if someone's coming. And if the bushes aren't too high this technique works pretty well; drivers need something to do anyway. In both scenarios, there's no delay and you proceed at full speed. Let's just say that these intersections have continuous flow—you always go through immediately, independently of when you arrive.

But Charlie got killed last year when the bushes were too high. So we'd better put stop signs on the smaller road. Drivers coming down that lane will incur the delay of slowing to a stop, looking both ways, and regaining speed. Delays for a driver going, say 25 mph, will be about 6 seconds. At highway speeds, for a driver going 55 mph, the penalty will be about 20 seconds. Now at the cost of a little gas, ever bigger engines and a lead foot, these times can, and have, been reduced; but 20 seconds is average. Every driver on the smaller road is forced to incur this delay, but the technique saves lives.

But kids and drunks run that stop sign. We'll be safer if we put a stop sign on the bigger street as well and make a four-way stop out of the intersection. Now everyone incurs that 6 or 20 second delay. Realize that as traffic gets heavier the probability of a collision for completely oblivious drivers goes as the square of the number of drivers—linearly increasing with the number of drivers on the first road who each have a probability

FIGURE 2-1A. An idyllic intersection

FIGURE 2-1B. Needs no explanation

of randomly hitting a car on the second road linearly increasing with the number of cars on that second highway. So we'd better put in those four-way stops quickly as our road population increases.

Of course, if traffic is allowed to freely proceed through the intersection for a time, the delay of stopping can be avoided while others—on the secondary road—wait. At some later time cars on the secondary road can be allowed to proceed through the intersection. A traffic cop regulates this procedure admirably. But trained individuals are expensive. Witness the birth of the traffic light; oh, how you obey the thing in Fig 2-1B, the electro-optic equivalent of the traffic cop. Of course a traffic light isn't quite as good as a traffic cop. It doesn't turn red or green at exactly the right time. Time is wasted as it goes through its minimum cycle; it sometimes seems to turn red just as you come along. Maybe that's why we run yellow lights.

But an intersection also performs another function. It allows a driver to turn left or right, and proceed at will down that second road. If traffic is sufficiently heavy, the driver who wishes to turn left must exhibit patience and/or skill choosing his timing. And a new opportunity to have a collision is born. The solution is the turn signal—that little green, yellow or red arrow—giving priority to the turning driver. In consequence, oncoming traffic incurs another source of delay.

And just like that, as in Fig 2-1C, our lighted intersection has that oh-so-familiar sequence. The lights dictate the queue, painful even to read: (1) green for, let's say, north/south traffic, (2) a short time interlude for a yellow warning followed by a second interlude to safely separate vehicles as someone runs the yellow, (3) green for east/west traffic turning left, (4) interludes, (5) green

FIGURE 2-1C. Ah, lament your frequent participation in this scene at one of today's major intersections.

for east/west traffic, (6) interludes, (7) green for north/south traffic turning left, and (8) the final interludes. And red for everybody else. Your turn, now your turn, now your turn, and now your turn! And repeat.

And of course the intersection performs yet another function: it must allow a pedestrian to cross the street. And allow sufficient time for that pedestrian to walk the entire width of the street. Not just any pedestrian, but the slowest pedestrian. Typically lights are set to allow by a factor of three the time required for the lithe-young-walker-in-a-hurry to cross. What's the traffic engineer to do? Have the slow, the infirm, the elderly, cut short, run over, as they shuffle across? Sensors to establish the crossing status of pedestrians have never been widely implemented.

The author grew up in a town without a traffic light. The first caused a stir. That same town, whose population has grown from 10,000 to 60,000, now has innumerable lights. All resulted from the increased density of traffic. Urban and suburban area traffic lights now come at frequent intervals—typically set well less than a quarter mile apart. Stop signs on most streets in these extensive areas occur every several blocks.

If the light would only turn green as my car approached! If lights could only be timed. Well, my friend, that would work well in one direction, but not for guys going the other direction. Most, not all, light systems end up with what seems almost random timing.

DELAY AND AVERAGE SPEED

Given the evolution of the intersection just described, let's look at its performance. How much does the intersection inhibit continuous flow? How long are the waits? Most importantly, at what average speed can one use the resultant roadway burdened as it is with lighted intersections? And finally, what is the intersection's capacity in terms of the total number of vehicles capable of traveling through?

We take as an example the intersection of Sepulveda Boulevard—a segment of California's famed Pacific Coast Highway 1, or PCH to the locals—and Manhattan Beach Boulevard, a mile from downtown Manhattan Beach, California and the Pacific Ocean. At this point Highway 1 has three lanes in each direction with a speed limit of 35 mph. Both the north and southbound lanes at the intersection have separate, lighted, left turn lanes with sufficient length so as not to block through traffic. Southbound traffic has two such lanes. There are no separate right hand turn lanes, and traffic slows behind turning vehicles.

East/Westbound traffic on Manhattan Beach Blvd. has two lanes each way at 35 mph. East/West traffic has single, arrow lighted left turn lanes. In addition westbound traffic has a wide right turn lane, separated from the through lanes and gated with an arrowed green light. Eastbound traffic however must take advantage of a wide right lane, normally accommodating parking, to squeeze forward before turning right.

Average delay incurred by a motorist traversing an intersection is the principal quantity considered in this chapter. Let's forget traffic capacity for the moment. To evaluate delay three concepts must be introduced and their value measured at the intersection. Don't panic, these are concepts you already know much too well.

The first concept is derived from the length of time the light stays green. The time green divided by the time for the lights to complete a cycle—remember the rest of the cycle the light will be red—we'll call the duty cycle. It's complement, (1—duty cycle), again multiplied by the cycle time, is how long your light will stay red. Unfortunately, as noted above for multi-lighted intersections, a light stays red longer than it stays green. Hence the value of a duty cycle, you'll notice, is almost always less than 50%. Only if you're in the lucky crowd that arrives at the right time, do you get to go right through with no delay!

The second concept is the time lost if your car needs to come to a stop, and then accelerate back to speed. The faster the road, the greater the delay. Stop-and-go is an ugly thing. Time lost is obviously very different for the lead-footed jackrabbit and the cautious granny, but for most of us an average time is a good measure. Now a car can easily decelerate—that is, brake—at about -0.5 g. Thus at 35 mph it should take only 3 seconds for the average driver to come to a stop and only half that, 1.5 s, would be lost. And if the driver isn't making a "California stop", maybe 1 second is then taken to evaluate the reason for which he has stopped. Likewise a car can easily accelerate to 35 mph in 6 s, and with a constant throttle only about 2 more seconds would be lost. For a total of only 5 s. Unfortunately in heavy traffic, the slowest set the pace, and many reasonably find a more gentle pace to be appropriate. And the lower the speed limit the more gentle a reasonable pace seems to be. Many ease to the final stop, and gradually press down further on the accelerator as they start. For the analysis of our topic intersection with traffic at 35 mph, very aggressive drivers are assumed and 5 s

will be used as the total stop-and-go delay. Later, with data taken in traffic using several different drivers, less aggressive driving is assumed, which for example at 35 mph results in a 10 s stop-and-go delay.

The third delay we'll call the stacking time. When the light turns green, you don't move immediately; you have to wait while all the cars clear in front of you. In heavy traffic this time can be substantial. If there are too many cars in the stack, you may not get through at all. The light turns red again, and you get to wait multiple cycles! Stacking delay is about 1.5 s for each car in the queue. This delay means that if your car is the 10th car in a lane, you'll wait (10—1) x1.5 s before you start to accelerate. It seems drivers sense a proper distance to be behind the car in front and translate that to a time from the beginning. Remember cars on a freeway trail the car in front by a little more than 1.5 s.

So what is the average delay? Let's write out an equation in terms of our three quantities. If you're mathematically inclined you can easily reduce it to simpler terms, check the results below, and estimate delays for different hypothetical intersections.

> Delay = [(time light is red + stacking time)/cycle time][1/2 (time light is red) +1/2 (stacking time) + deceleration time + acceleration time]

The first term is the fraction of cars unlucky enough to have to stop. The rest experience zero delay. The second term is the sum of the three delays defined above. Note that the average driver arrives half way through the red light's time, and ends up in the middle of the stack—hence the ½ assigned to these two values. In the data taken, although cars arrived in bunches, the ½ approximation held up very well.

Table 2-1 is shown in some detail so as to illustrate how data was taken for southbound traffic on Highway 1. As the dominant road the light stays green a long time. About 10% of traffic turns left (E) and about 10% turns right (W). At 1,980 cars per hour traffic is heavy but not at capacity. Data is reduced in accordance with the equations above. Note that in California, it is legal to turn right on a red, and hence many cars turning right experience only the stop and go delay. Other cars, however, must wait, yielding to cross traffic, or stack up behind another which is yielding. Hence delay datum for each car is listed, then averaged. Thirteen cycles of data are taken over 40 minutes from 3:15 to 3:55 pm on Thursday, July 10, 2008.

	straight		left turn		right turn	cycle times
cycle	number of cars	green light time(s)	number of cars	green light time(s)	delay for each car(s)	cycle time(s)
1	100	91	–	–		
2	75	125	14	20		
3	110	100	12	17		
4	105	103	–	17		200
5	80	96	16	19		195
6	96	100	10	18		203
7	72	95	6	18		205
8	90	78	12	18	25, 30, 0, 0, 0	193
9	97	75	10	20	0, 0, 0, 0, 30, 0, 0, 0, 0, 0	199
10	80	98	15	22	90, 90, 45, 30, 0	203
11	97	84	6	18	30, 60, 50, 50, 30, 20, 0, 0, 0, 0	197
12	94	80	10	21	95, 45, 30, 40, 20, 20, 5, 0, 0, 5	207
13	104	80	2	15		193
Average Value	92	93s	10	19s	22s	200s
Duty		47%		10%		
Delay	46s		100s		22s	
Flow Rate	1656 cars/hr		180 cars/hr		144 cars/hr	1,980 cars/hr

TABLE 2–1 documents traffic flowing south on California Highway 1 as gated by the lights operating at an intersection.

Data for Table 2-2 were acquired in the same fashion but presented in abbreviated form. Note priority is given to PCH by allowing its lights to stay green longer. PCH drivers see green lights almost 50% of the time while east-west traffic sees green less than 25% of the time.

By applying the equation derived above we can reduce this data to calculate delays for traffic in all directions. See Table 2-3. Traffic headed north is somewhat lighter and hence suffers less delay than traffic flowing south. East and west traffic incurs longer delays as their paths are given lower priority. Not surprisingly any driver turning left suffers the longest delays.

Within many urban areas, a major intersection, such as the one which we have just characterized, might be incurred once every mile. But numerous smaller intersections—left turn signals for the single car, the light for the single pedestrian, the new mini-mall—will slow traffic within that "free" mile. Thus to fair estimation, let's approximate delay on major boulevards as caused by a major intersection every ½ mile. Obviously, the delay for semi-rural areas will be less; and grossly more for heavily developed corridors such as Wilshire Blvd in L.A., 5th Ave. on New York's Manhattan Island, or Chicago's Michigan Ave. Delay is also underestimated for congested areas such as shopping malls, or at the confluence of major traffic arteries, particularly when constrained by geography, right-of-way, or history. But our approximation is a good one for huge areas of urban America.

So what is the impact of such delays? What is the impact on the average speed and thus the average time to travel, say, 10 miles? Using our estimation and the data above, for one to travel south a half mile on Hwy 1 it will take 97 s = (½ mile/35 mph + 46 s); or fully 33 minutes to travel 10 miles. To take over a half hour for a small trip of ten miles equates to an average speed of 18 mph. Incurring 3 seconds less delay every ½ mile traveling north

TRAFFIC AND LIGHTS

	straight		left turn		right turn	cycle time(s)
	number of cars	green light time(s)	number of cars	green light time(s)	average delay	
South	92	93	10	19	22	200
North	75	93	9	19	24	200
East	29	41	12	34	31	202
West	27	31	10	26	14	199

TABLE 2–2 shows a summary of similar data taken for the four traffic flows at the intersection.

DELAYS AND FLOW RATES

	straight		left turn		right turn	
	Delay(s)	Flow cars/hr	Delay(s)	Flow cars/hr	Delay(s)	Flow cars/hr
South	46	1656	100	180	22	144
North	43	1350	98	162	24	126
East	85	517	86	214	31	162
West	92	488	94	181	14	180

TABLE 2–3. Shows the average delay incurred by each vehicle and their number entering from the four directions.

on Highway 1 results in 94 s to move ½ mile, or 31 minutes to move 10 miles at effectively 19 mph. East on Manhattan Beach Boulevard requires 126 s for a half mile and 42 minutes to travel 10 miles at 14 mph. West takes 133 s or 44 minutes at 14 mph. Table 2-4 says all this more easily.

Can a city increase these effective speeds by increasing the speed limit for which it designs its streets? Table 2-5 was created to show why the city cannot. The Table's bottom line is the average speed of traffic constrained by intersections of the type above when the road's speed limit is increased and traffic rushes faster between the lights. Note the dismal performance as traffic is allowed higher speeds between frequent intersections. Average speed barely increases as the speed limit is raised. The delays used are representative of huge urban and suburban heavy traffic areas. *The car and the intersection doom city transportation to speeds we have today*.

Obviously by carefully timing lights and tailoring cycle times, transportation departments can and do reduce delays. But improvements here also come in agonizingly small increments. In January 2009, Los Angeles Mayor Antonio Villaraigosa called a press conference to announce the successful results of a key Los Angeles Department of Transportation (LADOT) project to re-time and optimize 150 intersection light sequences. The average intersection delay had been reduced by 8 seconds. Data was proudly displayed on the LADOT website.

Vehicle Direction	South	North	East	West
Average Speed (mph)	18	19	14	14

TABLE 2–4 notes the effective average speed of motorists traveling on the two streets.

AVERAGE SPEED VS. SPEED LIMIT

Speed Limit (mph)	25	35	45	55	65
Time at Speed Limit(s)	72.0	51.4	40.0	32.7	27.7
Stop and Go Delay (s)	6	10	14	17	20
Wait Delay (s)	40	40	40	40	40
Average Speed (mph)	15.3	17.8	19.2	20.1	20.5

TABLE 2-5. With lights placed every half mile, raising the speed limit has little effect on the average speed.

TRAFFIC CAPACITY

Naively, if one knows that cars can properly follow one another with a spacing of one-car-length-per-every-10 mph, one would assume Highway 1, as a 6-lane highway at 35 mph, would have a capacity of 8,200 cars/hour per direction. After all, 8,200 cars per hour is equal to 3 x 35 mph/(1 +3.5)15 ft/car and we assume 15-ft-long cars. The equation of course assumes cars smoothly travel continuously with proper spacing in all 3 lanes at 35 mph. But drivers are variable, and from freeway data we know the practical limit even under ideal conditions is about 2,000 cars per lane per hour, that is, about 6,000 cars/hour for our 3 lane boulevard.

But Highway 1 has those intersections. And those traffic lights. Fully 63% of the cars must come to a dead halt, and then struggle to regain speed without impeding the cars that trail. Cars traveling at an average of 18 to 20 mph, but with spacing for 35 mph burst speeds, produce a roadway capacity closer to 4,000 cars/hour. Cars slowing to exit and entering at slow speed further impede the stop-and-go herd of flowing cars. So the data on southbound traffic taken July 10, 2008 at 3:30 pm shows Highway 1 at well over 50% its practical capacity with 1,980 cars/hour. If traffic were to increase delays would precipitously do so as well, slowing the average speed.

Furthermore, Highway 1 is actually a boulevard with priority over somewhat smaller thoroughfares. Note the average speed imputed for Manhattan Beach Boulevard is only 14 mph, and that 16 mph is the average speed in the four directions. Thus a better number for a busy intersection of two equal 6 lane boulevards might be closer to 3,000 cars/hour. To bolster this number with data, traffic was monitored on a Friday (4/23/10) at 5 pm, when the intersection was indeed operating at full capacity—traffic backed up for a half mile—and the flow measured to be 2,600 vehicles/hour. Thus this rounded, and somewhat optimistic number, 3,000 vehicles per hour per direction, or 12,000 vehicles per hour per intersection, will be used for discussions below.

Synchronizing traffic lights in concordance with a driver's progression promises to mitigate the intersection's malfeasance. In modern parlance, the lights are timed. If the light is always green when I approach—no harm, no foul! Immediately obvious, however, for most intersection spacings, is that the idea doesn't work for the guy going the other way. Of course, if most are commuting north in the morning, and south in the evening, the idea has merit. It works even better if you make the street one way; and the next street parallel go the other way. And many cities do. But the approach wreaks havoc on east/west cross-town traffic. And creates an uneasy compromise between the interests of local traffic and those of through traffic. Just try to go-around-the-block with all those one-way restrictions! The increased use of one-way streets in dense urban cores is symptomatic of the density limit to which the automobile culture restricts a city.

Interestingly, the traffic circle—the infamous roundabout to Americans—is a technique which avoids the item which is this chapter's subject. Used extensively in Europe, and now the darling of many American traffic engineers, it successfully avoids the waits described above, and works particularly well with careful, considerate drivers, and low traffic densities. The traffic circle, however, becomes increasingly problematic with heavier traffic—think the chained circle around the Arc de Triumphe in Paris, or traffic in Rome or Boston—and this book wishes to address solutions for heavy traffic.

THE FAILURES OF THE 1ST GENERATION

The intersection has exacerbated two fundamental flaws of the 1st generation street. First, as we have seen, the intersection has reduced the speed at which traffic can flow down the street. The more cars, the slower the flow. Second, the intersection has reduced the maximum number of vehicles that can travel down the street. As we will see in a moment, the intersection has reduced both speed and vehicle numbers to values which are unacceptable to the modern metropolitan area.

The intersection has reduced your speed so severely that you live in a neighborhood far smaller than your city. You don't have the time to visit more. You can't belong to the entire city. As well, the intersection has reduced the vehicular capacity of the city's boulevards and thoroughfares such that they couldn't handle the traffic if you, and everyone else, had the time! So when drivers from other areas of the city do attempt to travel our roadways, add to the local load, we will see the system crash. Hence a large metropolitan area cannot act as a single economic entity. The swank part of town can't get the labor it wants. The poor side the work it needs.

Throughout this book a neighborhood will be modeled as that area within which you can expect to freely visit anywhere, anytime, three times a day with round trips from home. In a medieval village, one might walk to the boulangerie, wander over to a place to gossip, and then ride a mule out to one's cow pasture or rice paddy. In the modern world, we drive. We stay in physical contact with our 'hood by commuting to the office or job site, taking kids to school, getting a cup of coffee, checking out that new specialty market, shopping an old boutique, visiting the girlfriend, or smelling the roses at the beach. In an ideal world, we would make the entire city our neighborhood able to take any job, take our kids to any magnet school, sample every new tapas bar across town any time we wanted.

In most societies, many sociologists attest, people are willing to travel regularly one hour a day, and occasionally far longer on a journey. The average American indeed travels that hour a day 'round town and three hours a week on longer highway trips. Thus, the 10 hours a week. Condemned to travel at 18 mph, and willing to spend only an hour on those 3 trips, an average destination can only be 3 miles away, since a round trip distance of only 6 miles can be tolerated. If you could drive straight to your destination, your neighborhood would be a circle of some radius, with you at the center—a good assumption in a large town, a poor one in a small town. But since you typically must drive on a rectangular grid of streets your neighborhood will be a square—defined by boundaries tilted 45 degrees from the streets' directions. In a moment we'll find this means your neighborhood is no bigger than a 6 mile square. We will also soon find that automobile based societies establish population densities with somewhat less than 10,000 people per square mile, and thus your neighborhood will have less than 350,000 people.

Yes, you can cheat. You can spend more time on the road. You can cleverly schedule your day and plan routes to combine objectives and take fewer but longer trips. But you can't easily. Or you can do what so many of us do, become a commuter, and live during the week in two small "bubble" neighborhoods at each end of your commute. But no longer are you a full member of those two communities.

A SMALL TOWN EVOLVES

Why is it that street traffic in a small town seems so languid, so polite, so pleasant? And why is it, that as a town grows, traffic transitions to hectic, heavy, and just plain nasty? And ever more congested as development draws people to certain areas? If the preceding section on the intersection illustrated why you don't have the time to travel far in a city, this section will illustrate why the city couldn't provide the roads if you did. It's not the city's fault, the failure is intrinsic to the system of transportation we use. Realize that in smaller towns people indeed have the time to drive anywhere in town 3 times a day. And they do. But as the town grows, they drive further. And the troubles begin.

Let's make three simplifying assumptions for our model small town. First, the town's land area is laid out with a rectangular grid of streets, and the town's perimeter is a square. Second, everyone visits all areas within their town uniformly. Starting from the town's center, as Calculus geeks will assert, everyone must therefore drive, on average, 2/3 the way out to the town's boundary, but given they drive on diagonals they travel $[2/3]/2^{1/2} = 0.47 = \frac{1}{2}$ the distance that is the length of the town's square sides. Thus, later when the average round trip is found to be at maximum 6 miles, they will find their neighborhood to be at maximum a square with 6 mile sides. And now the third assumption: as is the national average, each of the town's licensed drivers is making 4 trips today. Three of her trips will be in town, but her 4th trip is going to be out of town, out in the countryside. In a large town the 4th trip will be in someone else's neighborhood, on his boulevards or on his freeways. But in the small town each of the town's licensed drivers, who number 2 out of 3 of the town's citizens, is driving 3 trips today on town streets.

Now for the town's layout. If planners set up town blocks 540 ft x 300 ft in size by parceling out 50 ft x 130 ft lots, 20 to a block, with 40 ft wide streets, the town gets 172 blocks per square mile. Assuming 3 people per house, 60 to a block, the town grows with 10,000 people per square mile. Realize as well that drivers will now come to an intersection on average every 386 feet. (Sadly, as an aside, the modest 40 foot wide streets—two 12-foot lanes and 8-foot borders for parking—pave over 21% of the town's total land area. To park all the cars off the street takes another 6%, and we're not counting the driveways.)

Since the town is lucky enough to have grown in a square, with sides of length, say, S, the average trip will have a distance of ½ S each way. Thus our town has grown to have 10,000 S^2 people 2/3 of whom drive 3 x S miles a day on city streets. Please notice that the total vehicle miles driven in town grows as the cube of the town's dimensions; the streets only as the square.

Let's focus on the intersection. That's where our town's sweet design will break down first. One's tempted to say that's where the rubber meets on the road! So we ask, how many cars on average come to every intersection per day? The answer is 3,183 S. And if the town grows to that maximum neighborhood square of 6 miles, the answer is 9,550 intersection stops per day per intersection. See the left side of Table 2-6 .

Just how many cars can a residential intersection handle? First remember that as the town grows each of these intersections will have stop signs. Cars proceeding through a signed intersection—if traffic is backed up in all four directions and every driver waits and is alert as his opportunity arises—do so about 3 seconds apart; so the answer to the first question is 1,200 per hour or less. And indeed data taken at the corner of Valley and Pacific in Manhattan Beach, California on December 15, 2008 yields approximately that answer. Note that a line of cars approaching a single stop sign proceed through with about 4 second spacings, if everyone's alert. Waiting traffic at a four way stop can squeeze one car though from one of the four directions every 3 seconds. That's 1,200 per hour counting

Town Pop.	S (mi)	length of 3 trips (mi)	no. of stops/ driver	number of stops/ intersection	Single lane streets % of capacity		
					8 hrs	4 hrs	2 hr
625	0.125	0.75	10	398	4%	8%	17%
2,500	0.25	1.5	21	796	8%	17%	33%
10,000	0.50	3	41	1,592	17%	33%	66%
40,000	1.0	6	82	3,183	33%	66%	133%
90,000	1.5	9	123	4,775	50%	99%	199%
360,000	3.0	18	246	9,550	99%	199%	398%

TABLE 2–6 lists quantities for a town assumed to have a 4 way stop at every intersection. Drivers take 3 trips, ½ way across town, up to 18 miles/day at which point they simply capitulate.

all directions. Or about 300 cars/hour squeeze through in each direction in heavy traffic. Exactly 1/10 that of big boulevards with street lights such as PCH discussed earlier.

Now a town without congestion enjoys those 3 trips, on average, mostly within an 8 hour period. But when viewed locally, that is, measured at one intersection, traffic peaks at specific times. For instance, around a school yard most traffic for the day occurs during short periods, as does traffic around a luncheon restaurant, after work at the shopping mall, or on Saturday afternoon near the soccer fields. Or the most global of all traffic surges, driving to and from work. It is also true that traffic flow from the four possible directions at an intersection is seldom equal. Congestion occurs if only one direction incurs more than a maximum flow. Congestion occurs if just four cars decide to turn left all at once, for instance.

But if we generously use 8 hours, then the intersection of two single lane streets has a daily capacity for vehicles of less than 8 x 1,200 = 9,600. And so, the right side of Table 2-6 can list the intersection's capacity utilization **in percent** vs the number of cars approaching. The Table also lists a utilization factor when traffic peaks in four and two hour periods. The Table clearly shows that somewhere around a population of 30,000-70,000 the successful traffic model for a town using single lane residential streets falls apart. There are too many cars.

A MID-SIZED TOWN COPES

Of course with good planning in anticipation of growth, the wise city fathers can improve the residential street model. Major arteries or commuter streets can be built to crisscross the town. Paving over yet more area allows these streets to have multiple lanes; and given priority these streets will have fewer stop signs—or rather now, fewer traffic lights. Let's further assume the city planners make these commuter streets as 6 lane boulevards. As we have seen for Sepulveda Boulevard, they will now have capacity for 3,000 cars, per hour, per direction. Thus the new boulevard intersections now have 10 times the capacity of the small street intersections. But, of course, the city can't build as many boulevards as it can small residential streets. So while boulevards obviously mitigate the congestion predicted in Table 2-6, their effort is muted.

A mid-sized town can operate with a grid of boulevards, which will draw traffic from the smaller, slower streets. The town can further isolate this smaller residential streets from annoying, and dangerous, through traffic by curving streets, designing cul-de-sacs, and adding speed bumps, extra stop signs, etc. Fresno, California, a fast growing city of 500,000 blessed with an accommodating topography—and the dead flat San Joaquin Valley is as accommodating a topography as is imaginable—has adopted such a network of 6 lane boulevards and isolating its suburban tract housing. Typically Fresno has chosen to provide boulevards in a square grid on one mile spacings.

Modeling a complex system as two or more separate and simpler subsystems is a very useful technique to establish the principal modes and performance of most complex system. Modeling as such is also far easier. In our case the boulevards with their traffic are modeled as one sub-system, and the small streets with their traffic are the second sub-system. As the model is improved to allow for small interactions between the two sub-systems, the extent to which the modeled performance is "perturbed" can be evaluated. A solid state physicist would say we are using a two fluid model. Soon, we will be tempted to add freeway traffic as a third fluid; and finally to add Rail Car traffic as a fourth fluid flowing separately but occasionally transitioning between the 1st and 3rd Generation roadways.

To model the performance of Fresno's boulevards, let's assume traffic flows on the boulevards, and separately, with different objectives, other traffic flows on the small streets with stop signs. The two flows only lightly interact, since for instance, those drivers on long errands use only boulevards, those on short use only streets. Only occasionally does a car transition from a small street to a boulevard; or visa versa. That fourth trip for the day, which in our small town drivers took in the countryside, is now on the boulevards. But seen locally, sometimes most of the traffic is on the boulevards, sometimes on the small streets. Note that the small streets seldom get busy because no one ever has to travel more than a mile on them. How well do Fresno's boulevards work? Let's find out by asking a very simple question.

How many cars travel each boulevard direction per hour on average? We'll first model traffic as resulting from a Fresno driver's convenient ability to travel whenever she wants as appearing to have every driver navigate his/her one daily hour at a uniform rate within an 8 hour span. Yes, we have previously derived the numbers we need to answer our question. We've learned that suburban areas feeding the boulevard's traffic will have roughly 10,000 residents per square mile and roughly 6,600 drivers determined to drive their 18 miles at their own convenience. To prepare for this onslaught, Fresno has built boulevards on a one mile grid and if we carefully do our accounting that's two miles of boulevards per square mile, four miles of roadway per square mile if we count each direction. We also measured that a six lane boulevard burdened with intersections handles 3,000 cars per hour in each direction, knowing that anything above 2,000 cars/hour seems very heavy.

Suburban Fresno will generate 120,000 miles driven per day per square mile of suburbia (6,600 drivers times 18 miles per driver), and 120,000 miles will be driven every square mile. If we generously assume that both sides of each boulevard are equally loaded with traffic, Fresno thus will generate 30,000 car miles per mile of boulevard. With an absolutely level load—in time, location, and direction—that's 3,750 per hour each direction. Yes, the boulevards work, but barely. Traffic, of course, isn't spread evenly, nor is it pleasant.

Traffic isn't spread evenly for good reason. Just as the world seeks out world-class things—from products to athletes to travel destinations, towns seek out town-class things—from schools to restaurants to shopping streets to the big box retailer. Unfortunately, these town assets go in precisely where town planners have funneled traffic. It should come as no surprise that citizens rail against the rapacious developers whose product focuses traffic onto selected town streets. Obviously, traffic levels will peak at various times and peak differently on different boulevards. And not only

do the neighborhoods of a mid size town endure the same surges as does a small town, but they also endure traffic generated by outside drivers on longer trips simply passing through as they drive cross town or collectively converge into a neighborhood. Maybe the neighborhood is on a commuter path, the way to a recreation area, maybe it's a Friday night entertainment center, or has major employers. We ignore that small parallel streets will help. The 4th driver is now on those streets. The resulting congestion's only silver lining is that traffic is reduced on residential streets compared to our street model above. The net effect of all this may be to make the street model good for street traffic in towns above 70,000.

Note above that if people drove further the traffic density would increase. But the functioning ability of the boulevards barely matches the time people have to drive them! And in fact, the boulevards continue to work as towns grow past a six mile diameter simply because drivers have been weeded out and no longer visit 3 times a day.

The author's father used to say that towns merged together in metropolitan areas. You could discern the town centers by noticing the buildings were taller, and the boundaries where they were lower. It's not far from true to say that many commercial centers of the automobile based metropolitan landscape are roughly 6 miles apart. A shopping center won't cannibalize another if drivers can't visit both. Exactly as you would have guessed!

A BIG TOWN WITH BIG PROBLEMS

Limitations in urban density and neighborhood size are among the laments this book levies against the automobile based society. But the book intends to show the impact of Rail Car transport on urban society, so what if … our model town is built at a density greater than that allowed by the automobile. Greater than 10,000 people per square mile?

We use for our example the borough of Manhattan, which is the County of New York, in New York State. Manhattan, little more than the island of 22.4 square miles, has 1,650,000 residents, half of whom go to work in the morning and join the 1,450,000 who commute in, and say goodbye to the 100,000 who commute out. The resultant daytime population of 3,000,000 constitutes 134,000 people per square mile. That is, Manhattan violates our dictum for an automobile based town by a factor of 13! We'll ignore the fact that the daytime population is also grossly weighted south of Central Park.

Let's assume that daytime New Yorkers want to enjoy their town with the same intensity that we all do. New Yorkers would zip around town taking 3 two-leg trips a day—stop for morning coffee, go to work; brief the client downtown, back to the office; party in the East Village with tapas and drinks at 6 pm; visit the Met or a bar in Harlem, and go home to sleep. Two thirds of all New Yorkers would take trips like these daily and almost all, 83%, would own a car—just like the average American!

First, just for fun, let's extend the small town numbers above to illustrate what these city folk would experience. This will only be a gedanken experiment in that, at the national average, 111,000 cars per square mile if allowed a little bumper space would almost blanket the entire Island and no one would go anywhere! The numbers will make clear that New Yorkers have made the right decision to walk or take the subway.

Then, armed with this predictable failure of the 1st generation street, we will ask just how well a 3rd Generation Roadway would work? Would it have the capacity for our obviously immense hypothetical traffic? While the model will quickly show that the Roadway could handle the expected traffic levels, it is also clear that one would need to be very careful in the design.

Now, working as we did for the small town, but adding boulevards—in New York we'll have to call them Avenues—as we did for Fresno, we note the following. Much of Manhattan is laid out in rectangular blocks 270 feet by 1,000 feet. Since the island is long and thin, very substantial Avenues run north-south at 1,000 foot intervals, and small streets run east-west on 270 foot intervals. The Avenues have one way traffic, four or more lanes, but have lights at every intersection. Every tenth or so east-west street is a big one, and thus on 2,700 foot spacings. On average 1,300 daytime New Yorkers live or work on each of these blocks and would own 1,100 automobiles if they bought and owned at the national average. Behaving as in Fresno, if 2/3 of them drove a neighborhood of 6 mile sides, they would generate 1.8 million miles of traffic driven per day per square mile—see the problem coming?!

Ignoring delays associated with the traffic lights at the small streets, which are minimized by one way Avenues and timed lighting, but also ignoring the traffic handled by these small streets, we are left with 10.3 major intersections per square mile to handle 4.3 million cars intersecting per day, given that drivers meet 3.62 major intersections per mile driven. Our intersection equation is now $630{,}000[S/6] = 1.8\text{x } 10^6 \text{ x } 3.62/10.3$. Let's generously assume these major intersections can handle 10,000 cars per hour, adding up all cars from the two, three, or four directions. Thus traffic is 525% of what an Avenue intersection can handle in a 4 hour period for ½ S = 1 mile [630,000(1/3)/4x10,000 = 5.25]!

The left side of Table 2-7 shows Avenue utilization versus the average distance attempted by drivers. The streets clog at 300 yards! Yes, if New Yorkers used automobiles to visit their neighborhoods, they could go no further than 300 yards.

In contrast, the transport proposed here will have a Roadway capacity of 85,000 vehicles per hour per intersection, configured as a non-stop interchange, with vehicles roughly averaging 36 mph. 36 mph will enable our 3 trips and 18 miles per day in roughly 30 minutes, replacing the full hour of today's suburban task. A 36 mph average should result from a 40 mph speed limit and the occasional interchange turn at 25 mph.

The first column on the right side of Table 2-7 shows that capacity can be exceeded. Indeed the grid is now overwhelmed for neighborhood size of about 2 to 4 miles. Clearly, high speed Roadways and/or Roadways with multiple lanes would be needed to augment the local lines. For Manhattan's case two parallel high speed Roadways, one up the East Side and one up the West Side would suffice. Three or so cross town links would complete the

Neighborhood		**1st Generation Avenues**		**3rd Generation Roadway**	
Destination distance	Population	Crossings per intersection	Percent capactiy	Slow Speed Grid on Avenues	Augmented grid
(mi)	–	–	4 hour	% capacity	% capacity
0.125	8,400	26,250	66%	7.5%	7.5%
0.25	33,500	52,500	131%	15%	15%
0.5	134,000	105,000	263%	30%	28%
1.0	536,000	210,000	525%	60%	45%
1.5	1,206,000	315,000	1050%	90%	53%
3.0	4,824,000	630,000	2100%	181%	57%

TABLE 2–7. The left columns illustrate the limited capacity of 6 lane 1st generation streets to handle neighborhood traffic emanating from a very densely (134,000 people per square mile) populated city. The right columns illustrate the 3rd Generation's abilities.

high speed network. Anyone traveling more than a mile or two would take part of his journey on the high speed line, and the effect of longer journeys would no longer be burdened onto the local lines. After all, any banker leaving Wall Street for his 6 pm date in Harlem wouldn't want to take 12 minutes to get there, when he can do so in just over 7 minutes on the high speed line. The capacity implications of this augmented scheme are shown in approximation in the second right column of Table 2–7.

A full square neighborhood of 4,800,000 people can now be serviced with the Roadway at 57% of capacity. One's "neighborhood" now has 4,800,000 people within a 5 minute travel time. A Manhattanite's "neighborhood", truncated as it is by the Hudson and East Rivers, would be somewhat less at about 2,000,000 people. That is, if they refused to go to Brooklyn, Queens or Jersey.

Parking, and time consumed for the task, of course will add to one's 30 minute travel budget. Proposed in a later chapter is an automated, dense, public parking structure fitting onto a standard city lot of 50 feet by 100 feet. Situated for convenience, one per block, 100 foot tall structures would house those 1,100 Rail Cars per block, and those hypothetical 2,600,000 vehicles on the Island. Walking to, and from, the garage would be guaranteed to entail a theoretical distance less than 635 feet on our hypothetical average Manhattan city block.

This discussion has foreshadowed the next chapter where placement of a 3rd Generation Roadway network will be discussed at length. A 3rd Generation Roadway down 10 of Manhattan's Avenues has changed many things. Most streets have been returned to the pedestrian friendly landscape of a village—one without a Railed Roadway, just the occasional, small, quiet Rail Car and maybe a delivery truck. One can travel the entire island quickly without concern for congestion. We have tamed Manhattan's immense traffic problem with approximately 140 miles of 3rd Generation Roadway.

CITIES WILL GROW

The 1900 U.S. Census lists the population of Las Vegas, Nevada at 30. It's grown! While everyone recognizes that for a city's population to explode in a century from 30 to 2,000,000 (Clark County) is fast, older cities also continue to grow. The city of New Delhi, in the last century, has grown from a town of 400,000 to a metropolitan area of 20,000,000. Cities continue to grow not only because the world's population continues to grow, but because advances in civilization allow a city to do such without committing urban suicide—effective suicide almost guaranteed by pestilence, poor sanitation, starvation, or other reductions in the quality of life such as congestion in many, many forms. Without these limits, cities are magnets.

The world's leading cities of Ur, Babylon, and Memphis had populations approaching 100,000 in the 2nd and 3rd millennium BC. Imperial Rome made a huge leap forward with a population approaching one million in the 2nd century AD, a population not duplicated by any urban area until the early 19th century by London and Beijing. By 1900 London had grown to 6,500,000 and in 1950 the world's most populous area was New York at 12 million. In 2009, Tokyo had 35 million metropolitan inhabitants as the world's largest.

Although today relatively precise census data are available, defining the boundaries of urban areas is a difficult art, and many lists quote somewhat different populations for today's major, extended metropolitan areas. Below is one list.

1. Tokyo, Japan: 34,100,000
2. Mexico City, Mexico: 22,650,000
3. Seoul, South Korea: 22,250,000
4. New York, US: 21,850,000
5. Sao Paulo, Brazil: 20,200,000
6. Mumbai, India: 19,700,000
7. Dehli, India: 19,500,000
8. Los Angeles, US: 17,950,000
9. Shanghai, China: 17,900,000
10. Jakarta, Indonesia: 17,150,000
11. Osaka, Japan:16,800,000
12. Kolkata, India:15,550,000
13. Cairo, Egypt: 15,450,000
14. Manila, Philippines:14,850,000
15. Karachi, Pakistan: 14,100,000
16. Moscow, Russia: 13,750,000
17. Buenos Aires, Argentina: 13,400,000
18. Dhaka, Bangladesh: 13,100,000
19. Rio de Janeiro, Brazil: 12,100,000
20. Beijing, China: 11,950,000
20. London, UK: 11,950,000
22. Tehran, Iran:11,800,000
23. Istanbul, Turkey: 11,400,000
24. Lagos, Nigeria: 11,000,000
25. Shenzhen, China: 10,450,000
26. Paris, France:9,900,000

27. Chicago, US: 9,750,000
28. Guangzhou, China (Canton):9,400,000
29. Chongqing, China (Chungking): 9,200,000
30. Wuhan, China: 8,950,000
31. Lima, Peru: 8,500,000
32. Bogota, Colombia: 8,250,000
33. Washington-Baltimore, US: 8,100,000
34. Nagoya, Japan: 8,050,000

Source: Th. Brinkhoff: The Principal Agglomerations of the World, http://www.citypopulation.de, Oct. 1, 2005.

A city is a wonderful thing. It enables vast numbers of people to be in physical contact with each other and experience the delights produced by many. City residents assume their mobility allows interaction and transport across the entire metropolitan area. But if transport times exceed a certain value this interaction is lost, or at a minimum suffers greatly.

If a city's density exceeds a critical density, transport slows, and the city is forced to spread out—further increasing transport times. As a consequence, if areas are central and have shorter commute times, real estate values rise, driving more and more people away. Thus modern automobile based cities increase density to certain stable values—which urban planners may think to be far from optimum when viewed with different goals. Goals, for instance, centered on improving the quality of urban life.

If we choose for any reason—privacy, spaciousness, avoiding congestion, a feeling of belonging to the earth, or the cost of real estate—to live at densities of no more than 10,000 people per square mile, our neighborhood square encompasses 400,000 or fewer people. We don't live in a Los Angeles of 10,000,000 people but in many separate communities. We don't live in Los Angeles; we live in Brentwood, Malibu, Van Nuys, Cerritos, or Duarte. Yes, you can live in Palmdale and take a job in Winnetka, live in Palos Verdes and see the Disney Hall on Friday night; but you do so at a price. You can sample what the city has to offer but you can't live it!

Written from the perspective of an Angeleno, with affluence and roadway infrastructure abounding, denial of the Disney Music Hall on Friday night might make the list of complaints, but what are the more profound effects of congestion on the cities of New Delhi, Mexico City, or Rio de Janeiro? Trapped in an isolated favela, inability to find work, never to visit a relative far away on the other side of town? Again, can these metropolitan communities operate as an economic entity?

Faster transport. Some will argue that such a capability would simply result in people traveling further. After all, studies show that indeed drivers in many cultures drive on average 10 hours a week and, economics aside, will drive until those 10 hours are up. Faster transport, some will say, simply results in further sprawling of cities—further into the 'burbs. Maybe so. But note that the 3rd Generation Roadway allows for fully functioning transportation within more densely populated cities. It is just as likely that only the city core and its population density will grow. Population will increase, but not the city's footprint. The right answer is that people, and their government, will have a choice. And choice, a new degree of freedom, is usually a good thing.

FREEWAYS: THE 2ND GENERATION

If necessity is the mother of invention, then the Mother of the Freeway is the duel need to create a roadbed reasonably safe at high speeds and to eliminate the intersection. That is to say, the latter need is to restore the quality of the intersection back to that of the pastoral crossing with continuous flow.

Some forty or fifty years after the introduction of the automobile, and about the time that roads in the western United States were being given hard surfaces of concrete or chip seal, the idea of the freeway was born. Credit for Father of the Freeway is given by some to, of all people, Adolf Hitler, who helped develop the autobahns of Germany in the late 1930s. Und ein klein Wagon fur jeden Volk. Some credit the California Department of Highways (today's Caltrans) and the building of the Pasadena freeway in the late 1940s. And some credit President Dwight D. Eisenhower in creating federal funding and mandating best practices for his nation's major roadways: the national Interstate Freeway system. Eisenhower may have liked what he saw in Hitler's war. And Hitler's need may have been to facilitate that war. But California's need was to connect Pasadena down the empty Arroyo Seco to downtown Los Angeles. The 8.2 miles of the roadway successfully includes, with some notable quirks, the key elements of the concept. Later, Eisenhower's goal was to allow the entire nation to enjoy the key fruits—safety, speed, and capacity—of a maturing engineering art form.

The timing of these events is not surprising. The mid 20th Century, with the advent of faster vehicles, brought about the need to straighten highways. Most dramatically, the advent of more numerous vehicles created many more needs, and designers responded with new ideas. Highways were divided to make certain that all were going the same direction. Extra median and shoulder lanes allowed emergency exits for failing cars. Restrictions were placed on who and what could enter the Roadway. Minimum vehicle speed was set. Bridges were used for crossing streets. Amazing multi-level structures were invented to avoid traffic ever crossing. Caltrans likes to talk about grade separated, limited access, high speed highway. So distinctive were these roadways that new terms—Turnpike, Freeway, Expressway—were coined to identify this new and 2nd Generation of Roadway.

The solutions contained two key concepts. The first was to control access to the roadway. Typically fences or walls were placed along the entire length of the Roadway and kept wayward deer, cattle, pedestrians, automobiles and even tractors from suddenly appearing on the Roadway. At designed entrances road signs prohibited unqualified vehicles, from bicycles to small scooters. Thus all vehicles were operating under the same rules, going in the same direction, and they were traveling at approximately the same speed.

The first concept allows the driver to concentrate on a single task, which primarily is to follow the driver ahead. (The reader should note that likewise in the 3rd Generation, even further restricting access—only a Rail Car can enter—will allow a computer to concentrate its magic on the task at hand.) The chief responsibility is not to hit the car ahead, principally achieved by following at a reasonable distance. A reasonable distance, for a human driver anyway, is usually defined as one car length per 10 mph and in practice results in a maximum of 1,800, maybe 2,000, vehicles per hour per lane of the freeway. Thus a freeway with four lanes each way, operating effectively near capacity sixteen hours a day carries 2 x 4 x 1,800/hr x 16 hr = 230,000 cars/day. And indeed many major freeways operate at 250,000 vehicles with some up to 330,000 per day.

The second major concept improves the intersection. By means of underpasses and overpasses the freeway crosses secondary roads without the flow of either being impeded. These duty cycles are 100%. The intersection with another freeway is called an interchange. Witness the birth of this huge structure, a monster within an the urban scene.

An early design, the so called four leafed clover, creates an interchange using only two levels of roadway. It does so by successfully allowing the driver, without stopping, to continue straight, turn right, or turn left. A right requires a simple 90 degree turn from the slow lane, while a left requires a complete 270 degree loop entered after crossing the intersecting freeway. The four such loops required give the structure its name.

Later designs, needed to create interchanges which could match the capacity of the incoming freeway segments, can usually be classified as high speed interchanges. High speed turns must be more gradual, and high speed interchanges can't afford the larger land requirements of a full 270 degree turn. Thus unfortunately they must employ three, four or five levels to allow a direct 90 degree turn to the left. The interchange between the Santa Monica (I-10) and the San Diego (I-405) Freeways built in the late 1960s may be the first example of such an approach.

Lets now look at the result of such an approach. Ignore how designers got there. Imagine again that you are from that advanced civilization on Mars. Look at Figure 2-2. Note the size of the interchange. Note the size of the principal purpose of the interchange: the man in the corner. The humans are to scale. All this concrete. All this steel. All to carry that man to his destination. Carry a 160 lb package at best 20 times the speed he can walk, at maybe four times the speed at which he can run (for short distances anyway).

FIGURE 2–2. Man and his freeway.

Why is the structure so large? Why does it have to destroy whole neighborhoods?

First, the vehicles are guided along their paths with the same mechanism the inventors used for its initial guidance: a wheel. Steering is difficult, the car wanders. And so, lane widths are set at a full 12 feet for a vehicle scarcely 5 feet wide. (Go try a little exercise to please the adrenaline junky inside you and drive down the Pasadena freeway, with its 11 foot wide lanes—yo!). Curves are banked and have long radii. Shoulders are built at the edge, and center dividers have margins. All reduce the death toll and all increase the width of the roadbed.

Second, consider the size of the vehicles in which the people sit. And no, we're not attacking the SUV, or that Americans seem to believe they need something called an Expedition to go across town or something called a Sequoia so as to dominate the next guy. Simply stated, the system also supports trucks. Think 18 wheelers weighing 40 tons. And so the designer prudently builds a structure to withstand the punishment of trucks for 50 years. The system is designed for the 40 ton object, ignoring the average far more numerous payload weighing 160 Ib. In terms of weight, for the vast majority of vehicles, there is full factor of 500 between the design burden on the structure and the payload, that is, the primary utility of the structure!

Controlled access, symbolized by the fence, is famous for dividing neighborhoods. The width of a freeway is famous for devouring neighborhoods. One lives either north of the freeway or south of the freeway. Similarly in the 19th Century one lived either on the "right" side of the tracks or the "wrong" side. From these characteristics spring the NIMBY attitude of many areas toward new construction. From NIMBY springs the inability to build more freeways in established neighborhoods.

And what can a freeway do for us? Wonderfully, it enables us to cross an urban area unimpeded at 60 mph. A 150-foot wide freeway can accommodate over a quarter million of us per day. Our freeway system also carries 50% of this country's freight across town and inter-state. Impressive achievements. But how many vehicles can it carry in an hour? How many one way in an hour? That last answer is 8,000. Not a big number if the Dodgers are playing the Giants at 7:05. Not a big number if you, and everybody on Facebook, want to get to work at 8:30.

In most metropolitan areas, given many major, diverse development impulses, jobs are created far from affordable housing. Offices are at city center; housing on the perimeter. The moguls live by the water; their offices nearby. So morning rush hour is from Jersey to Manhattan, from Corona to Newport Beach. Evening rush hour ... well, you know the drill. Areas grow

fettered by limitations in transportation. Transport of a labor force numbering several times (multiple freeways) 8,000/hr is woefully inadequate.

An analogy can be drawn with the limitation of neighborhood by surface streets. Instead of our hypothetical 3 visits a day to maintain 'hood status, an employee travels to work once a day (Americans don't dare adopt the Spanish and Italian habit of lunch at home and two commutes a day). If the urban planner wants a viable plan without "mass transport", that planner wants no employment center to have a workforce bigger than 100,000. That's the maximum number of employees delivered by several freeways supplemented by several boulevards in several hours. The center builds to 100,000; employees spread their schedules just enough; and everything maxes out. Thus a freeway system limits urban employment centers to smaller than otherwise desirable sizes.

Los Angeles is a city which grew up with the car. It adjusted its growth pattern to accommodate the car. And the city's large flat basin topography has allowed an almost pure expression of that accommodation. It is no accident that the city's central business district is surprisingly small. No accident that the city features many "mini-centers" which employ moderate sized work forces: West L.A., Century City, Wilshire, Downtown, the City of Industry, Burbank, Glendale, Pasadena, El Segundo, Del Amo, Long Beach, South Coast Plaza, and Newport Beach to name a few.

In Los Angeles there are at least two telling clichés in traffic related jargon. The first, "How far is it? Oh, about 25 minutes!", expresses one's sense of how difficult a destination is in terms of that most precious of commodities: time—usually estimated with over-the-top optimism. The second cliché is one of pessimism. "I don't care how many lanes they build (it'll just clog up again as traffic builds)". Both clichés express an appetite for more.

With demand exceeding freeway capacity, the performance comparison seen by our north woods friend is even worse. Usain Bolt can sprint faster than many average speeds on today's congested Los Angeles freeways. Average congested freeway traffic moves at about the rate a middle aged person can cruise on his bicycle. Indeed, for example, for the seven miles from UCLA to Marina Del Rey in Los Angeles, at 5 pm on a work week, it is faster to ride a bicycle on surface streets than to take the freeways directly connecting those two centers. Faster too, to ride a bike than to take a car on the same streets. The Los Angeles scene in Figure 2-3 is common, expected, and inestimably aggravating for the commuter and day-tripper alike.

As a cooperative research project by Caltrans, the Electrical Engineering and Computer Sciences Department of UC Berkeley, and PATH, the Performance Monitoring System, PeMS, produces various data on California's urban freeways. One set of data is quasi-real time freeway speeds taken with a massive network of sensors. Figure 2-4 shows data, displayed as a map, taken at 4:53 pm one Wednesday afternoon in L.A.. You just try to get home from work!

As modeled earlier, it is tempting to consider traffic flowing on a freeway network as a third fluid in parallel with traffic on boulevards and small streets. In Los Angeles, the third fluid flows on the freeway network Caltrans designers appear to have placed very approximately in a square grid with 5 mile spacings. With 4 or 5 lanes in each direction each freeway has a capacity about 4 to 5 times that of a single boulevard, and the math works out just about the same.

But let's ask ourselves a slightly different question. Driving on a freeway, have you ever asked yourself, "Where's everybody going? Are they all going to the beach today? Are they all shopping? Is every car in Los Angeles on the freeway today?" Well ... can every car in L.A. fit on the Freeway?! That is, still fit and move at 60 mph? For L.A., we've already seen all the numbers necessary to answer that last question ... NO, is the answer, not even close. Only 1.8% fit.

Don't believe that number? Consider this. At the national average, the 8 million people of central Los Angeles County must own over 7 million cars, and they have 481 miles of freeway on which to drive. Now imagine we were to start, with much fanfare, a single driver to navigate an Escher-esque loop around these 481 miles. If all goes well, at 60 mph, she would arrive back at the starting line in 8 hours. But we can only start a maximum of 8,000 cars per hour on our average of 4 lanes, so only 64,000 cars can play the game. An equal number of course can drive Max Escher's loop in the opposite direction, summing to 1.8% of L.A.'s auto population.

But 6% of L.A.'s cars on average are indeed running 24/7. That's our 10 hours a week in a 168 hour week. If only streets, boulevards, and freeways exist to accommodate them, what happens when a third of those cars' drivers do decide at some time to use the freeways on the way to the beach. Or, at some prearranged time of day, to go to work? Note also in the model of Sidebar 1-1 that drivers spend 100 hours/year on the freeway. A hundred hours is 1.1% of an entire year and given the ratio of cars to drivers, 0.9% of all cars will be on the freeway as a 24/7 average. An average fully half of full capacity. No wonder the freeway system always verges on crashing!

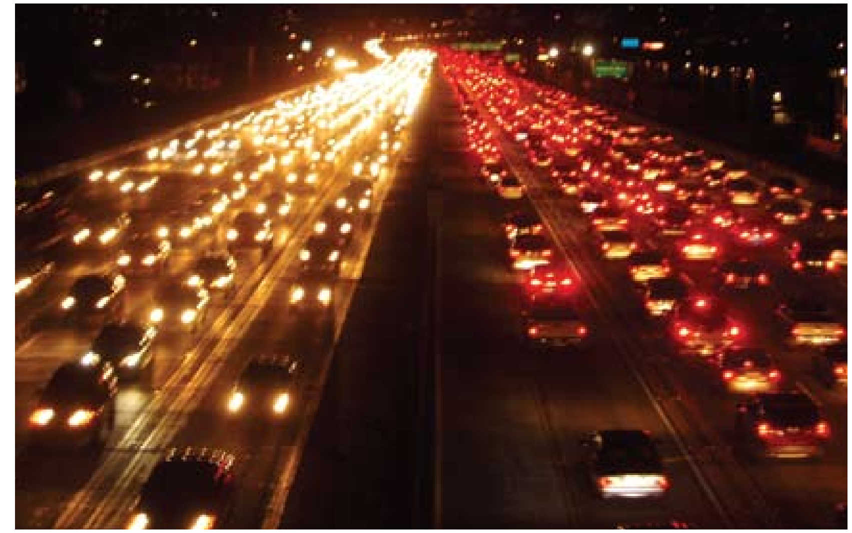


FIGURE 2–3. Evening Traffic on the 405, three weeks after widening.

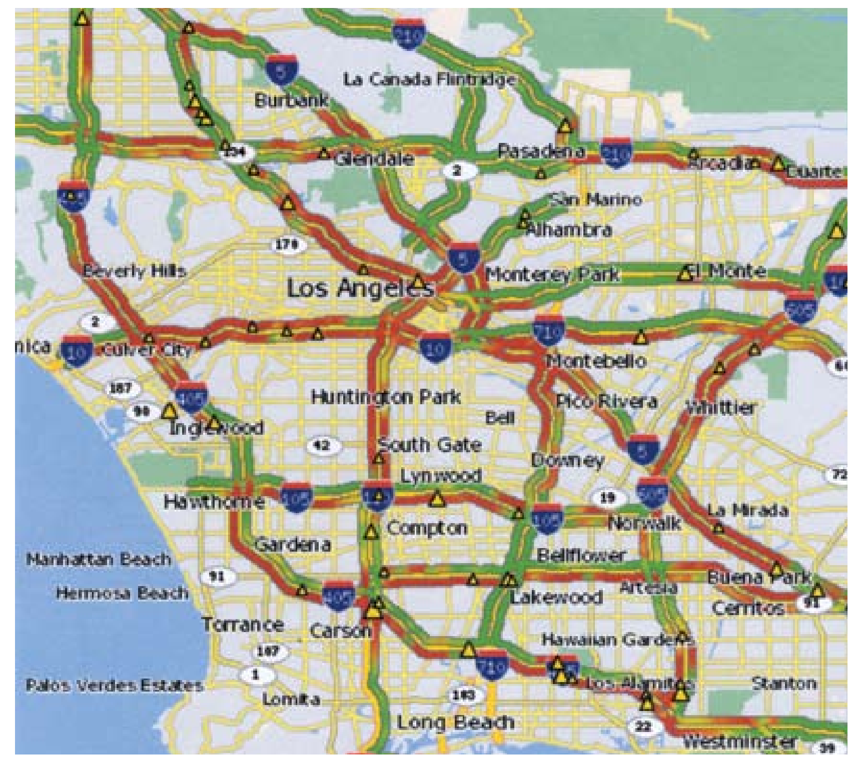


FIGURE 2–4 is a PeMS map illustrating real time traffic speeds one day on LA's freeways as of 5pm. Red indicates speeds below 35 mph and green above 55 mph. Realize a driver will spend a longer time "crawling" through a red area, then "fly" through the green, and to the next red.

With all this in mind, ponder the images presented in the full pages of Figure 2-5. Note the extended time over which many sections of Los Angeles' freeway system are over taxed, beyond capacity, and jammed. Note the changes in scheduling that must have taken place to accommodate the problem. There is no easy way to leave work at a better time. Note how building more probably won't meet the demand, only allow people to leave work at better hours.

To fly, one rents a seat on an airplane for a few hours. In the name of economy one suffers fighting elbows and cramping legs to squeeze into a space 19 inches wide with typically a mere 33 inches to the next big guy in front. Amortizing area for that magnificent promenade known as the center aisle, one rents 5 square feet. But the cattle-car approach makes renting affordable.

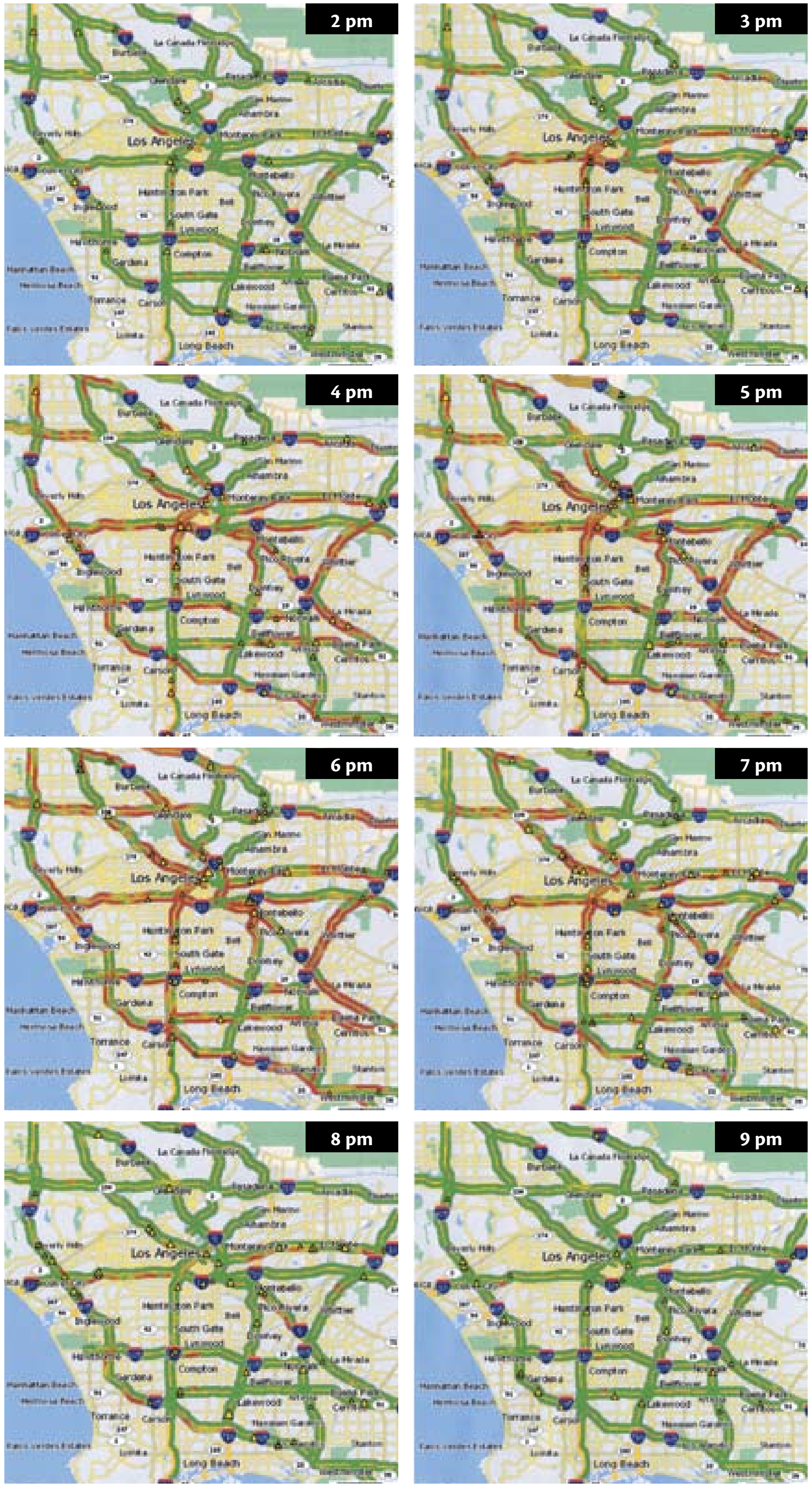
Not so on a freeway. Safety dictates that one doesn't tailgate, one maintains open space, and one rents immense areas of concrete. A happy freeway is functioning at capacity with 1,800 cars per hour in each lane flowing past at 60 mph. With cars occupied as they typically are (1.2 people per car) and using 12 foot wide lanes, we are thus renting 1,750 square feet each. Wasteful by a factor of 350 compared to the airplane. No wonder we devour entire neighborhoods!

Not fair you say, not a fair comparison, because independently moving bodies need more space than "packaged sardines" moving as a single unit. And, well, you're right. So… how would Rail Cars compare? Two-way side-by-side Rail traffic fits into a 12-foot wide path; each Rail Car's 1.2 passengers would occupy a 7-foot length; 80% occupation at full capacity. That's 44 square feet per passenger. Nine times "worse" than the airplane, but 40 times better than the freeway.

Figure 2–6 depicts the seating arrangement for 348 airplane passengers in a hypothetical super-super stretch B737, a lone driver occupying his space on a road, and 38 Rail Car passengers. Two way Rail traffic is depicted in uniform four Car trains, and each Rail Car is occupied, on average, by 1.2 passengers. Please note that a freeway lane is somewhat wider than the usable width of a B737's body, and that needed by a two way 3rd Generation Roadway. Strictly scaled only one occupant, and 1/1.2 automobiles, fit on the page.

If the state were a good landlord, buying freeway real estate at $200 m per mile, at what the selling agent said was 10 X expected yearly gross rentals for a good route with 180,000 cars per day, the state would rent

FIGURE 2–5 uses real time PeMS data to illustrate congestion on the Los Angeles freeway network. Green indicates traffic flow at above 55 mph, yellow as traffic slows, and red denotes



traffic flowing at less than 35 mph. Try navigating across town during the morning rush from a little before 7 am to after 10 am, or the afternoon rush from before 3 pm to 8 pm.

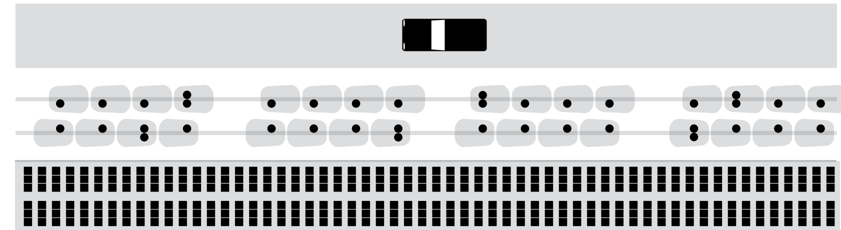


FIGURE 2–6 depicts a freeway lane with a single vehicle which needs the entire length shown, Rail Cars with their passengers on a two way Roadway, and seats on a very long airliner. All to scale.

at $0.31 a mile. Or $18.40 an hour for a car going 60 mph. Now a good way to teach your teenager to safely drive the freeway is to urge them to maximize the area they rent. Maximize a safe trailing distance, don't travel next to another car, and head for open space like a football running back. Double your space, and get a $37 per hour value for half price! Good for your child's safety, bad for mass transit.

We only want the freeway to be a solution for mass transport. Its victory creating high speed and continuous traffic flow wonderfully allows the automobile to show its glory, but its pyrrhic victory is achieved at such high cost in terms of real estate and dollars that established and dense communities reasonably reject its invitation. In its design and subsequent use, the paradigms employed limit its ability to transport the multitudes. It works so well for the few, we want it for the masses. If it were only so.

CONGESTION

Traffic flows. Like a fluid, it flows smooth and easy as individual drivers assess conditions and adjust. But as traffic thickens, it becomes viscous, drivers interact, they react, acceleration enables acceleration, braking begets braking. Sometimes the secondary acceleration and braking are bigger than the primary, hence waves generate; with multiple lanes shear develops, lanes are changed, turbulence follows. Confluence with a side stream, one cell phone user who doesn't drive like the others, one accident for some to view, and traffic snarls. Stop and go. Throughput drops. Jams lengthen.

Congestion is a wake-up call to the transportation department. Here is the place where improvement is needed. Here is where tax dollars can be efficiently applied. Highway improvements become the passive response to otherwise random urban development.

But this short section may surprise you. As much as we dislike traffic congestion, and as much as we discuss congestion, its direct effect is less than is that of the system by which we drive. Congestion, it is estimated, costs the average driver in Los Angeles 92 hours per year, and nationally it is estimated that drivers waste 4.2 billion hours. Presumably we can assume the vast majority of these delays are incurred by the very 100 million drivers targeted by the 3rd Generation Roadway. So if we were to aggressively assign 4.0 billion of these hours as lost by these 100 million drivers, they on average would lose 40 hours per year each. Less than one hour a week out of their 10. Would 9 remain if traffic were light? If so, we must conclude that it is normal transportation by automobile that requires 9 hours to navigate our weekly travels. (These numbers roughly parallel those published in the Texas Transportation Institute's annual Urban Mobility Report which pegs the direct annual cost of congestion at about $80 billion—approximately equal to 4.0 b hours X $20/hour.)

Having quoted national statistics, the answer doesn't seem quite right. At least for the suburban or urban surface street. Recall the last time you drove when no one was on the road. You remember, the 2 am escape for Summer vacation, the midnight run to the grocery store. How fast, how pleasant, how clear of congestion. National congestion statistics may compare delays to normal daytime traffic, and the "normal" delays we've all come to accept. And we've all come to expect to drive at 18 mph!

Time lost on a freeway is an easier quantity to measure. One's speed should be the highest speed at which all drivers can safely navigate the roadway. The highway department says that's 55 or 65 mph. The average driver says that's 70 mph. And when that speed is not obtainable, our frustration is immediate. Take a poll in L.A. and the second reason for wanting to leave Southern California is traffic (yes, housing cost is first).

The real damage may be indirect. Our frustration stems from our reduced expectations. And an unexpected line of red tail lights as-far-as-the-eye-can-see is certainly a bummer. Dinner's going to be late. Psychologists will verify that people are most unhappy when they are forced to lower what they expect of life; their most happy moments come when their expectations are exceeded. Economists will tell us that uncertainty causes us to build in margin. Traffic congestion makes it impossible to predict our time of arrival, so we start our trip a little early. The efficient "just in time" production of ourselves at the big meeting does not work. The economic inefficiency can be major.

Think of the term "rush hour". Sounds almost quaint. Heavy traffic hours now occur for many hours in the afternoon, many hours in the morning. We have all modified our schedules to accommodate traffic. We go in early, we go in late, we telecommute. Presumably we drivers all calculate a crude optimization to minimize the damage caused by congestion delay, congestion uncertainty, and the less than optimum time we then chose to arrive. No wonder that, when a freeway is widened, and everyone redoes their individual optimization equation, congestion returns.

And no one doubts that congestion is getting worse. More traffic every year on the same roads. Take a look at Figure 2-7 generated from U.S. DOT RITA BTS (got all that? The United States' Department of Transportation's Research and Innovative Technology Agency's Bureau of Transportation Statistics) data. A similar plot has appeared in the magazine "The Economist" to explain congestion. Since 1960 the total passenger miles traveled on American roads have quadrupled; the total length of all roads has grown

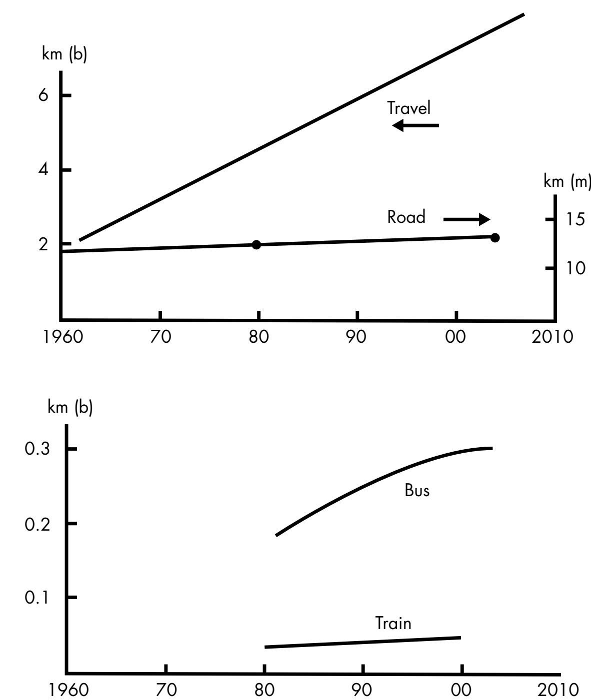


FIGURE 2–7. Contrasts the fourfold increase in total U.S. travel to a virtually static road infrastructure, and the relatively infrequent travel by bus and train. Units on the left are billion passenger-miles and on the right million lane-miles.

only by 30%. If we were extreme optimists, we'd say we're simply making more efficient use or our roads. Efficient use of a capital investment, right?

So far, the discussion has centered on large numbers and the capacity of highways to handle traffic flows—maybe "macro-congestion" is the word. But as every driver knows, congestion also comes with a finer structure—a conflict between individual vehicles in small number—that takes place of smaller streets. Different vehicle types, different driving habits, different objectives all contribute. The truck or bus changing lanes, the tourist who doesn't know where he's going, and the double parked busybody are but singular examples. Vehicles arriving in number at a special event, exiting from the shopping center, or turning the corner, upset traffic flow with disproportionate effect. Maybe "micro-congestion" is the word.

The freeway seeks to alleviate these disruptions. And it does so by demanding qualified vehicles, minimum speed, and carefully designing exits, entrances, and merging scenarios. Thus the 2nd generation roadway obtains uniform flow, and consistently obtains a capacity for traffic close to the numbers discussed. So too does the 3rd Generation Roadway, which goes a step further and restricts vehicle access—only a Rail Car may enter—to just one type. Optimization is such a simpler art with one vehicle type automated with enforced performance.

Thus, even compared to the 2nd Generation, the 3rd Generation will achieve both extreme capacity and uncluttered operation. Obviously, at interfaces between the Roadway and 1st generation streets, designs must be careful. But if Rail lines directly exit into garages built exclusively for Rail Cars, major potential conflicts are resolved. Huge traffic flows simply exit, passengers disembark, and the Cars park themselves. The garage is part of the Roadway. At the other end of the journey, in residential areas, streets are better able to handle the smaller flow. Certainly by removing massive numbers of travelers from the street, the 3rd Generation Roadway reduces ordinary congestion.

PUBLIC TRANSPORTATION

A proper discussion of public transportation will be underrepresented in this book. While clearly buses, urban trains, and subways have a place in urban society, and although this book is describing in some detail the limitations of surface streets and freeways, the dominance of the automobile is vividly demonstrated in most societies. The automobile accounts for about 88% of all miles traveled in this country. Public transportation about 5%.

Of course, honesty and the ethics of full disclosure dictate a mention that this book is written in Los Angeles! It may well be true that nobody walks in L.A.. It is a city which grew up with the automobile, spread out accordingly, and now is configured very poorly for conventional mass transit service. Not only is the population density relatively low, but traffic emanates and converges from many disparate areas. The ability to service such diverse and geographically extensive routes is exceedingly difficult. Add the fact that over time heavily traveled routes change, and the problem gets even more difficult.

Obviously, buses suffer the indignities of congested streets and traffic lights to the same degree as do automobiles. Due to schedules, transfers, and many stops, transit times for typical routes are typically double those of surface automobile trips. These times do not account for additional effort to get to and from the pickup and drop off spots. In L.A., those who can afford a car, and are able to drive a car, generally avoid the bus. The median income of one who rides a bus in L.A. is $12,000.

Having said this, bus transport plays a contributing role in urban transportation. For the poor, the less able, the lightly rooted, and for those who don't want the responsibility of driving, the bus is vital. In Los Angeles the average weekday number of bus passenger boardings is 1.2 million. Roughly the same number take the bus in Chicago. New York boards twice that number. Please beware the term "boardings"—if you commute to and from work with one transfer each way you've boarded 4 times.

If the bus is viewed as the public equivalent of surface street automobile transport, the "light rail" metro system is the equivalent to the freeway system. That is, both the metro train and the freeway use exclusive right-of-way routes with limited access and eliminate intersections. And as with freeways and freight trains, "light rail" right-of-way is hard to obtain and breaks neighborhoods. But Metro trains can obtain high speeds, and unlike an automobile in freeway congestion, metro trains can usually maintain a schedule.

Unfortunately as built in L.A., many sections of "at grade" metro-link line simply exercise complete priority at intersections, enforcing this priority with mechanical guards and lights, and thereby creating dangerous "crossings" for city streets. Indeed, the 23 mile Blue Line that runs a surface route through city streets from Long Beach to Los Angeles has incurred 93 fatalities since 1990. The L.A. Unified School Board opposes street level crossings near their schools. As reported in the "L.A. Times", Steven Semple, retiring from a long and successful tenure as President of a major university in the center of Los Angeles, USC, describes his biggest setback as the " 'major, major, major disappointment' that he could not persuade transit authorities to place the Expo Line light-rail route fully underground along Exposition Boulevard between USC's main campus and the museums, sports facilities and gardens in Exposition Park. He said the line will create physical and psychological barriers and dangers for pedestrians." Sections of light rail along L.A. freeway medians and those sections underground are far safer—and less divisive. But sections underground are extremely expensive to build and thus are limited in length.

Daily boardings on the 73 mile long Metro rail system in Los Angeles are 300,000, about 1% of the metropolitan area's many trips. Realize that most metro rides are major undertakings—to cross town to work for instance, and many automobile trips are small excursions to the grocery store. That said, note that fully half of all users take the Red Line train to avoid a single segment of freeway—US 101 over Cahuenga Pass—to get downtown. So again, unless you are one of a lucky few whose route to work and home are serviced, travel times for a given distance again are roughly twice that of driving. A doubling of gasoline prices from $2 to $4 a gallon increased passengers by only 10%. Rail riders in L.A. have a median income of $22,000.

Subways have the ability to penetrate dense urban areas. Ridership in New York City's network approaches 5,000,000 passengers on a weekday. But commute times for New Yorkers are the longest in the nation, and subways contribute to that statistic. Use of the subway also tends to induce a bimodal existence—daytime at one end in Manhattan, where you work, evenings in Brooklyn or Queens at the other end, where you live. At best there is a one-dimensionality to the urban experience—if it's near the K line you can get on/off and visit/work. A good location can reduce the time it takes to travel, and real estate values rise if a subway line is close. With the subway's ability to avoid the urban intersection, to obtain unfettered high

speed, and not divide neighborhoods, it is the public system that most closely resembles the 3rd Generation Roadway.

For intercity service, of course, Am Trak maintains a vestige of past service. The plane, the auto, and until recently the bus have virtually supplanted the train. As singers and American cultural icons Arlo Guthrie and Willie Nelson have observed in the ballad 'The City of New Orleans', "And the steel rails still ain't heard the news ... this train has got the disappearing railroad blues."

Using public transportation seems so socially responsible! The system so green. So many travelers sharing the same seats. So many in one vehicle. The vehicle always in use. But is public transportation that green? Is public transportation that cost effective?

The cost of a bus that has 50 seats or that of a commuter train car that holds 200 passengers must be cheaper per seat than an automobile! Well ... no, they aren't. A new automobile (we exclude SUV's and light trucks) on the dealer's lot turns out to be a bargain. At the national average of $22,000 and seating 5, a seat costs $4,400. L.A. recently bought 2,600 clean, natural gas burning buses to replace a diesel fleet for $1.2 billion. That's $450,000 each. And for delivery in 2010–2011, L.A. is buying 700 or so NABI (North American Bus Industries, Inc.) 40 seaters for about $300,000 each. Volvo sold about 1,000 Nova model buses to the Canadian market for about $500,000 each. Brazil seems to buy chassis from Mercedes Benz and assemble the Marcopolo for considerably less at about $170,000 each. Seating about 50 for $500,000, that's $10,000 a seat.

Train cars are no better. Bombardier of Canada has a large market share. In 2006 Sweden purchased 80 high speed Bombardier cars for over $4 million each. In 2003 Montreal bought 22 bi-level commuter cars for $44 m. Reuters and others report that the Delhi Metro Rail Corp. has ordered 424 low cost Bombardier metro cars at $727 m for 80 kph service. L.A.'s MTA is having Italian Ansaldobreda 76 seat (with 141 standing spots at 6 people/m2) cars assembled in Southern California at $2.9 m each for 105 kph service. Hyundai sells a new model with safety crumple zones for $2.35 m, although discounts seem possible for good customers. If we generously use 100 seats purchased for $2 m, that's $20,000 a seat.

Sampled over a full day, the percentage of filled seats within public transportation vehicles is much better than that of the private automobile. We have noted that the average automobile operates fully 6% of the time. Of course with a disappointing national average 1.65 people aboard—that's the driver and on average all of 0.65 passengers—the automobile operates only 1.65/5 full, and its seat utilization is only 2%. A bus is far better. Given L.A. has 1.2 million boardings per weekday—and half that on weekends—if we assume each boarder takes a 20 minute ride, then each seat must be warm 10% of the time. The 300,000 Metro Rail boardings in L.A. with its 374 train cars also imply 10% [20min/1,440min]x [300,000boardings/374x100seats]x [6/7] .

New York does somewhat better on a far larger scale. With almost 5,000,000 passenger boardings onto subways and 2,500,000 boardings onto buses each weekday, New York's public transportation has about 15% of the seats warm on a 24 hour basis.

What's the energy efficiency of public transportation? The NABI seats 40 and but gets only 3.4 mpg when burning diesel. If it's competing to be green with a Prius getting 48 mpg with 2 people in it, the NABI bus had better have 29 or more passengers in its 40 seats. Of course, 15 Prius automobiles plug a street far better than a single bus. The New York Subway, which publishes electrical power consumption for its electric fleet, amazingly delivers passengers using only 1 kWhr each. 1.8 billion boardings per year for 1.8 TWhr.

The Automobile Association of America says the cost of owning a car is about $8,000 per year. Using it for 4 round trips a day occupied by 1.65 people, that's 13.2 daily boardings in MTA speak, implies $1.66 per boarding. In the Spring of 2010, to board a bus in L.A. was $1.25. To board the rail line was $1.25 . Subsidies for L.A. bus fare are said to be $0.78 a ride, meaning the real cost is $2.03 per boarding. Subsidies for rides on an L.A. commuter train are quoted at a seemingly outrageous $7 to $10 a ride. David Lazarus of the "L.A. Times" claims fares cover only 28% of the MTA's overall costs. It is true, as critics complain, that automobiles are also subsidized with free roads. But government transportation expenditures, at $100b/yr nationally, are only $0.10 per 'boarding', and the urban dweller tends to get short changed on that. This argument in turn is also disingenuous. Different accounting rules apply. The government is largely only repairing roads; all but written off is the wise investment made many years ago, when it was cheap to obtain right-of-way and build. The cost of building metro Rail lines, and the bonds sold, is counted against the cost of a trip.

And Metro Rail lines cost about that of a freeway. The "L.A. Times" reports that the below grade (tunnel) sections of the red line to Santa Monica are projected to cost $280 m/mile, the above grade sections about $150 m/mile. Since the LAMTA reports 8,000 boardings per mile of line, and a typical

freeway has 200,000 automobiles travel past any one point, if a train boarder on average travels 25 miles (a generous assumption), each system gets used equally. The construction capital comparison is thus a wash.

We live in a diverse world. We do diverse things. We go diverse places. To plan, each of us builds infrastructure. With private ownership, we buy and maintain the automobile or bicycle to our tastes, no minor task. With public transportation we access schedules, we memorize routes, we know the routine. But as life pushes us out of our routine, the automobile's dominance increases. If we need to go to new areas of the city, the rules of the road don't change, we have our GPS, and roads go everywhere. But the rules of the city's transportation may change. The game unknown. What are the best lines, the required transfers, and the schedules? The very existence of public transportation to our destination comes into question. An automobile reduces our unknowns; it's ours; it meets our standards—clean or cluttered, luxury or basic, reliable or barely good enough—we know its buttons.

A crude analogy can be made to our cell phone and the public phone. In principle the pay phone looks so attractive. We use it only when we need it. Someone maintains it for us. But now we need to locate a pay phone, it might be dirty, it might be in use, it might have new buttons. It's simple and cheap, but it presents unknowns. The cell phone on the other hand may be expensive and complicated; but it's ours, it's ready when we are—we know its buttons. And … which is dominant? The Rail Car will be ours, as familiar as our automobile, but rather than the simple expedient of a Google map to tell us where to drive, the computer will actually take us there. The unknowns even less.

Clearly public transportation has a central role in our society. For anyone who cannot afford a car, for anyone who is unable to drive a car, public transport is vital. And for anyone who is lucky enough to regularly commute along a path serviced by public transportation, it is a god sent. Transport provided by the Redding Railroad, of Monopoly game fame, enabled the author's uncle to teach anatomy in downtown Philadelphia while living in rural Pennsylvania. A friend lives in leafy Evanston and teaches law in downtown Chicago. Forty five minutes each way reading the paper, writing the lecture, or taking a snooze is so to be preferred to the freeway drill.

In summary, given comparable cost, and service to the disadvantaged, there does exist a net social benefit in urban public transportation. But, from an individual's viewpoint, once an ability to afford and drive a car is obtained, a preference for the automobile is amply demonstrated. Convenience is too powerful a motivator.

Soon, in the next chapter, the Rail Car outlined will have properties to close the gap in social responsibility. As a vehicle scaled to have only 2 seats, if it carries on average 1.3 people and if used on today's time average of 6%, its warm seat performance will be 3.9%. With a projected cost of $16,000 a vehicle, the seat cost will be $8,000. Getting about 100 mpg on the street, the vehicle will burn half that of a Prius, and use less fuel per person per mile than public transportation. Shielded from the wind in trains, at high speed, the vehicle will travel 9 miles on a kWhr of Rail provided electricity. The convenience of an automobile in light traffic remains. The convenience of not actively driving matches that of public transportation.

BUT WHY INTERSECTIONS?

In this chapter we have identified the intersection as a villain, condemning traffic to average speeds incompatible with modern goals. With its partners, human caution and slow reflexes, the intersection also limits traffic capacity, which in turn limits urban density. But as we end this chapter it is important to remember the obvious, which is why the intersection is tolerated and indeed essential to today's transport.

We live in a two dimensional world. Yes, yes, there is a third and maybe more if you believe in string theory, but unless you "slip the surly bonds" and fly, we all spend our entire lives on the surface of the earth. And a surface has two dimensions—with any two points on the surface separated by a path distance measured with two dimensions. But even two dimensions are one more dimension than public transportation can handle. An inherent problem of any conceivable public transportation system when it groups relatively large numbers of people into a single vehicle is that it transports them on a line. A bus line. A subway line. A railroad line. A flight path. And a line is intrinsically one dimensional. Access to the 2nd dimension is achieved with something called a transfer— to another line.

Sometimes a line can service a community. Air travel in a sparsely populated Chile is both inexpensive and convenient. Chile, a nation shaped like a string bean, and separated from the world by the Andes and the Pacific, has its major cities—Arica, Santiago, Puerto Montt, Punta Arenas—strung in a straight line. How far do you want to fly north or south? But most of the

world's countries require transport in two dimensions. Airlines have spokes, hubs, and transfers. And the act of transferring airplanes takes the inconvenience associated with a red light at an intersection to a whole other level.

Freight can be serviced by lines; no one minds if their cargo waits for a transfer as long as it gets there on the scheduled delivery date. Indeed more than 40% of this country's freight goes by train; and of course virtually none of its passengers.

Within a single city the same rules apply. Buses and train/subways achieve two dimensional service with transfers. The transfers take time, schedule coordination, frequent service by the provider, and effort by the passenger.

Stated simply, the world doesn't want one dimensional lines, it wants two dimensional grids. And grids require independent transport for individuals, each able to choose direction freely and independently at each node of the grid. Also stated in fundamental terms, the intersection allows a roadway network to be laid out in a grid, most commonly in a square or rectangular array. Each intersection allows an individual driver to make a choice—left, right, or straight—and after several such choices his path can connect any point A with any point B. You want a grid.

Additionally grids, particularly grids constructed with city streets, allow development at an appropriate density. And society has built a length of grid based streets far, far greater than that of train or subway lines. And the need is clear. On Saturday, if you want to deliver boxes to Aunt Sallie, you want an alley near her back door. The subway line doesn't go there.

Unfortunately grids, intrinsically, also come with a problem of their own; inherently they have frequent intersections. And so we suffer intersections. To avoid the delay of an intersection, we invent the interchange, its upgraded cousin. But to date, the interchanges we've invented and come to know are monsters in their own right.

MASS MOBILITY

Let's end this chapter by spending a moment thinking about your choices in transport, and let's broadly define transport, and broadly pick the distance over which you might want to transport yourself. Let's say you want to move from point A to point B, which might be separated by anywhere from 1,000 millimeters to 1,000 kilometers, that is, a spread in magnitude of six orders. Let's look at your principal options: your own two feet, your bicycle, your car, the bus, the train or subway, and finally the airplane.

For less than 100 meters, no one would seriously consider anything other than walking, unless of course, you were handicapped in some way. Only for more than about 400 kilometers, would the airplane be your choice. Why? A scientist's answer would include the word "latency", or its rough inverse "availability". In the usual definition, latency denotes the time between when a decision has been made, the impulse, and the time at which a noticeable consequence begins, the response. Time is only the usual quantity considered; others can be used for the figure of merit. A business community answer might monetize a slightly different concept "barrier to entry", and a teenager might ask "how much hassle?" before the response follows the impulse. In tech circles the term "friction" likewise connotes an individual's perceived or real set of complications before use of a new toy.

The latency for walking is minimal. The "availability" of walking is huge. As long as you've maintained the requisite infrastructure—grown up big and strong, stayed healthy, and eaten your Wheaties for breakfast—the preparation for movement and the resultant latency determining task is simple ... stand up! A very easy action. On the other end, increasingly, the ignominious prize for longest latency/largest barrier is awarded to the airplane. The airplane may go fast, but you are justly appalled at the time and effort you and the infrastructure have endured before you leave the runway. The "availability" of the airplane is small. Taken to the absurd, latency explains why you'll always walk next door and never take an airplane.

Your other four options fall in between. Two of them, while requiring some preparation, still have low latency. The bicycle has to be in a "parking" spot nearby; you have to have suitable clothes for the weather and for pedaling. The car is perhaps easier. The parking spot required is bigger and maybe further, but as long as you've maintained the appropriate infrastructure—bought the car, paid the mechanic, got your license, and filled the gas tank—the main impediment is getting the key. It is the minimal latency or the availability for easy usage, along with the comfort, speed, and range of the automobile that makes it so dominant.

And two options have far higher latency. Society has had to provide the bus, train or subway, they are public transport, and your latency involves getting to where it has been provided, and after transport, getting to your final destination, point B. In getting to and from public transport you will have to carry whatever you've chosen to take to point B. Additionally your latency has another term, you have to get there when it is provided.

Synchronizing your timing with the city's will add complications to your decisions even before you begin to move. Third, mid-transit there is the latency of transferring lines. En route, accommodations must be made for other travelers—most noticeably frequent stops and short waits required for boarding and unboarding. The route may also be indirect to maximize the city's efficiency.

As a measure of society's responsiveness to latency and the consequent dramatic influence of latency, consider the quasi-public transport system known as car pooling. The principal impediments for, say, two colleagues at work is the question of "when" along with a little bit of "where" if they live in the same neighborhood. How often do you carpool? What percentage of the work force carpools? On the surface carpooling seems to be a small burden, such a small change in our automobile convenience. But people want any possible release from constraints. There is such value in free movement.

Transfers and scheduling also greatly degrade air transport. Witness the VIPs' private jet, ready to go when they are. But, having awarded the airplane the sad prize for the "most difficult to access" transportation mode, we note that once flying the friendly skies, the freedom is marvelous. The progress continuous. Only rarely must an airplane slow from its maximum cruise speed. Unlike the automobile on the metropolitan street, the machine is used to its maximum capability. Why? The airplane's "roadway" is three dimensional. An FAA air traffic controller may have one of the most stressful jobs on earth patrolling airport approaches, but mid-flight an airplane's freedom is awesome. By separating planes mid-flight by elevation in 1,000 foot "lanes", the FAA has created vertical "interchanges". A concrete freeway achieves its magic by working with two to four levels of roadway; for commercial cruising between 19,000 and 42,000 feet the FAA has mandated a system using 24 levels.

Mass transit. Absorb that term for a moment. Only those forms of transportation above with high latency and low availability—the bus, the train, the plane—would be classified as mass transit. Each of the three forms with low latency—walking, the bicycle, and the car—are not for masses of people with multiple needs. Walking and the bicycle can transport massive numbers of people, witness walkers in New York and New Delhi and bicycles in Ho Chi Ming City and Amsterdam, but for most people those two modes are limited in range and speed. Only the car has low latency and range with speed. But, alas, no roadway exists for automobiles to transport truly massive numbers of people.

In summary, we seek three things in transport. First, low latency—that is, easy access and start up. Second, reasonable speed, reasonable comfort, and exceptional safety during transport. Third, which society needs, is high capacity—the ability to move massive numbers of people who need to cross paths. With the exception of safety, today's automobile achieves the first two. In addition to safety, the 3rd Generation Roadway can add the third.

3
THE RAIL CAR

Your urban vehicle is nimble and efficient; sitting in your garage it has attractive features similar to your road automobile, but, for operation on the Rail, comes with a suite of sensors, adaptive cruise control, on-board computing, and a sophisticated mechanical adapter for mating Car and Rail together. We'll call your vehicle a Rail Car.

Remember the design, development, and delivery of the Rail Car is a product of private industry. The Rail Car's only regulated requirement is for it to be "street legal". The state and federal governments, working through their departments of transportation, will provide the requirements and the definition of street legal. Of course, compared to today, the definition of street legal now has some new twists! Compatibility would need to be assured for both surface streets and the Rail system. Presumably the present freeway system would be off-bounds for the Rail Car in the same way freeways are now off-bounds for bicycles and small motor scooters. The Chevy sedan, the SUV, and the truck will belong to the 1st and 2nd generation roadways; and the Rail Car will be for the 1st and 3rd. As it is able to travel both the 1st and the 3rd, we'll say our Rail Car has dual mode capability.

The importance of the Rail Car possessing dual mode capability should not be underestimated. As we learned in the last chapter, the 1st generation street works very well in a small town. It is not until traffic density increases and as the distances traveled in-town increase that problems grow. The Rail Car can travel surface streets for "the last mile" home, while the 3rd Generation Roadway will complement our present system only when needed. Thus, while the U.S. has roughly 8,000,000 lane-miles of 1st and 2nd generation roadway, in the next chapter we will soon see that merely 40,000 miles of 3rd Generation Roadway will be needed to fully service the nation. A matrix of surface streets feed the occasional stretch of high-speed, high-traffic-density 3rd Generation Roadway.

But the individual uses one piece of machinery in his travel from door-to-door. The individual drives the local streets; the computer drives the Rails. Thus, drivers are assisted in their Rail Cars in much the same way we are assisted by computers in today's society. Note, for example, that we personally handle the math for the equitable and politic division needed when the restaurant bill arrives, or when the number of eggs for the breakfast gang needs to be calculated; but computers, for example, compile the repetitive data needed for national health care records or the precise relativistic correction to Kepler's laws for an exo-solar-system meteor flight path. Likewise, drivers will navigate their own driveways and small streets skillfully adjusting to a myriad of special situations, from slowly crawling when Aunt Sallie's three-year-old is playing ball with his buddies or around your misplaced lawnmower, then circumnavigating the double-parked truck and pulling up to the loading dock in the alley. On the 3rd

Generation Roadway, the computers will handle the standard calculations occurring in mind-boggling numbers at mind-boggling speed for cruise control adjustments, merging, and routing; but there is one type of car, one type of Rail, very few scenarios, and the computers will be spared the finesse required to match the skills of your average driver on small streets.

Dual mode Cars will be widely used. The approach rewards the Rail Car owner with the exclusive ability to use the Rails for a faster and safer ride, even as he sits in a small vehicle, securely isolated from street traffic. This reward and isolation will motivate the individual driver to freely choose a small vehicle. The 3rd Generation Roadway is the carrot which convinces her to buy the only useable product—to happily suffer whatever negatives a small vehicle may have. The next time you wait at a stop light, which assuredly will be soon, observe the predominance of passing vehicles with one occupant. What advantage does their huge vehicle convey at this particular instant? What probable advantage for this particular day? Why are they driving such a behemoth? Yes, the driver is prepared for many scenarios. The big motor allows high speed in the country and on the freeway. The big vehicle drives smoothly, its height allows better visibility, and its weight achieves some degree of safety when colliding with lighter vehicles—although not if with a telephone pole. And yes, the guy with the biggest pickup gets the girl. Now, look at your fellow drivers waiting at the stop light. What would they gain if they drove a small electric vehicle? Some gas saved, yes. A good feeling for being green, yes. But they'd still be sitting there at the stop light, defending themselves against the SUVs and the "light" trucks. What would they gain if they had a Rail Car and a separate Roadway? Your answer is the reason to design the vehicle that is the subject of this chapter. By rewarding users of very small electric vehicles with far faster and safer travel, with full isolation from larger vehicles, the new roadway and its specialized Car will be the standard for urban travel.

And individual very small electric vehicles will achieve far greater positive ecological impact than will electrifying today's large automobiles. Electrifying today's 100 hp, 3,000 lb automobile will not greatly reduce energy consumption and may indeed increase automobile carbon footprints. While it is sometimes assumed that electric vehicles have "zero-emissions", the assumption is clearly false. The generation of today's electricity is sometimes dirtier that burning gasoline. This is certainly true where coal is predominant, as coal emits more CO_2 and typically more SO_2 per unit of energy generated than does gasoline. As well, although a large power plant

may be more efficient, it is estimated that up to half of all electricity generated never gets to the light bulb—or the car's battery. Some is lost to ohmic resistance in the copper wires; some is radiated from our long transmission lines which become antenna-like geometries as they conduct power at 60 Hz. That is to say, transmission lines 700 miles or so long form ideal quarter wavelength antenna structures. So we must generate up to twice the energy needed to power our electric cars. This chapter will calculate that small Rail Cars will need only 1/10 the energy of today's U.S. fleet average. Given our fleet today uses 20% of our total energy consumption, we could conclude that wide use of the 3rd Generation Roadway will enable a third of our citizens to travel as freely as we do today using only 2% of our present per-capita energy needs to do so—albeit with a better electric distribution system. 2%! No reason to feel guilty about personal mobility.

Government specification of a single vehicle type is for the common good. The freeway, our 2nd generation of roadway, creates its magic and promotes uniform traffic flow as the government restricts access to certain vehicle types—all capable of speed but of incredibly different sizes. In comparison the 3rd Generation Roadway will have restricted access, not to a set of very different vehicles types, but to a single vehicle type, suitable for people and small loads. Thus the engineer can create diminutive structures, and the control equipment can focus on a simplified task.

Perhaps the world will be a little more complicated with two choices in the garage. Which car do I take? What optional trips are eliminated for today if my choice is wrong? If I choose not to own an automobile, shall I rent an SUV for the big weekend? But the modern world has presented us this type of complication in a hundred different scenarios. Only in a world of today's size and complexity could we be presented with the option proposed here. Only in a world of this size would we need such an option. Now realize that the world of people and the size of our cities in all likelihood will continue to grow. Maybe, if society wants to stick its head in the sand, it should simply claim there are too many people.

The Rail Car, detailed in this chapter, will be somewhat less than optimum as a road automobile—lacking in power, seating, and storage capacity. It is compromised to be compatible with the Rail. Its size and power will be reduced. Its passengers will be limited to two. But this chapter will define a Car with attractive features: a Car that will be nimble and highly suitable for the urban and suburban street, a Car that will be our first choice for the majority of our journeys.

Those who complain should look at today's automobile. Its usefulness in the city is compromised to accommodate the freeway, the lonely highway in Nevada, and the family expedition. That is, how absurd is it to cruise the grocery store parking lot with all the machinery necessary to go 140 mph on a ribbon of asphalt? Machinery to carry a load of 1,100 Ib? How absurd is it to drive alone to work in a 5-passenger car? Or have 300 hp for a 160 lb person? Today's automobile is certainly negatively compromised in an environmental sense, consuming far more non-renewable energy than necessary. Its size is far from optimized in crowded urban confines. Its lack of maneuverability an inconvenience. Its purchase price more than it should be.

One can equally note how the urban street compromises the automobile. Unlike the airplane in the open sky, our roads fetter the machinery we bought. The automobile you bought seldom goes as fast as its design enables, seldom flexes its agility on the open road. Note those clean, mean machines as they idle, scoot, and brake to a stop as they hobble through the city. We drive on average at 20% the speed an open throttle can deliver. As songwriter Joe Walsh laments, "My Maserati does 185; I lost my license; now I don't drive."

To design a "street legal" Rail Car, in addition to the usual panoply of concerns for the surface roads, will entail, at a minimum, compatibility with the mechanical properties of the Rail, communication with its computerized subsystems, responsiveness to computerized instructions, safety for the passengers, and safety and assurance for operation of the system taken as a whole. The Rail coupling mechanisms—we'll call them "hooks" or to borrow a word from railroad train terminology, "Doobies"—will have difficult specifications.

Car weight, Car width, height and length, bumper geometry, bumper couplings, docking sensors and electronics, minimum acceleration, and computer capabilities will all have definite specifications. Reliability of the Cars will be a major issue. Minimum power to enter the Rail system, and minimum power to operate while on the Rail will be defined. Performance requirements and protocols for docking and decoupling from the "train" mode are to be specified. Additionally, power supply and battery specifications will insure compatibility given the very likely probability that the Rail will provide electrical power.

If this list sounds extensive, remember the long list for today's automobile: the many pieces of safety equipment, the performance of emission equipment, the many turn, head and tail lights, ground clearance, maximum weight, and fleet fuel efficiency to name a few. Remember, too, the minimum power and speed requirements to enter and drive today's freeways.

That said, some of the specifications will be tough to meet. Weight and size are to be minimized. The motivation for this is clear. The load the Rail must accommodate is directly proportional to the vehicle weight and impacts the size of the resultant Roadway structure. To keep the Rail on a human scale in the urban landscape is a major challenge for the designers. The Roadway's visual impact is a qualitative figure of merit—beauty is in the eye of the beholder—and may be the toughest goal of all. Car length will determine the length of trains and the vehicular capacity of the lines. Car width and height will determine the extent to which the Rail must provide clearance. The disturbance suffered by an onlooker is proportional to the bulk whizzing past—to be small and quiet is good.

And so the quest for light and compact. If you were a lazy designer, think golf cart. Think smart and think a smaller version of Mercedes Benz's Smart car. Or a hybrid like a mini Prius-like vehicle. Only remember a huge advantage for the engineer, compared to road cars today, our Rail Car required here need only be viable on city streets, nimbly moving at 25 or 35 mph, tall enough to be visible in street traffic, and able to protect its passenger(s). For safety, think full road car standards.

The following sections will set numerical goals to specify the Rail Car. As they would be to optimize any complex product, each separate goal is aggressive. Each is a challenge to the engineering team assigned to meet a particular goal. Taken together they are known as a point design defining the Rail Car. Point designs are important in complicated systems in that they allow disparate groups of engineers to separately, simultaneously, and happily, tackle their separate problems. In this case a point design for a Rail Car will allow the Doobie engineers, the electronics engineers, the motor engineers, the safety cage engineers, and the many other teams to immediately start crunching their numbers. Nothing catastrophic happens if one group fails to successfully reach a point design goal, only a sometimes nasty redesign in the others' work needs to occur. Point design goals need to be developed for each piece. We begin.

SIZE, WEIGHT, & POWER

SIZE

A height similar to a modern car, halfway between the traditional sedan and an SUV, would promote visibility and thus safety. For reference let's pick the height of the Toyota Prius, 59". Width should be sufficient to accommodate a cozy two seats, and doors with airbags and some high-tensile strength impact pipe. Remember, most cars are not carrying a second occupant at any one time. Bucket seats are cozy. 55" of width ought to do.

Length will be at a premium. A two seater. A slot behind the seats for luggage and groceries—think carry-on airline luggage or five bags of groceries. Remember the Car needs no motor in the conventional sense—and so the windshield and bumper could be against the passenger toes. Let's propose 7-feet overall with a resultant 5-foot wheelbase. A little rocky maybe, but a motorcycle and a bicycle are substantially shorter and make do. Active suspension systems of the future will ameliorate discomfort for those who need luxury. Such increasingly sophisticated adaptive suspensions are available today in luxury automobiles. Development of an effective crumple zone for front and rear collisions must be a consideration. Side impact resistance, since the Car is very short, all else assumed equal, should be better than that of a standard car. The light weight of this vehicle is, of course, a negative for safety.

Figure 3-1 shows a foreshortened photo of a Mercedes Smart car. As produced in Europe, the Smart car is roughly a 2.5 m x 1.5 m x 1.5 m box. It's 73.5 inch wheel base and severely curtailed skirts yield an overall length of only 98 inches. The idea for the Smart (Swiss Mobile ART) car came from none other than Nicholas Hayek, a financial icon of Switzerland, savior of the Swiss watch industry, creator of Swatch (Swiss WATCH), and whom the AP credits with the marvelous quote that no city car need room for more than " two big adults and a crate of beer." He sold to Mercedes Benz in 1998, disappointed that the car was not a hybrid or all-electric. Benz clearly couldn't deliver an all-electric vehicle at their target price. The 2009 Smart car has received 5-star (excellent) ratings for both frontal and side impacts for its class of vehicle. MSRP is $13,500.

How far is it from the Rail Car we propose? The scissors-induced foreshortening job to create the illusion in Figure 3-1 has removed approximately 7 inches at the door hinge area, and 7 inches from the trunk area

FIGURE 3–1 illustrates a slightly foreshortened Mercedes Benz Smart car montage-cropped to have a wheel base and overall length as proposed for the Rail Car. As shown the auto is foreshortened 14".

in front of the rear wheels. Thus, Figure 3-1 shows a car with about a 5-ft. wheel base and an overall length of 7 feet. What is remarkable is that Mercedes Benz has designed such clipped bumpers around the wheel well, fitting nicely with the desired features of the Rail Car. If a full road car from a reputable manufacturer works with such bumpers, they should be suitable for the Rail Car. Realize that accident protection on the open road presents a far more challenging task than the one we face for docking and train procedures.

SUPER SIZE ME

As an alternative concept, consider the tiny vehicle imaged in Figure 3–2 shown on New York City streets. A product of a cooperative venture between Segway and General Motors, the Personal Urban Mobility and Accessibility (PUMA) seats two and uses Segway's stability scheme. Sales of the original Segway in 2009 were only 20,000, but the PUMA allows the rider to sit, accommodates two, and provides a cabin. While the rest of the book will use the modified Smart car as its model, the reader should note the positive impact a PUMA-like vehicle would have on 3rd Generation Roadway

FIGURE 3–2. A two seater of full height but minimal length and width has many advantages.

vehicular capacity, required width of right-of-way, and expected vehicle weight. Also note the problems of a small electric vehicle in urban traffic, which required British law to prohibit use on public streets. For reference, see "Reinventing the Automobile" from the MIT Press, March 2010.

WEIGHT

To set a 500 lb weight goal for an automobile is certainly aggressive, maybe outrageous, even if only a qualitative goal. But the Car is small, and need not operate at high speed. These properties are powerful leverage for weight reduction. The size of the chassis is small, as are its strength requirements—remember an ant is far stronger than an elephant, relatively speaking. Eliminate the need to accelerate at high speed, and a smaller motor is adequate. Eliminate the need to even function at high road speeds, and one reduces many anticipated forces, promoting lighter construction of many components. For instance the Car need not have as powerful brakes, as capable a chassis or as strong a suspension system.

Reduce one component's weight and others' can be reduced. As weight (and operating speed) is reduced, the need for a big heavy motor is reduced. Without that huge engine to crank, the Car's lead-acid battery won't weigh 40 lb as it does today. It's heavy gauge wire harness will lighten. Tires and wheels are another excellent example. A 3,000 lb vehicle designed for a top speed of 120 mph has a wheel set that weighs 200 Ib if equipped with, say, 5 "lightweight" stock alloy wheels and new Michelin 195/60R15 tires. The Smart car, as a lighter vehicle, has a set that probably weighs half that value. In the extreme, a vehicle designed for 200 lb and, say, a top speed of 45 mph has a wheel set weighing somewhat under 5 lb; the value for a good road bicycle. Thus if a Rail Car engineer were given what seems a reasonable goal of 33 lb for a set of Rail Car wheels, she would be proceeding

consistent with a vehicle weight reduction by a factor of six. And it is a factor of six—from 3,000 lb to 500 lb—that is our goal.

An expert eloquently agrees. To quote Dan Neil, the former "Los Angeles Times", now "Wall Street Journal", columnist for all things automotive, "Lightness cures what ails sports cars like Lourdes cures scabies. All things being equal, lighter cars change direction more quickly (less mass, therefore less moment of inertia). Likewise, lighter cars have better cornering grip (the vehicle doesn't overwhelm the tires). A lighter car accelerates harder and stops more quickly. Meanwhile, all the stresses on the components are reduced—the tires, brakes, suspension and gearbox. It's one big, beautiful, positive spiral."

Advancing technology will radically change weights. Your automobile's radio, standardized as a small shoe box filled with ruggedized printed circuit boards, probably weighs 5 lb. What does an iPod weigh? It was ruggedized with monolithic integrated circuitry and solid state memory that became cost-effective only in the last five years. What will white GaN LEDs do for lamp assemblies when fully implemented? LEDs are incredibly small, incredibly efficient, and last long enough to never require replacement. Or require all the mechanisms needed for field replacement of today's lamps. Newer plastics hold promise. Formula 1® cars, screaming machines weighing less than 1,000 lb, use carbon-carbon plastics for the chassis, and actually add dead-weights to improve the vehicle's balance and meet regulations designed to slow the race.

Other components may present challenges. Reducing engine weight in proportion to our Car's goal may be difficult. While a lightweight aluminum block 150 hp engine in today's automobile might weighs only 220 lb, Honda Motor Corporation's respected mini4-stroke line of engines weigh fully 5 lb per hp produced. For instance, the GXV-530 15.2 hp, 530 cc OHC/OHV V-twin weighs 70 lb. Only a factor of three lighter. Likewise, many components will most easily come from automobile parts suppliers as stock units—the airbags, seats, door handles, etc.—with stock weights. Although technology has or will radically change each of these, development required exclusively for a Rail Car will be slow and expensive.

The Mercedes Smart car is small, but otherwise is a modern, conventional, high-speed automobile. As manufactured today, it weighs 1,600 lb. That's 1,200 lb lighter than a Toyota Corolla which is 80 inches longer. Designing a foreshortened Smart car-like vehicle only 84 inches long might save another 150 lb; a smaller engine, gear box, and drive train 300 lb; and decreased requirements in the suspension, braking, and steering systems of a low speed, lighter vehicle substantially more. It should be pointed out Daimler-Benz's engineers had little motivation to reduce the Smart car's weight; their target market niche was/is a vehicle with an attractive length for today's city.

The 640-pound 2-passenger car built by Volkswagen deserves discussion. Created to meet a goal of traveling 100 km on less than 1 liter of fuel, and dubbed the "1-litre-car" for its fuel consumption (not its diesel engine's 0.3 liter displacement), the car features extensive use of carbon composite, magnesium and titanium materials. Impressively, the car includes many of the modern safety features employed by today's high-speed road cars: ABS brakes, ESP stability control, front crumple zone, airbags with pressure sensors, and crash resistant structural tubes. The car is street legal in Germany. See the photographs in Figure 3-3 .

Presumably adding to the car's final weight, the designers for obvious reasons stressed aerodynamics—a feature not particularly needed by our Rail Car. For aerodynamics the car is long and thin—the passenger sits behind the driver—has a special under pan, wheel covers, and an aircraft-like windshield/roof line. Volkswagen engineers even added retractable side view mirrors and air intake vents. All of which achieves an amazing 0.16 drag coefficient, but probably weighs more than it would otherwise.

Complicating our own 500 lb goal, of course, are several additional features required by the Rail Car. A coupling mechanism is required to mate with the Rail, and probably another pair to couple to adjacent Cars as several form a train. A capable computer must be on board. And fourth, as proposed for fuel efficiency, the Car is a hybrid requiring an electric motor/generator and a gasoline motor. Finally, although one electric motor (and generator) is probably sufficient for each mode, a drive train for the road and the Rail are required. As will be explained later, components could be eliminated if the Rail provides propulsion, and/or the Cars form only virtual trains which have no physical coupling. Likewise, continuing advances in computing will allow "notebook"-sized machines to suffice. An all electric version of a Rail Car would replace the gasoline motor with a modest battery.

Detroit, Tokyo, and Stuttgart will have their legitimate complaints, but the boys and girls at Carnegie Mellon and MIT will cheer with delight at the challenge. So would the older boys and girls at DARPA (Defense Advanced Research Projects Agency) if they had the charter. This will be a challenge

FIGURE 3–3 shows a production model of the 2 passenger VW carbon framed vehicle.

for the Department of Transportation's Research and Innovative Technology Administration (DOT–RITA) equivalent to those faced in advanced R&D efforts by defense (DOD), air and space (NASA), science (NSF), and medicine (NIH). After a certain consensus and momentum level is reached of course, Detroit, Tokyo and Stuttgart will have ample motivation to independently compete.

POWER

And the need for power—the enemy of light and compact. What's the minimal power needed? Well, the Car has to easily travel at 25 or 35 mph all on its own around urban streets. It must scoot, turn, pass others and generally be easy and fun to drive. On the Rail it must travel at 40 mph to 60 mph as a single Car, and then share its power in the connected trains which are designed to go up to 100 mph. What's enough?

First, what's enough for the street? Let's do a comparison to the many vehicles that exist today. At one end of the street machine spectrum you have the Corvettes, Ferraris, and Porsches—a ton and half of steel and power to burn, that is, upwards 600 hp. At the other end, the bicycle, at 180 lb including the weight of the average "motor", possesses upwards 0.5 hp, peak. See Table 3-1 for a selection of this spectrum. The Table lists published values for 2009 vehicle horsepower, dry weight, acceleration times from 0 to 60 mph, city gas mileage, wheel base and top speed. The chart further estimates some acceleration times to 30 mph assuming the same horsepower can be delivered to the road at low speed as it is from 30 to 60 mph. In the case of the Ford F150 King Rancher, "Popular Mechanics" magazine verified that the truck actually delivers full horsepower, losing only 0.9 s from theoretical as it accelerates from 0 to 30 mph (Times go as the square of the speed obtained for constant power.)

Most importantly, Table 3-1 proposes properties for the Rail Car and supports the argument that 15 hp would be sufficient for city streets. Note that with a dry weight of 2,932 lb and a 160 lb driver, the Toyota Prius must deliver 63% of its rated 110 hp, i.e. 69 hp or 52 kW, in order to accelerate from 0 to 60 mph in 10.5 s. If our Rail Car weighs 500 lb, is occupied by a 160 lb driver, and likewise delivers 63% of its proposed 15 hp, it should accelerate from 0 to 30 mph in 3.5 s. Fast enough in traffic, able to drag race the F150 truck.

While the gas-powered F-150 lost 0.9 s starting off the line, since our vehicle will have an electric motor, and electric-powered vehicles are notoriously zippy off the line, we'll stick to our number: 3.5 s from 0 to 30 mph. Again to quote Dan Neil, "In an electric car one thing moves and the car moves." He continues by detailing the immensely complicated set of events in series that must occur before an automobile powered with an internal combustion engine can move.

While the preceding paragraph was intended to emphatically defend the quoted 0.9s advantage enjoyed by our electric-powered Car, one is

SPECIFICATIONS FOR VARIOUS VEHICLES

	Ferrari 599	Porsche Carrera	Mercedes Smart	Rail Car	Yamaha Scooter	Toyota Prius	Honda Accord	VW I-L	Ford F-150	Bicycle	Kawasaki Ninja250
Horse Power	620	325	70	15	(49cc)	110	177	8.5	300	0.5	36
Weight (lb)	3,000	3,200	1,800	500	166	2,932	3,200	640	5,700	20	304
0 to 60 mph	3.7	4.8	12.8	—	—	10.5	9.0		10.4	—	5.5
0 to 30 mph*	—	—	3*	3.5*		2.3*	2*	7.6*	3.5	20*	—
City Mpg	11	17	33-40	109#	110	48	22	265‡	14	900**	55
Wheel Base (in)	108	92.5	73.5	60	45.7	106	108		138.5	39	
Top Speed (mph)	205	177	90		55	105	135	75	100	35	105

TABLE 3–1 lists specifications for very different vehicles. * indicates estimate if power is fully available for acceleration. # is estimate from text. ‡ highway (open road) mileage at 75 kph. ** assumes bicyclist could convert gasoline to energy with the same efficiency as he or she can spaghetti.

advised to remember Neil's comments while reading the chapter, "Traffic Control". Under computer control, maneuvering within remarkably tight spaces, faltering responses can no longer be tolerated. Image the smooth, immediate response demanded as two Cars dock or separate or merge from two lines; and then imagine the effect of a bad transmission shifting, or a misfire of an internal combustion machine.

As an aside, several readers reviewing the text of this book have asked for an explanation of the "gallon of spaghetti" calculation. The 900 mpg figure results from knowing that a decent bicyclist, on a flat road, can peddle 100 miles while increasing his caloric intake by roughly 3,200 Kcal, obtained conceivably by a young geek who might actually try this stunt, eating nothing but two pounds of spaghetti. A mole of heptane at 100 gm contains 1,116 K cal of latent heat, and a gallon roughly weighs 2,600 gm. You do the math.

In the last 50 years the expectation for an average car has gone from 70 hp for a vehicle of 1,800 Ib to about 180 hp for a vehicle of 3,200 Ib. But the average street car has to perform well in many situations where our "buggy" does not. Today's car must perform on the rural highway and on the interstate freeway. It must handle well at high speed, it must accelerate well at high speed, it must be safe at high speed, and it typically must accommodate at least five passengers and vacation luggage. Our Car never goes over 35 mph until it reaches the safety of the automated Rail. It is the second car in the garage, goes to the workplace or grocery store with one driver, and sits in the garage when the family goes on vacation, Mom carpools to the soccer field, or Dad goes to the lumber yard.

When comparing a proposed generation of "green" electric cars to the Rail Cars of this book, realize green cars will still need to be powerful for the open road. It may be more efficient and renewable to generate power at a large plant, distribute it, and then store it in a battery; but one will still need large electric motors, weighty vehicle components for the open road, and will consume energy at a huge rate.

TOP SPEED, FUEL EFFICIENCY, & SAFETY

TOP SPEED

Is the Rail Car limited to 35 mph? No. 35 mph is just the top recommended speed on a street—which of course might be enforced with a speed governor. What would be the Car's top speed? For the Rail, top speeds would be useful information. The Car is speedy enough to cruise around the neighborhood street, but have we correctly powered the vehicle for the Rail system?

On a level road, top speed for a vehicle is reached when power dissipated to road drag and wind resistance equals the net power the vehicle produces at the road. The motor and the power train have reduced that value with their own dissipation. To project the Rail Car's top speed we must consider the contribution of each to the total power dissipated.

As anyone who's pushed an automobile in neutral knows, tires and bearings dissipate energy. Road drag is the force required to roll fully loaded tires down the road. Although obviously higher at zero speed, and although those in the arcane science of tribology might object, drag is usually assumed to be constant at all speeds. On a smooth road with high pressure, very flexible side wall, round tires, road drag is about 0.5% of the weight of a vehicle. Thus a 200 lb bicycle and rider on tires at 100 psi are usually assumed to have one lb (0.5% x 200 lb) of force to overcome. With big, square, road gripping tires pressurized to only 30 psi, as for an automobile, 0.8% is a better number. Thus, at 3,100 Ib the Prius has a road drag of 25 Ib (110Nt). A big hunk of a man, who can generate maybe 0.4 hp with his quadriceps when pushing those 25 lb, should get the automobile rolling at 6 mph (300 W). For a while, anyway!

Goodyear advertises its Fuel Max tire with "innovative rubber compounds" to save 2,500 miles of gas over the life of the tire. If true, and since Goodyear assumes 65,000 miles of life, the energy saving is 4%. Michelin claims 109 gallons of gas is saved per set; about an equivalent percentage. Soon we'll learn that road drag accounts for about one quarter of all losses, and so we must conclude these fancy tires reduce road drag by 15 to 20%. Volvo is also aggressive, advising drivers to inflate to "economy" pressure values on long trips, thereby saving 3 to 5%. A more conservative argument is made by Exxon-Mobil quoting government statistics that up to a billion gallons of gasoline would be saved by American drivers each year if they properly inflated their tires. That's almost 1% of total consumption, which an Exxon-Mobil product makes easier to achieve by never allowing the air to escape—their tire liner forms an impermeable barrier to Nitrogen—after the shop is done. In years past the industrywide conversion from bias ply tires to radials allowed more flexible sidewalls to save comparable energy.

Our second task is to make an estimate of wind resistance—that is to say, estimate the power lost to air at the vehicle's top speed. At a vehicle's top speed, air resistance is usually the dominant force of all we'll consider. We have chosen to make our small vehicle tall and short—for wind resistance that's not good. On the positive side we've chosen to make it relatively narrow.

Let's set a goal—oh, let's just assume with some justification—that our Rail Car will have wind resistance very comparable to any of today's modern sedans designed in a wind tunnel. The Prius with its carefully shaped cross section, smooth sides and low undercarriage has a wind drag of approximately 8 lb (37 Nt) at 30 mph. The Porsche has even less. Bicycle analysts usually will estimate wind drag of 11 lb (49 Nt) for a vigorous cyclist sprinting at 30 mph, or coasting down a 6% grade in equilibrium at the same speed. Amazingly, the cars have less wind resistance than the bicyclist!

Of course wind resistance will increase dramatically at higher speeds. The force of the wind's drag increases as the square of the vehicle speed. That's because, crudely speaking, a body plowing though air must accelerate the mass of all the air molecules it meets from a net zero velocity to the vehicle's speed as it pushes the air out of the way. And kinetic energy goes as the square. Shaping the body correctly allows some of the air to scoot around the side, reducing the effective amount of air accelerated down to some fraction of the body's cross-section. This fraction is known as the aerodynamic drag coefficient of the vehicle. Typical values for cars have been lowered over the years, aided by testing in wind tunnels, from 0.5 to 0.35. The Porsche and the Prius achieve a published 0.29. The bicyclist must have a very high number close to 1.

Power train dissipation has a large value. If we're interested in top speed, we should ask for dissipation values associated with that speed. So measurements were made on a Volvo V70 in various low gears at 4,500 rpm, the engine speed associated in 5th gear at the vehicle's top speed of 115 mph. The answer calculated is 750 Nt using both deceleration rates on

flats and equilibrium data on an 8% grade. If we further assume that power train drag is proportional to the effective size, i.e. power, of the engine, the Prius has 500 Nt, the Smart car 310 Nt, and our Rail Car as designed 70 Nt.

One more number. At low speed, the published accelerations of the cars make it appear that about only 63% of the engine's rated power actually appears on the road. Data is hard to come by for obvious reasons—everyone's cheating—but published data for the Kawasaki Ninja 250F states that 72% (26 of 36hp) drives at the road. For the Volvo that's 106 hp, the Prius 69 hp, the Smart car 44 hp, the VW-1L 5.4 hp, and our Rail Car 9.5 hp.

We'll match these powers to the forces opposed to travel. At some speed the sum of all the forces will dissipate power equal the engine's production, and equilibrium will be reached. For the Prius the calculation for maximum velocity(V) runs something like this. Power = velocity times drag = V(m/s) x [110Nt + 500 Nt + 37 Nt x (V(m/s)/30mph)^2] = 69 hp = 52.3 kW. The solution for V is 48.3 m/s = 108 mph. The published top speed is 105 mph. The equation for the Smart car solves for 92 mph. The published data is 90 mph. Close enough. Success for our equation.

VW Chairman Ferdinand Piech himself drove the experimental version of the VolksWagon "1-Litre-car" from Wolfsburg to Hamburg to join an annual stockholders meeting and averaged just 0.89 liters per 100 km on the road while driving at 75 km/hour—that's 265 mpg driving at 47 mph. Only recently did VW claim top speed for the vehicle is 120 km/hour. Its 0.3 liter engine generates all of 8.5 hp, only 57% of what we're proposing for our Rail Car. If we estimate the cross-section of the VW vehicle to affect only 1/3 of the Prius' wind resistance and use the formulation above, we'd conclude 70 mph (112 kph). Don't know how it went to 120 kph! (Actually, look at the stylized vehicle's cross-section and published drag coefficient of 0.16 and you may conclude 1/3 the Prius' drag is too high an estimate.)

With the success of our formulation, we can now proceed with confidence in predicting the top speed of the Rail Car. At 660 lb our Rail Car with driver would have roughly one fifth the road drag and roughly equal the wind resistance of the Prius. If it can deliver roughly the same percentage of its rated 15 hp to the road as does the Prius, or 63%, 9.5 hp (7.1 kW) are available. The tiny road drag and the ease in cutting wind at low speed are now immensely advantageous given the small engine. Road, wind, and power train dissipation within our equation will limit the Car's top speed at 59 mph. For purposes of discussion in this book, let's use an even 60 mph.

The author once owned a 1962 Ford Galaxie 300. Not the classic Galaxie

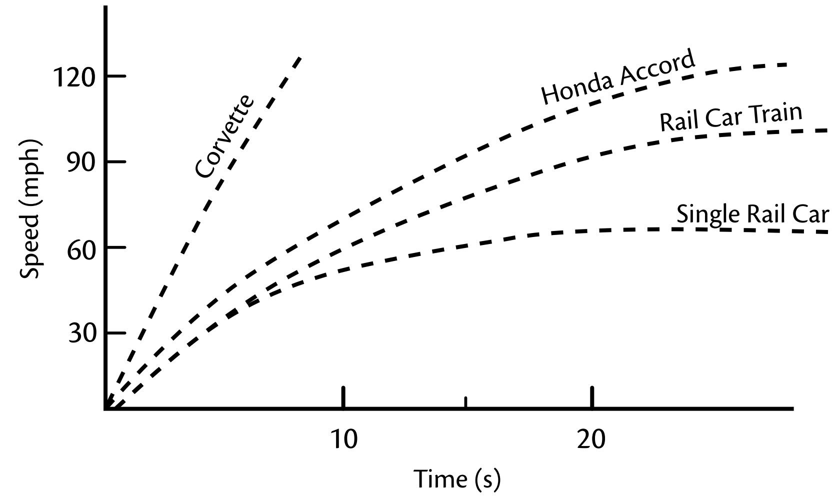
500 with its equally classic engine, but an underpowered slug of a beast that added insult to injury by getting 14 mpg on the highway. The poor thing had only two gears and a maximum speed of 35 mph when climbing the 6% grade in the California canyon known as the Grapevine—to the great annoyance of others on U.S. 99. Can our little engine climb city streets along with traffic?

At 1,000 Ib with driver, passenger, and a full load of cargo, our Rail Car weighs 454 kg and is driven with a maximum road-delivered power of 7,100 W. So if all its power goes to climbing, and at low speeds on a steep hill this is a good approximation, it climbs at a rate up to 7,100 W / (454 kg x 9.8 m/s) = 1.6 m/s vertical. On a steep 10% grade that's 35 mph. Good enough. This Car's not for U.S. 99!

Top speeds for the Rail Car trains? Although wind tunnel tests will be needed to answer this question, let's make some estimates. Remember that, as the cars couple together, fairings—small surfaces deployed to improve wind performance—could be positioned automatically to aid in the aerodynamics of the two coupled cars. Imagine closure of the coupling latch triggering four or five little flaps aerodynamically filling in the gap between the preceding rear and the following hood—two relatively vertical surfaces. Let's estimate that a train of 10 will have only twice the wind resistance of a single Car. That is to say, wind turbulence along the 70 (10x7) feet of siding and undercarriage will create only about as much drag as the front, rear and sides of a single Car. 10 times the power and twice the drag increases a single Rail Car's top speed of 60 mph to a 10-Rail Car train's of 100 mph [$(10/2)^{1/3}$ X 60 mph]. If this aggressive assumption for side wind resistance is off by a factor of three, and the train has four times the wind resistance of a single Car, the train still achieves 80 mph.

Figure 3-4A plots the acceleration curves of four common vehicles. The small train of Rail Cars achieves in top speed what a conventional road car does. It is the new 3rd Generation Roadway that allows the Rail Car train to regularly operate at top speed. Figure 3-4B shows the top speed obtainable by a train of Rail Cars as a function of the number of Cars in the train and the percentage of remaining wind resistance incurred by Cars following in the slipstream of the lead Car. Most of the rationale for forming trains is achieved with small numbers of Cars.

And finally, let's summarize speeds. On the street, our Rail Car accelerates from 0 to 30 mph in 3.5 s. It climbs steep hills at 35 mph and on the flat its top speed potential is 60 mph. Just remember the Car may have a



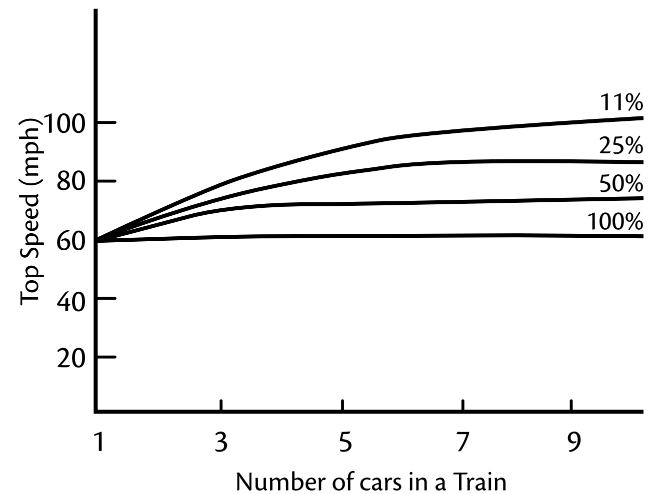


FIGURE 3–4A illustrates acceleration curves assuming15 hp Rail Cars. FIGURE 3–4B illustrates the top speeds for various length trains with different assumed wind resistance.

governor to limit its speed to 35 mph for safety's sake given the Rail Car's minimalistic suspension system, wheel base, and safety cage. On the local Rail line, speed will probably be regulated at 40 to 50 mph, slowing occasionally to 25 mph in very heavy traffic at the local interchanges. And on the high speed metropolitan lines, speeds for small trains will approach 100 mph.

FUEL EFFICIENCY

One is tempted to estimate the fuel efficiency of our Rail Car using the Prius as a model. The Prius and our hypothetical Rail Car have the same wind resistance. The Prius weighs 5 times as much, and hence has 5 times the road rolling resistance. Let's assume they recoup braking losses to the battery in the same fashion (i.e. stop-and-go battery charging and draining dissipation is proportional to the total power being handled, as is the drive train dissipation). Let's also assume that the rest of the power goes to wind and road surface resistance traveling at 30 mph in the city. And that the estimated city mileage of 48 mpg for the Prius is obtained under these conditions.

At 30 mph the wind drag on our two vehicles is a mere 37 Nt, but while the Rail Car has a road drag of only 22 Nt, the Prius' tires drag at 110 Nt. Thus the Rail Car's total drag sums to 59 Nt, while the Prius' sums to 147 Nt. If the Prius can get 48 miles per gallon pulling 147 Nt around town (this equates to an impressive efficiency of 32% converting gasoline energy to road propulsion!), in this somewhat simplified calculation the Rail Car should achieve 120 miles per gallon pulling against its 59 Nt [120 x 59 = 48 x 147]. For purposes of discussion, let's use 100 mpg.

As the wind picks up, high speed driving is associated with bad fuel economy. But hiding within a train, our Rail Car has relatively low wind resistance. Assuming the 32% efficiency for the Prius engine quoted above applies to the Rail Car's 15 hp motor, the engine will burn 0.6 gallons of gas in an hour at full throttle. Thus our 10 Car train at its top speed of 100 mph, with its 10 little engines chugging away flat out, would transport vehicles achieving 166 mpg.

As 166 mpg seems an exorbitant level of efficiency, let's plumb another mechanism to estimate Rail-Car-train energy usage—if only as a so-called sanity check. Consider the beast called the ordinary sedan that many of us drive today. Flat out with its 150 hp engine, the automobile might do 100 to 120 mph as its fuel efficiency drops to 20 to 25 mpg. That's 4 to 6 gallons per hour (100mph/25mpg, 120mph/20mpg). The Rail Car, with an engine 1/10 the size at 15 not 150 hp, should also scale consumption by a factor of ten to 0.4 to 0.6 gallons per hour. Thus, if we believe the Cars to be traveling at 100 mph as derived in the previous section, these numbers equate to 250 mpg and 166 mpg respectively (100/0.4, 100/0.6). Let's round that to 200 mpg.

In summary, at low speed scooting around town, our light and small road vehicle achieves fuel consumption of 100 mpg (2.4 L/100km). Configured in a small train, our Rail Car at high speed achieves 200 mpg (1.2 L/100km).

SAFETY

Greatly improved safety is a selling point of the 3rd Generation Roadway. Safety, of course, is not only an issue of the car, but of the roadway as well. Today, a driver must ask, "Will I miss the next nasty curve?" "Will my car fall off the canyon wall?" "Will a drunk slam into me?" "Is the stoplight working?" But the Car's design is your last defense, and so we'll consider its safety here.

First, let's consider the Rail Car on the surface street. Automobile safety on the street is of course by now a well-documented and analyzed issue. In comparison to today, we will considerably improve safety by limiting, with a governor, the Rail Car's top speed on the surface street to 35 mph. And we will considerably degrade safety on the street by limiting the Car's weight to only 500 pounds.

In a two-car collision, the smaller car's occupant suffers more severe injuries. National safety statistics clearly show the problem. Presumably many smaller, cheaper cars also have cheaper safety features, and they certainly undergo more violent accelerations. Since our Car is extremely light, let's examine the latter's contributing factor. In the almost perfectly inelastic collisions characteristic of automobiles, two cars of equal weight colliding head-on when both are traveling, say 35 mph, will both come to a dead stop. No pun intended. Momentum is conserved. The passenger undergoes rapid deceleration from 35 to 0 mph. If a average car of 3,000 Ib hits an SUV of 7,000 Ib head-on, the average car ends the inelastic collision going backwards at 14 mph. It might as well have hit a brick wall at 49 mph (35 + 14). If our Rail Car and driver at 660 Ib hits 7,000 Ib, the effective wall was hit at 64 mph. Only the Rail Car's safety features will mitigate.

The Insurance Institute for Highway Safety has found present "neighborhood electric vehicles" (Chrysler Corporation's 'Gem' is a principal example), to be wanting in crash protection. The National Highway Traffic Safety Administration has repeatedly denied petitions to establish a new category for "medium speed" vehicles which operate below 35 mph. For good reason they do so. For the Rail Car, full automobile safety standards must be met.

Crumple zones, safety cages, three point belt restraints, airbags—safety systems for the street automobile include many advances developed in the last 40 years. Electronic stability control will save more lives than do airbags, as will systems designed to keep drivers in their lane, and warn drivers of speed limit violations. Without doubt, the Rail Car will feature all of these protective systems. Ideally, it will also feature systems of the future. Promising systems in development anticipate collisions and apply the brakes before one that is inevitable. Volvo's system is called City Safety, uses a laser sensor, and is for slow traffic in the city. Daimler-Benz's system, Distronics, uses radar, operates at all speeds, gives a collision warning and then applies the brakes when and if the driver doesn't. Toyota advertises something similar. Benz engineers refer to an "electronic crumple zone" clearly of greater spatial extent than any physical one could be. BMW has a camera to detect lane departures and warns of vehicles in the driver's blind spot. We anticipate our Rail Car to have radar, either microwave, acoustic and/or optical, for the many maneuvers needed on the Rail. Adaptation for collision avoidance might be easy. Given studies showing the importance of distance between the dashboard/steering wheel/airbag and driver/passenger, perhaps a scheme to slide the seat backwards would be helpful.

For side impact collisions, the Rail Car will have at least one advantage. Possessing a very short wheel base, when hit from the side by a 4-wheel vehicle, one or both wheels is almost guaranteed to be hit. And a wheel, buttressed by struts, chassis, and transaxle, is a very hard target. One that is far more resistant to penetration than is a large door.

The safety procedures of Formula 1 racing deserve inspection. Lightweight, grossly overpowered cars whisking around narrow, winding courses at upwards of 200 mph have not produced a fatality since 1994. The cars have a central safety cage built as a monocoque, rip-away parts, and collapsible steering columns; the drivers have 6-point safety harnesses, helmets, padding, and fire resistant suits.

Obviously some F1 safety features and procedures look difficult to implement for the general public. But concepts of reasonable safety precautions change in time; and from generation to generation they are very noticeable. The introduction of the 2-point seat belt in the 1960's met resistance; and now it's almost a reflex to buckle up with a far superior 3-point harness. Bicycle helmets and more recently ski helmets are within the last generation. With the introduction of a new generation of vehicle with a new generation of drivers, a 4 or 6-point harness will seem reasonable, a helmet maybe possible.

Safety when the Car is on the Rail is, of course, far less understood. What types of accidents will occur? How will the Car and system perform in protecting the passenger? Given that the driver has handed over responsibility to the system, what liability law applies?

The 3rd Generation Roadway's Rail system and the performance of the Rail Car on the Rail will be characterized in the next chapter. But the general types of accidents might now be categorized. The Rail exerts such commanding control of the Car that many types of accidents common to the street are eliminated—the single Car accident due to driver error, for instance. Head-on collisions will not occur given that rails are one way—not shared as for train tracks—and off-ramps will not be navigable to an errant street driver. Side collisions can't occur between Cars. Spectacularly new and different types of accidents are conceivable, perhaps with spectacularly severe damage.

Rear end collisions between two Cars are possible. Assume, for instance, one Car's mechanical failure causes it to come to a dead stop on the rail, and the next approaching Car's ranging radar has coincidentally also failed—normally it should slow, mate bumpers, and push the dead Car to an exit—allowing it to plow into the stalled Car at full speed. Or, depending how the system regulates flow, a Car with a failed radar bumps a functioning Car that is slowing to make a turn. A standard rear end collision? Yes. But both Cars are attached to the Rail by a mechanism which might break and both Cars might plunge to the ground after the collision—worse case 20 feet. Falling 20 feet would accelerate the Car to 25 mph, which is not only considerable, but given that the Car will tumble, the collision with the ground could occur at any crazy angle. An angle not protected properly, perhaps.

A train of Rail Cars can plow into a single disabled Car. Getting hit by a train of Rail Cars would be qualitatively different than getting hit by a railroad freight train. Not qualitatively different because Rail Cars are far lighter—which will help—but because each Car in the train has a crumple zone and the train's front will slow as it compresses like an accordion. Compared to a two-Rail Car crash, the impulse will go on longer (which is bad), but the forces won't be much greater as the stalled Car is accelerated to the speed of the train.

Intrusion. What happens if some outside force/object damages or blocks the Rail roadway. Say, a truck takes out a post and the roadway collapses. How are the first Cars on the scene kept out of harm's way? How long will it take to repair? Remember, of course, that the Traffic Control system has a marvelously capable ability to reroute traffic, and other lines have immense capacity to adsorb the rerouted vehicles. On the other hand, surface streets would be easily overwhelmed.

Trash on the roadway. Every red-blooded 10-year-old boy of course dreams of putting a penny on the track and watching the ensuing train wreck. What happens if a Rail Car breaks down and leaves pieces on the Rail? What happens if a Rail Car breaks down in such a way that the entire Car is stuck and won't roll down the Rail? Image the tow truck arriving with a cherry picker "bucket" for a 1,000 lb load! In the most severe cases, a tow truck which would arrive with the alacrity of a fire engine.

Liability. Only occasionally does the legislature write and pass laws allowing the government itself to be sued. Thus, when you drive a 1st or 2nd generation roadway, you legally assume the majority of the liability. In a two-car collision, you or the other driver is at fault. In a one-car accident, you were negligent or driving too fast. Even if water improperly drains onto the road, and you crash on that night's ice, you are to blame.

But in the 3rd Generation, you surrender all control of your Rail Car. If your Car and its computer are working, legally it's as if you'd hopped on the Metro link. And if your Metro link conductor drives you into a freight train, as he did August 2008 in Los Angeles, the assumption is that you're going to sue. That accident, which killed 25 people, could test a new $200 million federally imposed limit on damages associated with single-train accidents. For the 3rd Generation Roadway, the government will probably assume limited liability and liability costs will have to be added to the total. Even if the Railed system of the 3rd Generation reduces fatalities by a factor of 100, these costs will need to be considered.

ON THE RAIL

TRAINS

Speed, vehicle density and fuel efficiency attract us to the formation of Rail Car trains. It is the light weight of the Rail Car that allows a relatively small engine to accelerate the Car at a sprightly pace. It is wind resistance incurred by the relatively tall vehicle which limits a Rail Car's top speed to less than that of a conventional car. High speed is only obtainable if a Car hides in the slipstream of another.

Solid mechanical couplers, so reminiscent of those reliably used by today's freight and passenger trains, would remove the vagaries of Cars trailing each other at close distance. But are the Car chassis strong enough to handle the tugging and compressive forces? Questions might parallel those concerned with the towing capacity of your automobile or pickup truck. Railroad cars meet a number of standards not required of road cars. One requirement is to meet the tremendous compressive and stretching forces exerted by the couplers as the engine pulls and breaks. A "light rail" car for passengers weighs 40 tons dry and 60 tons fully loaded, with pulling and pushing forces rising accordingly. How does the Rail Car handle smaller versions of such loads and avoid the requirements for larger loads?

First, it is noteworthy to remember that the Car itself is very light, and second also note that there is little motivation to form long trains either for aerodynamic or control purposes. Trains of 5 to 10 Cars are envisioned. Therefore any Rail Car trains will themselves be—relative to a train—very light. A train of 10 loaded Rail Cars might weigh 7,000 Ib. About the weight of a Ford Expedition. If the Car chassis were equipped with "axial strengtheners"—a pipe positioned where the drive train shaft exists today perhaps—it would have protection for head-on or rear-end collisions, and be immune to low level pulling and shoving intra-train.

But virtual coupling, that phrase for controlling relative position with sensor and adaptive motoring at very close range, is a very real option. Highly stable control at spacings of, say, eight inches are feasible and would achieve the three goals desired in forming trains. Thus, the need for mechanical couplers and "axial strengtheners" would be eliminated. On the other hand, a new problem is created. The train's lead Car must "break the wind". To augment its top speed of 60 mph to 100 mph the lead Car needs a push whose value is about 60 hp. Sixty horsepower can be delivered from the other Cars with a mechanical coupler. But not by a virtual coupler. If the Rail is delivering power, there will be ways to deliver power selectively, but now there is another requirement on the Rail's hardware. The expense of this new requirement may be more than the Cars' mechanical couplers and enhanced chassis.

Clearly, the development phase of the 3rd Generation Roadway will include something that engineers and system engineers call "Operational Analysis". That is to ask, in very simple terms, just how are we going to operate this thing? Although more difficult to explain in words, an idea that might simplify hardware is the following. Every fifth or 10th Car sold might be a "turbo charged" variant, possessing those extra 60 hp to break the wind. Fear not, this zippy version would still have a 35 mph speed governor, but would be prized by those wanting bragging rights. In return for these bragging rights, owners would have a responsibility. At the interface from a city line to a high-speed line, where their Car's power is needed to "break wind", the Car would be required to wait until 5 or 10 vanilla followers appeared. The virtually coupled train could then accelerate toward 100 mph. Of course, 'Operational Analysis' might find many other schemes.

PROPULSION

The Rail Car's propulsion is bi-modal. Not only must it apply drive power to the road, but if the Rail is passive the Car must apply power to the Rail. Let's assume most Rail Cars are either all-electric or hybrid—remember the manufacturer is free to sell, and the buyer free to use, anything that's "street legal." A hybrid Car would employ at least one electric motor for drive (in addition to the drive train from the gasoline motor or generator attached directly to the motor); and presumably use the same motor/generator to efficiently recoup energy during normal braking. In a panic stop, four-wheel dissipating brakes could be brought to bear.

The Rail Car needs a drive wheel to be among the wheels attaching it to the Rail. A 15 hp electric motor, packaged in a conventional so-named 265T or 215T housing is roughly an 8" cylinder 8" to 12" in length. It's placement on or in the roof to implement the "ski lift" configuration may considerably complicate a svelte design. Note that electric car ventures may do better. AC Propulsion offers a somewhat larger 12" cylinder 15" in length producing a prodigious 268 hp. Given that very little braking is anticipated on the Rail,

little motivation is seen for any generator to recoup power.

Many commercial light trains in use today are provided propulsion by the tracks. Don't imagine the sliding overhead contacts used by street trolleys for over a century. Power can be applied remotely, thereby saving the physical contacts, and synchronously, thereby controlling the speed of each vehicle. As we discuss increasingly sophisticated Rails in the next chapter, this approach will save batteries, motors, and drive wheels on the Cars and be weighed against the extra cost and complexity of the Rail.

Should the Rail be assigned to deliver electrical power by any means, the solution would achieve major goals in the electric car and renewable energy industries. The Rail instantaneously becomes the distribution system delivering power generated by wind, solar cell, solar steam, etc. to the user—the electric Car. The need for sizable and heavy battery packs is greatly reduced. The need to wait for a recharge is eliminated.

GAS OR ELECTRIC?

Purely electric-powered vehicles do suffer in comparison to gasoline-powered versions with limited range inhibited by the weight and cost of the battery. Lithium ion and metal nickel hydride batteries are limited to about 0.15–0.20 kW hr/kg. Thus a car burning 15 to 20 kW needs a 100kg battery to run an hour. Progress is slowly improving battery energy density. Batteries are also limited in recharge rate. Limited by internal resistance, recharge times are typically measured in hours. And drivers are accustomed to filling their tanks in minutes. Progress here, in what industry wonks call the C factor, is relatively dramatic.

Given the light weight, limited need for high speed and thus high power, and the short range intended for our Car, use of an all-electric power system does have some major advantages. The battery energy density quoted above will be sufficient to drive the Rail Car one mile per kilogram of battery mass. If an urban driver considers 25 miles sufficient for his intended uses, that is, he bets he'll reach the safety of an electrified Rail, his garage, or curbside power station within 25 miles, a 25 kg (60lb) battery pack is sufficient.

An all-electric Rail Car would be very green indeed. Its efficiency unmatched. The electric distribution network, almost by definition, solved. The recharging problem, solved.

Of course, that same 25 mile range can be had with a one-quart gas tank. How much would the 15 hp gasoline engine weigh? Honda has one at 70 lb off the shelf today. Remember these weights contribute against the 500 lb goal. Let the games begin!

THE CAR COMPUTER

Although a thorough discussion of computerized functions will be presented later in the chapter on Traffic Control, this Car component should be mentioned here. When the author first dreamed and spoke of the rudiments of this system to his fellow students while earning (decades ago) a degree in Physics at the California Institute of Technology, he was told the computing power required was "beyond impossible." My, how time and technology have taken care of that! A tablet-sized unit may soon suffice. Imagine the features included: program and map your trip while still in the garage; automatic acceleration and track alignment as the Car approaches the "on ramp;" automated Car spacing on the Rail; docking approach sequences when preparing to dock with others; train coupling; automatic separations; and deceleration sequences as the Car exits back to the street. Rail functions such as merging and exiting will be clearly shared by more centralized computers controlling the Rail network. Again, details and centralized functions will be discussed in the chapter on "Traffic Control".

CONNECTING TO THE RAIL

Our Rail Car needs one more important component. The Car needs a mechanism to securely attach it to the Rail. A mechanism which must allow easy movement down the Roadway, but with sufficient traction to propel or brake the Car on the Rail. A mechanism very possibly providing power to the Car from the Rail. A mechanism constituting a suspension system. A mechanism which changes Rails thereby allowing the Car to merge, exit, and make turns.

Many generic terms are used for a mechanism supporting a vehicle on a track. Americans use "wheel truck" or simply "truck". The British variously use bogie, boogie, bogey, dobie, or doobie. For no particular reason, this book will use "Doobie". A railroad car typically has two Doobies, one in front and one in back. Each has four steel wheels on two axles supporting a platform through giant coil springs, which constitute the suspension system. The car itself sits on the two platforms.

Two very different coupling methods will be the focus in this book. A conceptual cross section of each is illustrated in Figure 3-5. The first hangs the Car from its roof and is casually described as a "hook." That's because it's easiest to think of the Rail Car hanging like a chair on a ski lift. The mechanism is much like the clamp used by a ski chair to mate to the ski lift cable. Of course in our case the Rail is stationary, and the Car travels down the Rail. Each Rail Car's "hook" includes a drive mechanism, presumably a wheel driven by an electric motor, to propel the Car down the Rail. Electric power might be fed from the Rail to the Car and its electric motor.

Radically different power schemes might include the drive mechanism as part of the Rail. A moving belt might be reminiscent of a skier's tow rope. Magnetic induction can be incorporated for a drive mechanism as it is in many of today's light rail train tracks. Finally, since the "hook" must control swaying detrimental to train coupling and turning at interchanges, requirements for stability will lead to a mechanically substantial connection between the Car and the Rail capable of handling sizable torque in two dimensions.

The second approach discussed in this book shows the Car supported from the bottom by the attachment to the Rail. The Rail would literally run under the Car, within the cross-section of the cabin, down the center, much

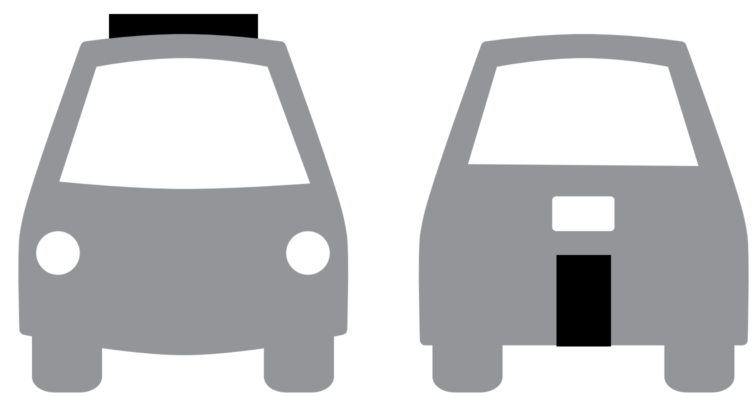


FIGURE 3–5. Two possible configurations are shown for a mechanism coupling the Rail Car to the Rail itself. The Car to the left has an analogy to a ski lift chair and a suspending "hook", while the Car to the right has an analogy with a monorail.

like today's monorails. The effect of the groove on the interior of the cabin would be similar to today's drive train hump between the bucket seats and in the center of the floor of older cars. This configuration produces a very stable geometry with the Car's Rail connection very close to the Car's center of mass. However, conceptual difficulties are incurred as one tries to engineer a method to change Rails. Again, in order to control swaying, a number of sliding or rolling elements will be needed in addition to the drive wheel.

This discussion must, and will, be continued in greater depth, but first we must learn far more about what the Rail actually is, and many of its details. Later, with clarity and specificity of the Rail apparent, we will continue this discussion in the section of the next chapter entitled, "Clinging to the Rail".

A SMOOTH RIDE

Automobile suspensions have a long history of inventive mechanisms. Suspension components, improving with the automobile's maturity, cushion the chassis and shield the driver from the road's vagaries. The pneumatic tire produced a ride on a cushion of air. Leaf springs, coil springs, oil-filled shock absorbers, live axles, independent axles, wishbone tails, McPherson struts, and cushioned seats are but several other means.

Steel rails and roller coasters don't have a reputation for an especially smooth ride. Of course, modern subways with rubber wheels have changed that somewhat, and coaster designers probably don't want a smooth ride. But let's argue with the perception that rail based travel must be rough.

Automobile suspensions have a fundamental problem. They face the unknown. Not only does the road ahead present ruts and potholes, bumps and debris; but each segment is unique, designed over hill and dale, through negotiated right-of-way, drawn at the local transportation department to a set of standards, and forged in the field with bulldozer, hauler, and blade. When a wheel goes down or up on a road, the chassis must judiciously follow or face the consequences of guessing wrong. That is to say, as seen by the suspension system, a shallow dip or bump on a damaged road surface is indistinguishable from the designed beginnings of a vertical curve. Not to follow a dip down could mean never seeing the road surface again. Not to follow a bump up might prove to be just as nasty.

In contrast, the Roadway is constructed from a set of standardized, manufactured pieces. The full set can navigate the world, but each piece is a known quantity. The Rail Car and its suspension will know, told by its intelligent highway, which piece they presently travel and what path lies ahead. If the actual path, under stress from load, wind, high temperature, manufacturing tolerance, or field damage deviates a small distance from the designed path, the chassis does not have to follow course, as it is confident of the destination.

Consider the following scheme. The Roadway, acting in the capacity as an intelligent highway, tells the Car what segment it is traveling—say a straight segment. In addition the Roadway signals the designed path from end to end with a small alignment laser. As the Rail Doobie wheels or gliders wiggle to and fro as they tightly follow the Rail, the suspension allows the chassis not to follow. The chassis follows the laser, which famously defines a straight path. The chassis thus smoothly travels with full confidence that the wheels will return to the nominally designed path. Only the minimal inertia of the light Doobie and parts of the suspension system needs to be accelerated as they wiggle to and fro—and not the far heavier chassis. Schemes for curved segments are similar.

4

THE RAILED ROADWAY

What, just exactly, is the Railed Roadway? Where is it to be placed? How much 3rd Generation Roadway will we need? How will it be constructed? What will it look like? How will the Rail Cars attach themselves? How are interchanges to be constructed and how will they operate?

As these questions are answered, other questions will become apparent. How is the new Roadway made compatible with existing streets and freeways? How do trucks continue to use the same streets? Given a completely new concept for an interchange, will the solution not destroy neighborhoods as present solutions for a freeway do?

This chapter will attempt to answer these and other questions by first examining the Roadway's large scale features and then proceeding to its finer details. Possible solutions to obvious needs will be presented, proceeding from the simplest and then to the more sophisticated and presumably better. It should be realized by the reader that many, if not most, of the real challenges, and better solutions, lie ahead.

Major sections of this chapter will include discussions of (1) where Rail lines might be built, and if on a street or freeway, where on the street or freeway, (2) the key mechanical elements of Roadway segments, (3) mechanical approaches for attaching Cars to the Rail, and (4) types and performance of 3rd Generation interchanges. Software and control hardware questions will be addressed later in Chapter 6. Questions directed toward an estimated cost of the 3rd Generation Roadway will be addressed in Chapter 7.

THE NEW URBAN GRID

WHERE DO WE BUILD IT?

Let's begin by asking: Where would it be necessary to run lines to service areas and how dense a grid would these lines have to form? We'll examine four types of regions whose variety illustrates how widely the 3rd Generation Roadway would be used. Suburbia will be represented by a sample layout needed by suburban Los Angeles, specifically Manhattan Beach, a largely bedroom community of 35,000. A medium-density, multi-centered (some would say sprawling) urban area will be represented by the greater Los Angeles area. And finally, the heavily populated, commuter dominated, single-center city will be represented by the Manhattan Borough of New York city. To emphasize the extensive adaptability for metropolitan transport, intercity high speed lines will also be characterized.

When reading, realize that significant service would be provided by a Roadway built on a more sparely built grid than will be used here as a baseline. An example within the R&D section of Chapter 7 outlines significant service to the city of San Francisco during a demonstration phase, achieved by building only 1/10 the Roadway length recommended here as the baseline.

THE LOCAL RAIL

Before we begin, we must answer a basic question: is there room? It's necessary to ask this question because the Roadway is to penetrate dense urban cores where space is at a premium, blend into suburban areas, and to do so by using existing right-of-way. Given these goals, we cannot propose large structures. But realize we propose a grid providing ubiquitous service, and one with non-stop local traffic flow. Grids imply intersections, and the structures which allow non-stop traffic at these intersections are called interchanges. We need interchanges.

Freeway interchanges are impossible. Are 3rd Generation Roadway interchanges possible? Is it possible that 3rd Generation Roadway interchanges, designed for local service, would fit above existing streets? Two attributes will reduce their size. Our new interchanges will precisely control the path of their small vehicles, and also accelerate them to limits not determined by rubber on suspect pavement but by the passenger. Take a look at Figure 4-1, which illustrates, in terms of area consumed, three

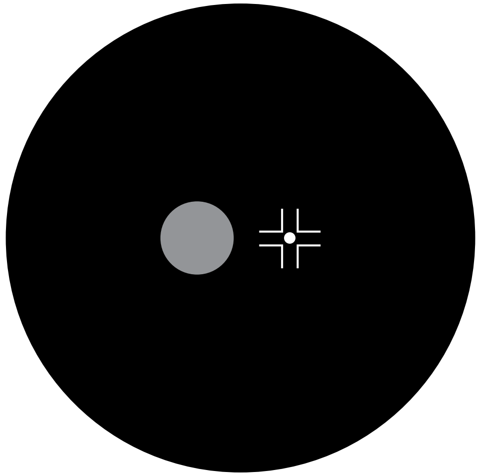


FIGURE 4–1. Illustrates to scale the relative areas needed to construct a high speed freeway interchange (black), a high speed 3rd Generation Interchange (gray), and a neighborhood low speed 3rd Generation Interchange (white). The freeway interchange destroys neighborhoods; the low speed 3rd generation Interchange fits above the small street intersection shown.

very different structures. The large circle is proportional to the area consumed by a representative high-speed freeway interchange. The actual area needed is approximately 40 acres—fully 26 city blocks! The larger of the two interior circular areas is proportional to the area needed for high speed, 60 mph 3rd Generation interchanges discussed later in this chapter. Their estimated area is 0.9 acres. Finally, the smallest circular area is that needed for local 3rd Generation interchanges, of the type to be commonly built for communities within the metropolis. An estimated area for one design presented later is 0.024 acres, that is, about 1,200 square feet or 12 yards square. Note the lines drawn interior to the figure, to scale, used to illustrate 60-foot-wide streets at their intersection, above which the neighborhood interchange is to be built. An interchange fits.

Local service is intended to pick up and drop off Rail Cars within a few blocks of their destination. In moderately populated areas with good surface streets, a convenient few blocks might be interpreted as less than a half mile. Thus a Roadway infrastructure using a square grid with one-mile spacings is a good start for planning local service.

Manhattan Beach, to good approximation, is a uniformly and heavily

populated two-mile square with 9,000 residents per square mile. Major 2-, 4- and 6-lane streets cut through smaller residential streets at regular intervals running north/south and east/west. The north/south major streets are the larger of the set as they service not only locals but commuter traffic from the bedrooms in the south to the offices in the north. They include California Highway 1 (the famed Pacific Coast Highway or PCH), Aviation Boulevard, and the two lane Highland Avenue. The east/west major streets provide access to the I-405 Freeway and the communities to the east, but become smaller to the west as the town borders the Pacific Ocean. They are Rosecrans Avenue, Marine Avenue, Manhattan Beach Boulevard, and Artesia Boulevard or California Highway 91.

Armed with the knowledge that full interchanges can be built within and above the footprints of Manhattan Beach's city streets, which streets should have Roadway and where would the interchanges be? Figure 4-2 illustrates the superposition of Rail lines onto a map of Manhattan Beach's network of streets. Two lines service the north/south commuter streets, with a third feeder line coming in from the southwest. Three lines are required east/west, but terminate as the Los Angeles basin transitions to a beach community. Interchanges are depicted with complete circles for fully developed interchanges and with a half circle for a T interchange connecting a terminating line to a continuing one. No resident is further than 0.5 miles from a line.

Local politics and local sensibilities have influenced the placement of the lines proposed here. Highland Avenue is heavily traveled and plays a key role in commuter traffic headed toward jobs in the north. But Highland is narrow, is a scenic route with views of the ocean, and falls within the dominion of the California Coastal Commission. Consequently the map instead shows coastal traffic routed along Valley-Ardmore Parkway to join Highway 1 inland, presumably returning to the coast at Marina del Rey, six miles to the north. Similarly a Rail line on Marine Avenue east of Highway 1, though of value as a feeder to the 405 freeway, would be feared by residents on Marine Avenue west of Highway 1, as the Rail line could dump traffic onto their street. Thus no Rail line will run this wide avenue.

For Manhattan Beach, 11 miles of Rail are shown. 5¼ miles are interior to the town and 5½ miles are shared equally with other towns at the city boundaries. Thus if we were accountants or crystallographers, 5¼ + 5½ ÷ 2 = 8 miles of line service 35,000 people. One mile of Roadway for 4,000 people. With similar accounting, 3 + 3/2 + 2/4 = 5 interchanges are required. One interchange services roughly 6,000 people.

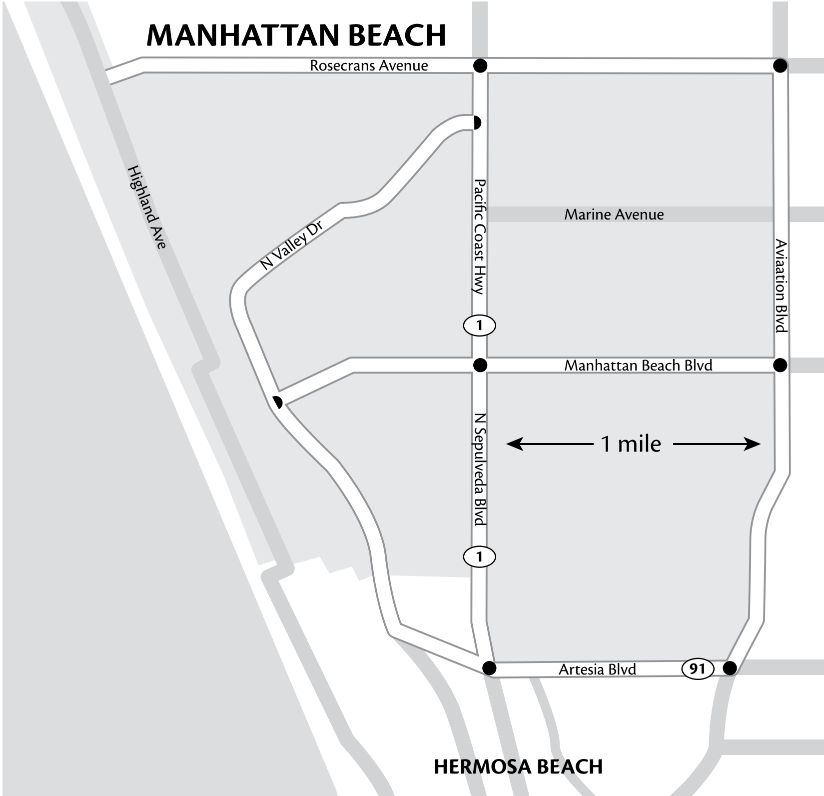


FIGURE 4–2 shows a local Rail route map providing full service to Manhattan Beach, California.

The two lines running north/south have the highest peak traffic loads, 2,600 vehicles/hour on Highway 1, and 2,300 in the northern sections of Aviation Blvd. These traffic flows are well within the capacity of local lines and low-speed local interchanges. Local lines and interchanges will be shown to have capacity approaching 15,000 vehicles per hour. Thus it will become clear the local Rail is suitable for travel and can handle traffic generated by suburban areas of at least 10 miles on a side. As higher density and higher-speed traffic is desired, different Roadway and interchanges will be needed.

THE METROPOLITAN RAIL

So far, so good. The local resident hops in his Rail Car, putts down the street, cruises a few miles on the Rail, and exits at the shopping mall, school, or near Aunt Ginny's: an attractive service model for a small community. But we need service for longer trips in larger areas.

In extending the area, one obviously needs to add high speed Rail lines to the service model and thus provide attractive speeds suitable for convenient travel in large metropolitan areas. A typical cross-metropolitan trip will now be conducted in five distinguishable steps. One drives to the local on-ramp, then cruises on the local Roadway at 40 mph, joins the high speed Rail to accelerate to 80-100 mph, exits onto another local Rail, and finally disembarks to drive the "final mile." The composite Roadway now is a close analog to the street and boulevard model of the 1st generation roadway, and the two fluid model of roadway traffic flow applies.

Can the Manhattan Beach service model be extended to the greater Los Angeles basin? Simplistically, each of L.A.'s existing freeway paths becomes a candidate for high-speed Rail lines. There are roughly 500 miles of freeway in the Los Angeles area, and it would reasonable to assume that all should have a high-speed Rail aligned down their existing right-of-way. Properly designed, a Rail down the freeway's center median would be the easiest to envision. This new network would include a key element. The inclusion of high speed interchanges will provide for continuous high-speed flow and preserve the Roadway's capacity for large numbers of vehicles.

Figure 4-3 is a reproduction of a copyrighted AAA map of the major traffic arteries of the central Los Angeles County basin. The region contains the overwhelming majority of the population within the county, and L.A. County is the most populous in the nation at somewhere around 10 million souls. The map inks in, very roughly, 1,900 miles of surface streets and a more precisely measured 480 miles of freeways. There are 44 high speed freeway interchanges.

Now assume 3rd Generation Roadway runs the length of each and every road shown! That's consistent with the local discussion in Manhattan Beach, but, obviously, ignores many details. The region has a population somewhat over 8,000,000, thus, as with Manhattan Beach, each of the area's 1,900 miles of Roadway services about 4,000 residents. If you like, every man, woman and child is to buy 16 inches of Roadway! In addition to the local system, 480 miles of high speed Roadway will be built. Approximately

FIGURE 4–3 The major roads shown on this AAA map provide a guideline for placement of a 3rd Generation Roadway grid.

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1,000 local interchanges and 44 high speed interchanges will be needed as we'll show in a moment.

By looking very closely at the maps, one can compare differences which might result from local interests versus our sledgehammer L.A. County approach. The County map and the local Manhattan Beach service plan closely resemble each other. But local sensibilities have kept a Rail from traveling the narrow and scenic Highland Avenue and replaced that asset with a Rail down the more spacious Valley–Ardmore Avenue, forcing traffic inland. An additional mile down Marine Avenue was eliminated from local service. Obviously as 3rd Generation Roadway is built across the County, local sensibilities will also modify the Roadway alignments.

Local interest might also request the construction of additional high-speed lines down routes that are now slow, congested thoroughfares. That process won't affect the total length of Roadway just modeled, but will increase the length of high-speed line and increase the number of high-speed interchanges. More accommodating communities, attracted by the Roadway's small size and pleasing aesthetics produced by some clever architect, might actually fight to have high-speed lines. Please add high-speed transit to the crowded corridor that is Santa Monica Blvd. Run a line from the city of Santa Monica to Century City, Beverly Hills, Hollywood, Silver Lake to State Highway 2 and the Glendale Freeway line. Add feeder lines from UCLA and the end of Laurel Canyon. For Palos Verdes, a lovely but somewhat isolated peninsula, please run high-speed access up Hawthorne Blvd. to the ocean, up Crenshaw to Silver Spur and across PV Drive North. Please route Roadway on the Malibu Coast. Los Angeles has many areas whose citizens have objected to the massive intrusion that a freeway would impose on their community, and/or where real estate is expensive. Use the high-speed Rails where long-planned but frustrated freeways never have gained acceptance—as in South Pasadena. All the long, and slow, boulevards featured in Randy Newman's song, "I Love L.A.", become candidates.

Separately, high speed Rail lines will be used to relieve traffic pressures on otherwise bucolic neighborhoods. To get to Santa Monica from Canoga Park, why do you need to drive, or build a Rail line for that matter, down Topanga Canyon, if you reliably can go through Sepulveda Pass at 100 mph? Why commute the Angeles Crest Highway when Roadway on the Antelope Valley Freeway route works so well?

RADIAL CONVERGENCE TO THE URBAN CENTER

Los Angeles is a metropolitan area with many centers, spread out, with traffic patterns connecting a multitude of bedroom and industrial communities, each with employment, shopping and entertainment centers. But many cities have a single center, a massive "heart" if you will, and traffic patterns which result from a flow of people to the center in the morning and a flow away from the center in the evening. Some Latin countries have a second flow at lunchtime—out and then in. In each case traffic flow patterns can be said to be analogous to spokes on a wheel. We'll call this pattern a "radial convergence to the center."

The point to be illustrated by this short section is not the potential for line service to the entire metropolitan area, which would have much in common with the discussion for Los Angeles, but to examine the problem of servicing radial convergence. A marvelous example of radial convergence will be to service the island borough of Manhattan, New York. We won't focus on line layout and commuter times on the island—questions such as which avenues would be serviced, how many would be serviced, how long it would take a commuter to travel from the Battery to the Bronx—but rather the unique, to this chapter, problem of massive numbers of commuters converging onto the island. That said, realize many major cities of the world have similar configurations and scenarios.

The daytime population of Manhattan is roughly 3,000,000 and the nighttime 1,650,000. About 100,000 people leave the island in the morning to work or play elsewhere, leading to a rough conclusion that just under 1,500,000 commuters come into the borough in the morning and 1,500,000 leave in the late afternoon. In an ideal world, where the penalty of commuting into the city at peak rush is zero, let's assume all 1,500,000 would come in between 8 and 9 am ready for that morning meeting. Let's further assume that some car pool and some still take the subway. 1,000,000 vehicles going one direction in one hour! Er … Um, about the theoretical maximum capacity of one hundred and twenty-five freeways if eight lanes each!

What arrangement will accommodate such a rush? Imagine a high-speed Rail line coming from New Jersey at 60 mph. A little slow because curves are required. In a solid "train" mode with 7-foot-long Rail Cars traveling at 88 feet per second the single line carries 45,000 Cars per hour. Equally loaded, 22 lines will handle the projected traffic of 1,000,000 Cars in an hour. Obviously loads wouldn't be equal, and maybe more commuters will try to come in at 8:22 am. Let's say 30 lines are adequate. Later on also we'll learn that without feeder lines it's not possible to assemble a completely solid train of continuous Cars. Merging Rail Cars and preparing them for exit may limit the "packing factor" to about 80% of a solid train. On the other hand if the Cars were traveling at 75 mph packed at 80%, the number of Cars would equal Cars traveling at 60 mph packed at 100%, and all our capacity numbers would still be valid.

These 30 lines in number would roughly equal the 20 bridges and tunnels that service the island today. To some approximation, it would be correct to consider the visual and structural impact to the city by visualizing a Rail line attached to each bridge. Now consider how small the proposed structures are when compared to the existing bridges. The Roadway will easily fit into New York's infrastructure.

To avoid bottlenecks a fully loaded line would have to have sections of an almost continuous train split onto at least two lines before directing Cars onto the "slow" neighborhood lines—a job for the centralized computer. So obviously there's an interface between the fully loaded, high-speed line and the city's lines.

INTER-METROPOLITAN RAIL LINES

Airplanes, Interstate freeways, and, increasingly, high-speed trains are the accepted modes for travel between major cities. Would Rail lines be competitive for these longer routes? If so, the impact of the 3rd Generation Roadway would be greater than the basic proposal this book discusses.

Let's compare the relative advantages and disadvantages associated with each our four options. San Francisco to Los Angeles will be our case example. Roughly 400 miles separates the two. Similar distances characterize many city-to-city trips. The heavily populated eastern seaboard from Boston to Washington, D.C. is an obvious possibility. The analysis will also be illustrative for shorter distances.

The S.F. to L.A. flight time is roughly one hour. With check-in, security, margin, and baggage at arrival, 3 hours is nominal for airport and flight time. Driving to the S.F. airport, car rental and driving in L.A., or accounting for your friend's round trip to pick you up, adds another 1½ hours. So 4½ hours door-to-door. We are not accounting for the time, of course, to coordinate your schedule with the airline's schedule, or shop for tickets.

Maybe $100 one way. 170 daily flights each way (94 Southwest, 31 United, 26 American, 9 Alaska, and 5 each for Virgin America and Jet Blue on Nov 6, 2008) are available mostly on 140-seat B737s; so roughly 20,000 travelers (170 x140 x 83%) must choose this method every day.

I-5 is the standard driving route. U.S. 101 is the only alternative. Six hours door-to-door is a good time. Drivers usually take the wide open San Joaquin valley at 70-80 mph and the two metropolitan ends at 60-70 mph. As a frequent traveler, the author estimates during peak hours about 1,500 automobiles per hour drive the distance each way with big rigs using much of the 2nd lanes. If 10 hours are such on each weekend day and 6 hours are such each weekday, 50 such weekly hours and off peak traffic means about 15,000 vehicles a day choose this path. 20,000 per day if we include U.S. 101, which maybe 1/3 as many take. A driver's cost is also about $100 per vehicle given $64 for gas (400 miles x $4/gal/25 mpg) and, what, $40 (10 cents/mile) for incremental wear and tear. A good deal if several are in the car, but then we've not accounted for the driver's labor in keeping the car on the road and safe for 6 hours. Of course the car was ready in the garage when the driver was; he didn't have to coordinate schedules; nor did he have to get online to shop for a ticket.

The proposed, and partially funded, high-speed train will average 160 mph for a 2½ hour trip. (The claim has generated some controversy.) And given that there will be several stations in both San Francisco and L.A., we'll add only 1 hour for the task of getting to and from the stations, for a door-to-door time of 3½ hours. If plane, car, and train share the market at 33% each, 13,000 passengers each way per day, 10 million per year, will take the train from S.F. to L.A. Proposed price is $50 per passenger. Hmm! $1.3m revenue a day for a $10+ billion investment.

Others reach different and far more optimistic conclusions. By adding Central Valley stops on Highway 99, most notably Bakersfield, Fresno and Sacramento, the California High Speed Rail Authority projects 54 million passengers per year by 2030. A good review of the plan is provided by John Gertner in the *New York Times Magazine* of June 14, 2009, who also argues, given the relative size of California and France (whose TGV transports 100 million annually) that this number has credence. But a panel from U.C. Berkeley's Institute of Transportation Studies, working post ballot, concluded that the standard patronage models used were too flawed to accurately predict useful numbers.

Rail Cars, configured in a train as proposed, would have a top speed of

100 mph. The small motor, optimized for urban transport at 15 hp, will be that limit. The Rail itself, along with the small wheels used by the Rail Car, will also define a maximum speed. Let's still assume 100 mph. So 4 hours. But the Inter-Metropolitan Rail line will surely transition seamlessly, first to a high-speed Metropolitan line and subsequently to a local line near the final destination. So let's add only 15 minutes. 4¼ hours door-to-door. Gas 3 gallons. $12. Wear and tear TBD. No schedule to coordinate, no transportation to arrange at the other end, no shopping for a ticket, and no driving fatigue or danger. Traffic at 26,000 vehicles per day counting both ways. Yes, the 3rd Generation Roadway appears very competitive.

PARK 'N RENT

Visitors to large metropolitan areas have much to gain from automated transportation. The large, complex, even intimidating area is unfamiliar and the tricks of getting around are unknown.

Obviously, a visitor arriving at an airport will need vehicle rental service as we do today. The automated, stacked Rail Car garage—to be discussed in Chapter 5—will have a very small footprint and allow the garage to be within walking distance. Goodbye to the shuttle bus to the rental car! Passengers departing from an airport could park closer to the terminal and at greatly reduced cost.

But this short section addresses another aspect of metropolitan transport affected by the Roadway. Visitors arriving by car from rural areas would no longer need to face the street traffic of an immense city. Instead, at the city outskirts, where land is still cheap, that driver could park and rent a Rail Car. That driver, given the option for automated transport within an unfamiliar metropolitan area, but one requiring a different vehicle, indeed has sufficient motivation to rent. The rental process would be as today—by the day or the hour.

Occasional drivers, college students, and the like could quickly rent a Rail Car for a small excursion. The Zipcar business model comes to mind. Rent online, pick it up from the last customer, and drop it off for the next. Obviously a convenient drop-off/pick-up spot would be at every on/off ramp to the Rail line. This model closely resembles PRT public vehicle or robotic taxi model, and services the occasional user, be they tourist or native.

The reduction of automobile traffic on surface streets resulting from

these rentals would be significant. Many cities have large populations of "day tourists" in addition to the traditional driver. Business trips from outlying rural areas are probably greater in number than those by travelers arriving by airplane.

THE 21ST CENTURY HOV COMMUTER LANE

In the past 30 years intermittent, debated, expensive, but determined building of high occupancy commuter lanes has augmented most urban freeways. The political determination is driven by the desire to increase lane capacity by a factor of two and sometimes three. Passenger, not vehicle, capacity is increased in the HOV lane by requiring two or three occupants per vehicle. A miserable 1.07 average is typical for vehicles in the other lanes. Critics reasonably complain when sufficient users don't fill the lane, implementation is excessively expensive, or excessive roadbed is swallowed up, but supporters have generally prevailed.

In fact, note that sufficient political goodwill exists for it to be expended elsewhere on other worthy causes. Witness the privileges enjoyed by the hybrid car as an honorary HOV; and more recently the 'green car' proposals underway. To increase usage of the HOV lane, several states, including California and Texas, are experimenting in selling access to single drivers at a price per mile. The fluctuating market price of this access and the level of congestion relief achieved will be useful litmus for the market value of an HOV lane.

The commuter lane is the embodiment of the political will to increase freeway capacity. And at present the commuter lane represents exigent right-of-way along corridors with need. One method to easily implement key sections of the 3rd Generation Roadway would be to transfer the right to use the HOV lane to a Rail line. Selling the idea to convert a freeway lane so as to increase vehicle capacity by a factor of 50 sounds like a slam dunk!

The ratio of 50 results from a Rail line carrying 25 times the vehicles, and both directions of a Rail line fitting into one freeway lane. Since only one commuter lane is used for the two-way Rail line, and if commuter lanes have been implemented each way, as they typically are, whichever lane is deemed to have less utility would be converted. Conversion using standardized piecemeal construction on an unimpeded path would be rapid.

Given a solid roadbed and no need to elevate Rail, conversion would be at reduced cost.

Converted HOV lanes are strong candidates for routes during early implementation of the 3rd Generation Roadway. Daily commuters will be eager early adapters even if the route were the only line built for their particular driving patterns . Of course, they must buy a Rail Car. The user's investment is in lieu of the daily task of coordinating with a commuter buddy, or the daily task of stop-and-go traffic. But the government has clear mechanisms to incentivize buyers of these very green cars. If lane conversion is quick, subscribers could put non-refundable deposits on Rail Cars, guaranteeing minimum use of the new lane on opening day.

Next Tuesday, at least conceptually, the Governor could sign into law conversion of high speed right-of-way ready-made for a 3rd Generation Roadway. These paths exist along key urban routes developed over the last 50 years.

ROADWAY COMPARISONS

In Chapter 2 we looked at the characteristics of 1st generation streets and boulevards as well as the 2nd generation freeways designed to relieve them. In this chapter we've characterized the 3rd. So let's now compare the three generations of roadway. Here we'll look their ability to handle heavy traffic flow, the length of roadway that is needed, and the resultant land consumed by building such. In the next section we'll look at a fourth characteristic: how long it takes to go from A to B when using the Roadway.

A small street burdened with stop signs and heavy cross-traffic is a poor performer: 300 vehicles per hour in each direction can pass. Streets or boulevards with traffic lights to facilitate flow are better: 1,000 vehicles per hour, per direction, per lane. One would think a freeway, if everyone drove with a one-car length-per-10 mph spacing, would carry three times that number per lane, but real life freeway data show that 2,000 vehicles per hour can pass at 60 mph if the gods are smiling, and that 1,800 vehicles per lane per hour is a better number. The 3rd Generation Roadway will carry between 15,000 and 60,000 Rail Cars per hour per direction—and one always assumes a single lane. A minimum capacity of 15,000 results at a local interchange if everyone is making a turn and everyone slows to 25 mph. A capacity of 60,343 Rail Cars per hour results with 100 mph speeds

and the 7-foot vehicles. Both numbers assume that the computer can pack the line to a limit of 80% full. These data are displayed on the left side of Figure 4-4 using a logarithmic vertical scale.

The District 7 office of Caltrans counts 51,000 miles of roads—streets, boulevards, and highways—within its kingdom. The core of Los Angeles County displayed by the map of Figure 4-3, has slightly different and smaller boundaries, so let's estimate our section has 45,000 miles of those roads. Amazingly L.A.'s famous freeways run but 480 miles. If the average freeway is 300 feet fence to fence, freeways must consume around 11,500 acres. If the average road is 45 feet wide, that's 250,000 acres of streets on our map. Huge, yes, but per-capita one of the smallest areas in the U.S..

By comparison, the aggressive 3rd Generation baseline just described to provide complete service to the area will need 1,900 miles of local Roadway. Also proposed is 480 miles of high speed line. 2,400 miles total. Assuming local two-way Roadways would be built as a side-by-side guideway, not as a double-decker in a vertical configuration, and their unused footprint beneath would be considered "used", a generous width of 14 feet results in 3,700 acres needed. High speed line built with16 feet of width will need 920 acres. 4,600 acres total. The relative magnitudes discussed here are graphically shown in Figure 4-4. Note again the logarithmic scale when contemplating the tremendous differences.

For the mathematically inclined, a little algebra can be used to gain insight as to why the above results are to be expected. The roughly

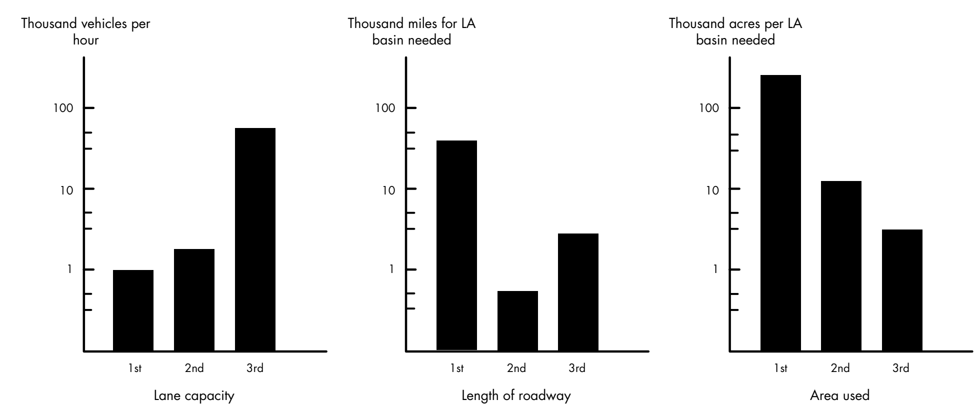

FIGURE 4–4 compares the 3rd Generation Roadway in capacity, length needed, and area consumed.

rectangular area of the AAA map of Los Angeles depicts 1,100 square miles with 480 miles of freeway. If one were to take 480 miles of line, chop it up, and lay it out in a uniform square grid within a rectangular space of 1100 squares miles, the grid spacing would be 4.5 miles. Very close to the previously estimated actual average of 5 miles. If the area were a square, the number of interior nodes in our hypothetical uniform array would be 49, fewer if a rectangle. Los Angeles has 44 freeway interchanges. Earlier we roughly estimated that the metropolitan nation is 19 times the size of L.A., thus we might now anticipate approximately 800 to 1,000 high speed interchanges would be needed within the United States.

Continuing, if one wanted to lay out a uniform square grid with 1 mile spacings, one would need 2,123 miles of line within 1,100 square miles. Los Angeles has 1,900 miles of major streets. Mathematically there would be 1,024 nodes in our 1-mile grid, so one could reasonably assume L.A. will need 1,000 low-speed Rail interchanges. Completing our algebra just for fun, if L.A. city blocks are laid out on 400 foot squares, L.A. should have 46,500 miles of street. Very close to Caltrans' number.

To summarize in round numbers, and assuming the metropolitan United States is 19 times the size of L.A., the nation could use our baseline to be fully serviced with 40,000 miles of Roadway, 20,000 low speed interchanges, and 1,000 high speed interchanges. Separately, one could estimate approximately 60,000 on ramps and 60,000 off ramps to provide the type of service we are describing.

These values are indeed shockingly large. But then it is a large nation. Soon, we will discuss what needs to be built—manufactured, elevated structures supported by posts. If each of the manufactured pieces is 100 feet long so as to be transportable by truck, that's 52.8 structures per mile, or 2 million structures per nation. Impossible, no, but big. Witness that as a nation, we have built our 1st and 2nd generation roadway bridges, constructed one at time, as large specialty pieces in the field—600,000 of them.

TRAVEL TIME COMPARISONS

Acquainted now with both the speed and placement of 3rd Generation Roadway, and convinced that the Roadway will run without congestion, we ask how long will our journey take compared with what we know today? The time needed for a trip today varies and depends on a variety of factors: distance obviously, but also the type of road available, the degree of development, time of day, amount of traffic, etc. Travel times even change over many years as development grows along state and county highways, lights are added, and congestion increases.

In Table 4-5 the reader will find a number of comparisons. Some are discussed within the text. Others are representative. Some times roughly equal values given by such services as Mapquest and Google. Others, particularly those for "congested travel times," are consensus. All times are obviously approximate. Speed on the local Rail is assumed to be 40 mph; and when slowed by the occasional 25 mph turn to average at 36 mph. Speed on the high-speed Rail is assumed at 100 mph.

An inner-city route can be represented by a hypothetical trip from East Los Angeles—Olympic and Atlantic—to the mid-Wilshire district—8th and Western—a distance of 10 miles. Google, usually a good estimator for light traffic conditions, lists travel time by car as 26 minutes. The Metro bus line schedule lists 46 minutes in light traffic at 5 am and 10 pm, 57 minutes during the morning rush "hour" and 65 minutes during the afternoon "hour". Has the city allocated 19 extra minutes of congestion?! By comparison, use of a local Rail Car line should require only 17 minutes. A high-speed line would reduce this last time.

With use of high-speed lines, how fast would a Rail Car trip across the metropolis be? Let's investigate the north woods youth's 30 mile trip. Again, his friend must drive on city streets to the nearest Rail, travel on this local Rail to a high-speed Rail, and, after completing that speedy segment, slow onto local lines and finally onto a surface street. Five segments. Let's add up the times. First, let's look at the greater Los Angeles basin and notice that, to fair approximation, every 5 mile square area is serviced by a freeway. Yes geography intercedes, and it certainly isn't a square matrix of freeways, but if you need to get on a freeway you usually don't have to go more than 5/2 miles. The 5/2 mile legs on the local lines at 36 mph will take 4 minutes each! The two 1/2 mile legs on the surface street at 18 mph will take 3 minutes in sum. Of course the traveler on average will only need half

TRIP		TODAY		RAIL CAR	
	mi	method	time	time	method
Rosecrans Ave	3	car on street	12	5	local line
S. Pasadena to Altadena	6.6	car on street	22	11	street, local, street
Bethesda, MD to the White House	7.2	car on street	27	12	street, local, street
East LA to Mid-Wilshire	10	street, freeway, street	40	17	street, local, street
		bus	55		
The northerner's journey	30	street, freeway, street	1 hr 5	21	local, high speed, local, street
NY to DC	230	taxi, train, taxi	4 hr	2 ½ hr	garage, local, high speed, local, garage
		taxi, subway, plane, taxi	4 hr		
		car on street, freeway, street	5 hr		
SF to LA	390	car on street, freeway, street	6 hr	4 ¼ hr	street, local, high speed, local, street
		taxi, BART, plane, car	4 ½ hr		
		high speed train	3 ½ hr		
UCLA to MDR	7	street, freeway, street	45	7	
Wall St. to Harlem	9	taxi	1 hr 20	7	garage, local, high speed, local, garage
		subway	40		
Santa Monica to Hollywood	12	car on street	1 hr 20	9	garage, local, high speed, local, garage

TABLE 4–5. Times Needed to Travel Various Journeys. Times in the upper half of the chart are for "normal" conditions, while the lower half highlights travel at congested hours.

these times as he starts and finishes by choosing the closest lines. And the remaining approximately 27 miles on the high speed line at 100 mph will take 16 minutes. Total time 21 minutes. The north woods boy and his friend hypothetically spent 1 hour, 5 minutes on today's roadways.

The New York to Washington, D.C. example might be explained as follows. An experienced traveler on the upper east side of Manhattan might allocate 15 minutes by cab to get to Penn Station, arriving but 10 minutes before the scheduled departure of Amtrak's Acela high speed train. He pays an extra $100 to get an advertized Acela Express arrival in 2 hours, 47 minutes, at which time our experienced traveler would hop a waiting cab for a 15 minute trip to K Street. Total time 3 hours, 25 minutes. Four hours even if he doesn't have the extra 100 and takes the slower Regional. Assuming high speed 3rd Generation Roadway is available for all but 3 miles on each end of the same journey, 224 high speed miles would be traversed in 2¼ hours with 5 minutes on each of the local ends. Total time: 2 hours 25 minutes.

Other entries in Table 4-5 are discussed in the text.

THE ROADWAY ABOVE THE STREETS: WHAT DO WE BUILD?

And so we come again to the point where we are forced to ask, what, just exactly, is the Railed Roadway? But now armed with knowledge of where it must fit and what it must do, we can design its key mechanical components. The largest, and arguably the most important, is the elevated support structure. We will explore four possible constructions. Services provided by the Rail to the Cars, such as power, synchronous propulsion, and positioning information, need discussion.

The Doobie, that important piece that adapts the Car to the Rail, will then be examined. The Rail and the Doobie must support the Car, switch the Car from Rail to Rail, and propel the Car. Several attractive designs of increasing sophistication will be presented.

With all that in hand, we can then take peeks at these forms of Roadway appropriately placed within various urban scenes. Ah, isn't the tool of C.G. with the talent of a graphic artist a marvelous thing.

In a sense the Roadway itself will also be a product of private enterprise. Clearly, a set of successful contractors will design and produce the Roadway as a manufactured product. The field assembly and placement itself will also be outsourced to a successful bidder. In this model, as for the privately developed Rail Car, the government will define a set of requirements for delivered Roadway.

Obviously there are differences. First, in all likelihood, the government itself will fund, that is, pay for the Roadway. Exactly how will be discussed in Chapter 7 entitled, "Anticipating the Cost". Second, and as importantly, the government will decide where the Roadway will be constructed, "determine the alignment" in highway speak. This step will be difficult, involving all that is City Hall, regional zoning requirements, environmental impact analysis, and citizen hearings. Third, the government will monitor the quality of construction and execute appropriate remedial action, be it reward or punishment.

The procurement task will be a difficult governmental assignment not faced in the development and selling of the Rail Cars. As any procurement agent knows, and especially any government procurement agent knows, setting the requirements for a job is a difficult art and a science in itself.

The art is to place into words the product desired, in verifiable terms, and at the same time to avoid telling the contractor how to build such a thing. For this product it would be a mistake to specify that the Rail should be of steel or that the Cars should be hung from above; until that is, after prior substantial research and subsequent decisions, all parties agreed that steel and suspension from above was the way to go. This statement is not to say that the specification list would not be long and that qualitative aspects would not be judged. Obviously, as for any architectural product, the sheer beauty of the product, or lack thereof, would be judged under the rules of some procedure. Awards would involve qualitative judgments and be reviewed, in federally funded work, by the GAO.

As an historical note, other development models exist. In the United States one other model is that of the private railroad network. Roughly speaking, the government gifted right-of-way, sometimes overly generous swaths, and entrepreneurs set up shop. The fortunes of Harriman, Stanford, Huntington, Crocker and other "robber barons" resulted from control, and regional monopoly, of the dominant land transportation system of the 19th Century.

A century ago private entrepreneurs built Chicago's extensive "L" network paying for both the railway structures and the cars. And they developed everything without the power of eminent domain! Their success, lead by that of Charles Tyson Yerkes, built fortunes one nickel at a time. Samuel Insull, a former worker for Thomas Edison and who made a fortune building electric power plants, unified and operated the entire system after 1924 as the Chicago Rapid Transit company until he lost everything in the Great Depression. The government didn't take over until 1945. The "L" dominated Chicago's transportation until the freeway and the maturity of the automobile reduced the status of public transportation. Yerkes used his fortune for philanthropy, funding his namesake telescope, an important contributor to modern astronomy.

One engineering goal is to change the very concept of roadway construction. Change it to one of manufacturing a roadway in efficient factories. Factory construction is to be largely reduced to that of manufacturing a set number of standardized pieces, at least for the vast majority of pieces. After transport of these pieces to the job site, the goal would be that only final assembly take place in the field. Think tinker toys, LEGO sets, and glue together ABS plumbing systems. Think modern manufacturing with its 'Just-In-Time' delivery of highly sophisticated and substantial subsystems to the minimal assembly line in the field.

A key to the entire concept of the 3rd Generation Roadway and Rail Cars is the design of these manufactured components of the Roadway. Poor performance, excessive size, visual blight, prohibitive cost, all could result from a less than imaginative designs. The application of clever design, advanced control approaches, superior materials, and cost-effective construction must prevail. Advantage must be taken of the light loads that burden the spans and Rails. There are hideous examples, including what Yerkes built—in the context of the goals of this book—of elevated rails built a century ago. It is here that, as the cartoon says, the miracle occurs.

To minimize the immense expense of obtaining urban right-of-way and of urban underground digging and construction, two assumptions seem solid. To avoid right-of-way issues, the Roadway will be built high enough to allow life to continue relatively unimpeded below—trucks and automobiles at intersections, pedestrians everywhere. To reduce field construction cost a minimal number of anchors will be drilled into streets—think two foot cylindrical posts every 80 to100 feet down the landscaped center median of four lanes streets. Such an approach will place a premium on bridge design between the posts, a discussion of which will soon be central.

SOME TERMINOLOGY

Before beginning, let's define a few terms. The 3rd Generation Roadway consists of a network of Roadway structure, its right-of-way, and its computerized control system. Long, straight runs constitute the bulk of the Roadway's mechanical structure and will be considered here to be an assembly of four principal parts. We'll discuss other assemblies such as interchanges, on and off ramps, etc. later in this chapter.

The first of these four principal parts is the Rail itself. The smooth, straight Rail is the piece to which the Rail Cars cling. They ride the Rails. If wheels are employed, the Rail Cars will roll along the Rail as does today a car of a freight train roll the rails of a railroad track. The Rail functions to secure the Cars, prevent them from swinging, provide them traction, monitor and communicate with them, provide electrical power and even propulsion if the final design incorporates these features, etc. The Rail is the heart of the system's hardware.

To maintain its shape, as it is suspended in air, the Rail needs to be secured to a rigid structure. We'll call this structure the skeleton, which itself consists of two pieces, our second and third. The first is a beam or set of beams which provide the skeleton with the required strength and low compliance, that is low stretchiness, when given a load. The beam may be compared to the backbone of a vertebrate animal—strong, light, capable of confronting a sack of potatoes or swinging from a tree. The skeleton's second piece is any of several connecting elements which articulate the beams into acting as one rigid skeleton. It's fair to compare these pieces to all the ligaments, tendons, muscles and smaller bones which working together with our backbones act as a solid skeleton. In one limit a beam can be the entire skeleton. A beam itself might be a triangular truss of tubes to obtain rigidity. An attractive alternative is to have two beams separated by rigid elements at key points so as to obtain extreme rigidity in one direction. We consider the collection of these various connecting elements to be the second "piece" of the skeleton. A skeleton must be sufficiently rigid to maintain its shape when fully loaded over a free standing length—a span—without support.

The fourth piece is a post. It is ... well ... a post. A post could resemble that for a street light. A vertical post fastened to the ground with four big bolts sunk into a pillow of concrete would do. On a very narrow street, where no median can be created, a post might take the form of an arch anchored at both ends on opposite sidewalks. A post might anchor on a sidewalk and have a bend as to support Rail Cars traveling above the parking lane. If, for instance, the Roadway is to be attached to a large bridge over water, a post might be a horizontal member adding the Roadway to the bridge's shoulder.

A post is placed at each end of each span, and while nominally a fairly simple structure, faces a number of daunting requirements. It, or course, has to provide secure support for the compressional force of the skeleton above, withstanding the changing axial and smaller lateral forces as the Rail Cars pass. Its placement on the street, both for its position and the setting of its foundations, must be carefully considered. The post is also the most convenient conduit to other parts of the system. As such, on an occasional basis, posts will shield electrical power cables, communication cables and the like. The street work and disruption required to get all this hardware to the post may be more an issue than the modified design of the post.

A SPAN

Let's start. What's the Roadway's basic building block? Well, rigorously it's a post supporting a section of skeleton and the corresponding section of Rail. But, it's probably easier to think of two posts supporting a span between. Let's assume for purposes of discussion that a span should be about 100 feet or 30 meters in length. Posts separated by 100 feet will allow entire intersections to be uncluttered by a post and a standard city block would have but two posts in its median or on its sidewalk. It's important to get the design right in that the U.S. needs 40,000 miles of Roadway, and, at 100 feet a span, would fabricate 2,000,000 of these basic building blocks. (Panic not, the U.S. today has 600,000 bridges, each huge, specialized and costly by comparison. We are a big country.) So let's explore several different designs for a skeleton spanning the distance between two posts and thereby gain some insight as to what a successful span might look like. We'll explore four.

Some elements of the skeleton, remember, will be under tension and some will be under compression. Steel is still the champion for reliable construction elements under tension. Realize that carefully fabricated carbon nanofibers have demonstrated about 4 times steel's tensile strength. Aramid fibers (Kevlar) and yes, even spider web fibers also have strength superior to steel. But high quality steel, exhibiting ultimate tensile yield strengths of 200,000 pounds per square inch, should be the starting point here.

Concrete, particularly clever, fiber reinforced varieties of concrete, is our champion for structural elements under compression. Large cross-section elements of concrete have immense compressive strength, are virtually incompressible, are affordable, and are even relatively pleasant to the eye in their monolithic smoothness. Relatively thin wall steel pipe, manufactured in appropriate shapes, can be used as a mold for reinforced concrete, poured on site. The low cost technique is commonly used for medium scale structures.

Design #1

A classic technique to support a path suspended in space is to hang the pathway from key points above. Typically key points are available only at the edge of a gorge or river and large cables are employed to distribute available support between the key points. Smaller cables connect these

larger cables to the path below. The main cables are pulled downward and thus toward the center by the load. Anchors at the cables' ends pull the other way. Hence, as are the smaller elements which directly support the path, the cables are subjected to tensile forces. Lightweight steel cables subjected to tension perform marvelously. On the other hand, the key points above must be maintained by elements capable of withstanding compressive forces. The forces are compressive in that the weight of the entire structure and load pushes down on any vertical element while the earth pushes up. The pathway itself, say over a gorge in Nepal, may have no rigidity, and hence flex in a frightening way under changing loads, or it may provide local rigidity so as to flex imperceptibly. Given that the path is supported from above at multiple points, local rigidity is often easy to obtain. Witness the suspension bridge.

The classic example of this classic design is San Francisco's Golden Gate Bridge, part of which is seen in the photograph of Figure 4-6A. The single span Golden Gate is of course a monster in scale with a free span length of 6,450 feet, main cables 35 inches in diameter, a roadbed weighing 150 thousand tons, and designed to support live loads of up to 4,000 lb per linear foot along the entire span. Our modest goal by comparison is a span of 100 feet, an extremely lightweight Rail, and a live but controlled load of less than 280 lb per foot. But the same principles can be applied.

Using this classic design as a model, let's explore how it would scale and thereby gain some insight as to how it would look. Let's start with the simplified model illustrated in Figure 4-6B. Simplified, and obviously not optimized. In the Figure, the two posts handle the compressive force of the load, steel cables draped from the post tops support the rest of the skeleton with drops at several intermediate points as does the suspension bridge. Given the strength easily incorporated into the skeleton, few drop lines will be needed compared to the bridges we know today. In our little drawing we show only three. In addition, we've allowed the cables only five feet of vertical drop for aesthetic purposes—the span has to be a pleasant addition to the neighborhood, and should allow the driver pleasant views. Thus as seen by the driver, the top of the posts and all of the five foot vertical drop is below a horizontal line of sight. The driver sits and looks at the scenery. Unfortunately, the cables at span center must now fall somewhat below the Cars' path.

How big would the cables have to be and how long of a span could be built? One question at a time. We've assumed that 100 foot spans are an acceptable answer for many local streets and will produce minimal

FIGURE 4–6A. San Francisco's Golden Gate Bridge supports a roadway with the tensile strength of steel cables

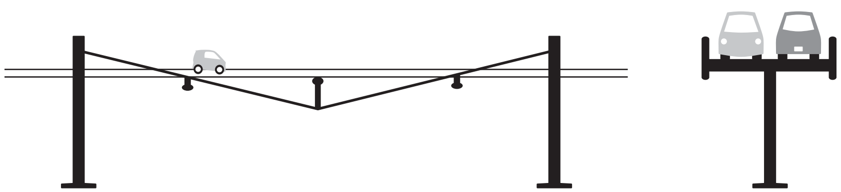

FIGURE 4–6B. A simplified suspended span of 100 feet using side by side Rails. Shown is a single span with an end view illustrating cable drop from the post to span center.

interference to street cars traveling beneath. How big must the steel cables be? Realize that 14 seven-foot-long Rail Cars can fit on the 100 foot span, each Car weighs 500 lb and each conceptually could have two heavy passengers and luggage weighing another 500 lb. Thus a load of up to 14,000 lb might be on each of the two Rails and 28,000 lb on the span. For simplicity of analysis, we've assumed all of the load is at the center, and that the cables form straight lines. Stretched thus at an angle of 5 feet in 50 feet of half span, the tension on the cable is 10 times the load at 280,000 lb. Factoring in safety, times 5 is a standard, we need cable strength of 1,400,000 lb—or seven square inches of steel cross section.

A standard method to maintain the flexibility exhibited by a small wire when fabricating a larger cable is to twist together 6 small wires which fit perfectly into a hex pattern around a seventh wire in the center. Repeating

the process places 49 wires into a 7x7 cross-sectional pattern. Adding grease allows everything to slide. Such cables have 90% of their cross-section filled with steel, and thus 7 square inches of cross-section can be obtained with a 3 inch diameter cable. Two cables hung from each of the posts would distribute the load onto four sections of 1½ inch diameter cable.

While a flexible cable has sufficient tensile strength, as loads change the cables easily distort allowing the roadway to go up and down. Or worse, as unbalanced loads or side forces are incurred and/or vibrational modes are activated, a cable allows lateral distortion. The roadbed, or to go back to our terminology, other elements of the skeleton must therefore provide local stiffness.

Stiffness in the skeleton is required to stabilize the span locally, but only locally. The cables are there to provide stability over the entire span by linking the local elements. If the road bed, a beam in our nomenclature, would bend less than, say, ½ inch over 14 feet when a load changes from zero to maximum, the overall span will be largely unaffected. Such local skeleton stiffness is easily obtainable. A solid 4"x12" wooden beam would almost do. One is tempted to propose that this part of the skeleton consist simply of two parallel beams, and further, that the beams be incorporated as part of the Rails themselves. The cables as proposed will allow the span center to sag as Cars pass, and the beams must comply with this sag or suffer damage.

Comparing our Roadway building block to the familiar suspension bridge, the posts are the towers at each end of the bridge, the Rail is the suspended roadbed, and the cables and hangers above are the skeleton. The rocky shores of the Golden Gate hold the cable ends to counterbalance the center span's weight for San Francisco's most famous bridge. In comparison, however, we can't secure our cables to an anchor outside the span to counteract the weight of a loaded span, and the post must support the pull. Unweighted, our next span does provide the balancing weight and consequent pull to relieve the post of longitudinal force. San Francisco's newest landmark in the bay, the Self Anchoring Suspension bridge, or SAS, a segment of San Francisco's other bridge, employes this approach. But unlike traffic on the Bay Bridge, the loads presented by our Rail Cars far outweigh the structure as conceived. Thus as Cars pass, the post must withstand a longitudinal pull approximately equal to the tension on the cables. Equally difficult, if the base of the post is narrower than its height, it must be secured to the ground with a strength greater than the strength of the cables. Meeting these requirements will allow a full train of Cars to safely travel on one span with the adjacent span fully unloaded.

Design #2

A pre-stressed, steel reinforced concrete beam can form the heart of the needed skeleton. Mate the piece to the posts and you're done. The Rail can be attached to the top or bottom or partially encased in some concave surface designed into the beam. If the Cars ride on top the driver is assured of an unobstructed view. In either case this skeleton has the simplest possible design.

As in Design #1 the reinforcing steel must have sufficient tensile strength to withstand the load incurred. In this case steel at the bottom of the beam will be stretched whereas the concrete at the top will be compressed. If we want a concrete beam with a height of 20 inches, only 1/3 of the cable drop of Design #1, we will need 3 times the steel. Since we pre-stressed the steel with tension to slightly over the maximum expected load as the concrete was hardening, the entire cross-section of concrete will remain under compression, as it must be to avoid failure.

We have previously shown, as an example, the mini-monorail configuration conceived by Aerospace Corporation in Figure 1-3e. Its simplicity of design has inspired many such drawings. A monolithic beam and rail developed for the Seattle World's Fair in 1962, still in public use and carrying a far heavier load than proposed here, is shown in the photograph of Figure 4-7 below.

CLICKETY-CLACK JUST WON'T DO!

Clickety-clack went the railroad track! We all know the song of the railroad train. Very romantic, and endured by all passengers. Endured until the technology of automated steel welding and grinding enabled the railroad companies to afford and eliminate those annoying joints between each rail segment. Nor are joints the railroad company's only problem. The next time you're wasting time watching a railroad train pass, watch the rails flex beneath the wheels as the weight rolls by. Over time all that flexing works the wooden tie or moves that enormous pile of broken rock downward. Slowly one or both of the tracks is worked out of level and the train

FIGURE 4–7. A concrete skeleton design is exampled by a photograph of the monolithic, concrete, dual rail built for Seattle's World Fair monorail.

travels up and down or sways left and right. If the train travels fast enough, induced sway and inertia will come close to throwing the vehicle off the track. And indeed many poorly maintained tracks require incredibly slow speed limits. The repair costs to correct tracks are enormous.

Indeed foundations present problems as the earth below varies greatly. In Amsterdam, a city resting upon sodden peat and with a water table at six feet, building code demands foundations be set upon posts sunk 18 m below ground level. In Florida, limestone sinkholes appear suddenly when the strawberry fields are watered nearby. In Los Angeles, buildings are often set on rollers as land can suddenly move horizontally as well as vertically. The comparatively light load presented by the Rail spans proposed will help immensely, and here this book deals only momentarily on foundations.

A train on the tracks lurches oddly as it rolls on its peculiar wheels—lurches oddly at least to one spoiled by modified McPherson struts, a live rear axle, and the delicate dance performed by his BMW. For a railroad car the suspension scheme of the Wheel Truck or Doobie compensates for changes in the path, relative position of the two rails, or lateral twists in both and attempts to control a very heavy vehicle with a wheel base of maybe 80 feet. For a light Rail Car with a single Rail and five foot wheel base we might expect pleasant differences.

The elevated structure that is the Roadway itself is our primary concern. Of concern because for both cost and aesthetic reasons, we wish to make the structure as light and unobtrusive as possible. And we wish to create at the high end of the quality spectrum, creating track as that for the France's Grand Vitesse bullet train which allows speeds of 200 mph. Of course, our Rails might be augmented with sophisticated laser guidance techniques to aid the Car's suspension system. And if the Cars are magnetically levitated, they can make use of the smoothing effect of inertia as they float.

The simplified span of design #1 above has a serious flaw ... well, at least one serious flaw! Steel is elastic. Pull on it—hard—and it will stretch. Pull on a piece possessing a square inch of cross-section with 30,000 lb and it'll stretch 1%. When subjected to fully loaded trains, the span as designed would sag about 8 inches. Not so bad you say. And at slow speeds you're right. But if a big train were whizzing along at 100 mph, Cars would incur fully 0.9 g of vertical acceleration. The Cars would almost leave the track! To say nothing of the effect on your stomach of a rhythmic up-down ride over, say, a full ½ hour ride. Flaw is a strong word. The Rail could be biased under no load—arched upward 4 inches—and would sag only 4 inches under a maximum load endured when full trains pass. On boulevard spans, given an anticipated local speed limit of 40 mph, vertical accelerations would then be closer to 0.07 g (acceleration goes as the square of the speed). But let's design for something better and set a specification fully ten times tighter: maximum sag less than 0.8 inches under full load.

Design #3

OK. Let's come up with a third design. First, we've agreed to improve the span's vertical stiffness by at least a factor of ten. Second, let's also set a goal to decrease the Roadway's footprint which will ease any right-of-way problems in tight urban areas. At the same time let's seek to preserve the ride's quality for passengers who will maintain an unobstructed view of the scenery. Too, we seek to please the passing pedestrian who observes the aesthetics of the new design.

The footprint of the two way Roadway can be decreased by stacking the Cars vertically. Thus the right-of-way needed will be all of six feet in

width—suitable for proceeding down the narrowest of medians, over an ordinary sidewalk, or even over parked cars at the edge of the street. Acknowledging that the driver can't have a completely unobstructed view given the stacked geometry, we'll support the Cars from one side leaving the other side completely open for 'viewing pleasure'. For the onlooking pedestrian, beauty is in the eye of the beholder.

The Roadway geometry of Figure 4-8 achieves its vertical stiffness by employing a substantial beam at the very top and another at the very bottom of the structure. The two substantial beams are to be aided by the rest of the skeleton and must be forced to act as one by connecting pieces. Vertical wires are employed to put the top beam under compression and the lower beam under tension when load is applied. Two small guy wires are also required to cross vertically in order to assure shear stiffness; and likewise two wires cross horizontally to reduce lateral sway . The entire structure behaves as a giant "I" beam.

This Roadway skeleton's stiffness can be calculated using an ME 101 textbook. But for our purposes perhaps it's better to note that if the skeleton tries to sag, the bottom beam will be stretched around a larger imaginary circle while the upper beam is compressed around a smaller imaginary circle. Since the two elements are separated by about four meters, and the guy wires are at substantial angles, all members have to be stretched or compressed substantially for the structure to sag a little. Thus the skeleton is very stiff.

While Design #3 allows a very light structure to be sufficiently stiff for our purpose, in terms of many opinions of visual clutter, the design is a step backwards. The use of guy wires to connect the skeleton is particularly egregious. How we hate power lines. How we fight to underground wires. In Design #4, we will find a method to make the upper and lower beams support each other without the use of vertical guy wires; and if the two are widened somewhat the horizontal guy wires are gone as well.

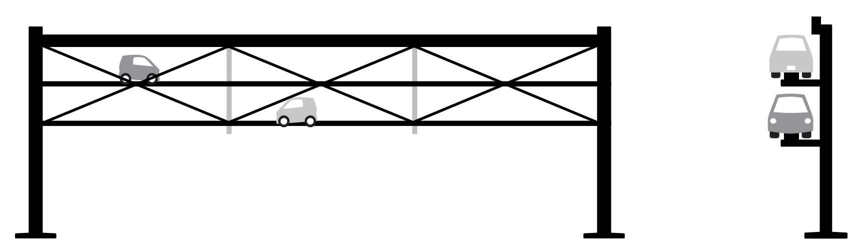

FIGURE 4–8. A vertically stacked Roadway span.

Design #4

One more. A Compressed Arch. An arch under compression has been used since the Roman Empire to reliably support huge loads. The Roman arch usually supported, and supports today, heavy stone buildings and aqueducts placed above. But an arch need not be a complete semi-circle. For example in 1933 using a supporting arch, a famous Swiss bridge designer, Robert Maillart, completed a now famous concrete bridge spanning 39 m across Salginatibel Creek. See Figure 4-9A. As many have been pleased to note, concrete pillars, monolithic concrete spans, though massive and with huge cross-sections, are, from a distance, somewhat elegant, even beautiful.

A arch supporting weight above need not be our only choice, because as Figure 4-9B elegantly shows, the geometry can support weight hung from below equally well. The arch remains under compression as the hangers pull downward. This novel, award winning design employes cross hangers to reduce the arch's sag substantially when compared to the performance of traditional vertical hangers. Abutments at the river's edges constrain the arch's two ends. Simply curving, that is to say arching, the upper beam used for Design #3 would be an application of the compressed arch. It should be noted, however, that our slender posts as envisioned cannot perform as anchors as can the solid abutments at the banks of the Ohio River.

FIGURE 4–9A is a photograph illustrating the elegance that monolithic concrete structures can obtain. (source: http://fr.academic.ru/dic.nsf/frwiki/1441377)

FIGURE 4–9B. A Compression Arch bridge completed in 2008 and known as the Blennerhassett Bridge crosses the Ohio River. The center span's length is 878 feet; the arch's rise is 175 feet; the roadbed's width is 107 feet. *(Image manipulated to show lengthened arch)*

Let's design a compression arch span for our purposes. Let's do so with the slender posts envisioned for the suburban street which lamentably can't perform as solid anchors, but will bend as the arch flattens with load. The arch will be under compression and the straight element replacing the Blennerhassett's roadbed will be under tension.

Alluding to the archer's bow is tempting. Look at a bow. Pulling the string under tension where it nestles the arrow's shaft produces substantial movement, but place the string side of the bow down against a table, press down on the wood, and little movement results. It's quite stiff. Indeed, unlike the arched bow which is thinned in one dimension to allow bending, our arch's mechanical moment is designed to resist vertical bending.

How stiff is our design? If the "string" element stretches—elongates in technical jargon—it will allow the arch's center to sag as the arch assumes, primarily, a larger radius of curvature. As with our first design the amount of sag is a function of angles, but if we design a modest 5 feet of vertical arch in a 100 foot span the arch's center will sag 5 times the elongation of the tensile element. Since we aggressively demanded a sag of no more than 0.8 inches at the center of the 100 foot span, the "string" can stretch no more than 1/5 x 0.8 inches with the potential maximum load of 28,000 lb over the entire 100 feet. For steel, this requires a staggering cross-section of more than a square foot. Although this quantity may not be prohibitive in cost—raw material would run about $2 million per mile—the steel mills would be very happy. See Figure 4-9C.

One very important scenario might allow the entire variable load to indeed be anchored by the posts—that is the posts could act as true abutments and no "string" would be needed. High speed lines aligned on freeways, where high quality roadbed already exists, strong posts can be anchored with quality. If the top of these posts bend under load less than

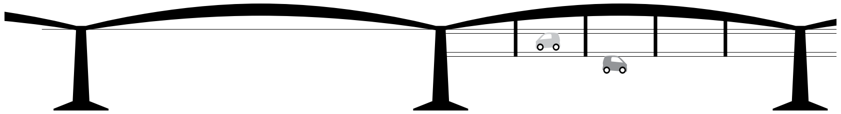

FIGURE 4–9C. A compressed monolithic concrete arch remains in compression as the lower beam resists tension. The left half of the figure simply illustrates the compression arch and tensile piece, while the right side includes the two vertically positioned Rails, Cars, and four 'U' shaped hangers to support the Rails.

that 1/5 x 0.8 inches, no "string" is needed.

Note also, for another very important scenario, the low speed suburban line, the 0.8 inches requirement could be relaxed. If the morning rush hour is heavy, it might be OK for your ride to rhythmically go up and down a little. Thus the steel mills might not get the business.

One final design type. A type to which an individual by the name of Theodore Zoli has made major contributions. Zoli, one of twenty 2009 MacArthur "genius" award winners, has worked to greatly reduce the cost and weight of bridges similar to the one shown in Figure 4-10. Built by the French to cross the valley of the River Tarn near Millau, the bridge's scale is apparent by viewing the vehicles on the four lane roadway. Its implications for the 3rd Generation Roadway are clear.

We won't go into designs further, but you get the idea. That is, you get the bigger idea that many simple, lightweight span skeletons can be designed. Longer spans. Better analysis. An architect's beauty. Much more can be done here. And some architect, somewhere, will make one functional, cost effective, and beautiful.

The span must be kept open, graceful, elegant, or it will be detested. "Don't blot-out-the-sky in my neighborhood!" says the local citizen. But that's part of the national discussion this book hopes to engender. And the homework problem set for a very clever student.

SEVERAL ROADWAY PLACEMENTS

At this point in the discussion, we are ready to visualize our Roadway designs deployed on today's surface streets and freeways. Different alignments or placements will use different hardware from our various designs. We should look at four alignments, each with their appropriate Roadway design. The first will be on the narrow median strips of relatively wide local

FIGURE 4–10. The Millau Viaduct, built in 2002–2004 for 394 million euros. The structure is 2,450 m long and supports a 32 m wide roadway which is at one point 270 m off the valley floor.

streets, our present boulevards, and be well suited as a workhorse design for loCaltransport, while a second alignment near the curb might be best suited for smaller, narrower streets deep in the urban core. An urban freeway alignment, most likely in the freeway's center median, and suitable for high speed, will be our third. A fourth, also for high speed, will be placements developed for inter-metropolitan lines or stretches on converted freeway HOV lanes. Both these later Roadway types have narrow but exclusive right-of-way, which is to say that other vehicles, pedestrians, et. al. will be excluded.

It should be noted that the first two scenarios are for urban low speed—40 or 50 mph—Roadway and that the stringent sag requirements derived for Design #4 above could probably be relaxed. For the next two Roadway placements, we will require large well anchored posts or Rail placement on the ground to achieve stability, allowing high speed—80 to 100 mph—lines with simplified construction techniques.

Figure 4-11A illustrates a vertical Roadway of Design #3 deployed in the median of a common suburban street. The curved post allows for a minimum width of right-of-way. A median width of 8 feet might be ample. Thus the scene depicted with 12-foot driving lanes and 6-foot sidewalks would have 68 feet between buildings. Pedestrians and automobiles safely cross beneath—the right-of-way is non-exclusive, but large trucks must cross the right-of-way only at intersections.

Figure 4-11B illustrates a configuration useful for the narrowest of streets. Shown is a 30 foot wide residential street with parallel parking on one side. Vehicles and pedestrians freely pass under the Roadway as they enter the parking lane. The desirability of a 40 mph speed limit is clear for this scenario as residents will want the small Rail Cars to pass silently. Note however the huge capacity of such a small line which could service large venues in compact neighborhoods.

Figure 4-11C illustrates a configuration suitable for the median strip of an urban freeway. As shown, no new right-of-way is required, and tall trucks could be in the fast lane. Implementations closer to the ground might save construction costs, improve aesthetics, or be needed to accommodate overpasses. As shown the line easily fits within the median strip of the freeway, and would allow cars to use the median in emergencies. At overpass bridge abutments the Rail line would be forced to swing out over traffic in the fast lane and demand a firm requirement forbidding tall vehicles. Minimum clearance achieved under overpasses might be reduced from 16 feet to 10 feet.

And finally, a Rail built on the ground making use of the HOV lane of a freeway is depicted in Figure 4-11D. Standard concrete barriers to fully isolate the lane from street automobiles are shown. Building the Rails on an existing hard surface will save fabrication costs. Where right-of-way is to be acquired specifically for Roadway use, for instance when building inter-metropolitan lines, on-the-ground implementations presumably would be the standard.

THE RAIL

The Rail itself has many responsibilities. As described above, it must firmly secure the Cars. It must endure variable loads, unbalanced loads, Cars swaying in a cross wind, Cars undergoing a turn, Cars braking, etc. It must be compatible with the switching schemes employed at the interchanges and

FIGURE 4–11A1 depicts a four lane street scape with a Rail line using the center median. This scenario would be used for the majority of 3rd Generation Roadway length.

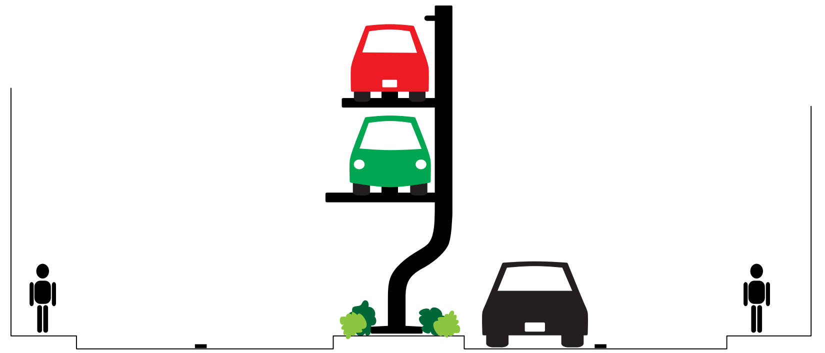

FIGURE 4–11A2 is a graphic cross-section of a boulevard median alignment using design #3.

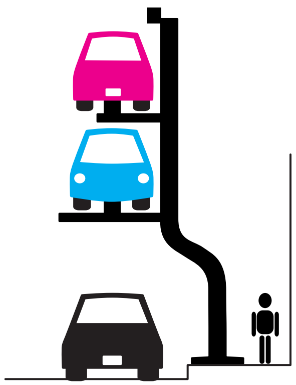

Figure 4-11B1 is a graphic illustrating a Roadway using design #3 configured over the parked cars near the curb.

Figure 4-11B2 is a photo-montage of the parking lane alignment. Configured for low speed, this small line would carry about the same number of vehicles as most freeways.

FIGURE 4–11C illustrates a two way high speed Rail Car line running in the median of an 8 lane freeway. The Rail has roughly 5 times the vehicle capacity of the freeway while occupying only 1/10 the space.

FIGURE 4–11D. Two-way traffic Rail traffic is illustrated within a single converted HOV commuter lane. The Rail is not elevated, needs no skeleton, and is protected with standard barriers.

for merging at the on/off ramps. Its smooth, level surface must promote a comfortable ride. It must be manufactured as an exchangeable unit. It must be producible at acceptable cost. Segments must connect seamlessly. It must allow the assembled system to have graceful thermal expansion properties. It must weather well, and endure, what, 40 years. It must be resistance to intrusion by snow, animal, and debris. In the unlikely event of a failed Car on a turn, it must support, without damage, loads substantially off centerline.

The Rail will likely provide electrical power to the Cars. This will obviously be the case if the Rail Cars are without a gasoline motor, and, out of concern for weight and cost, have only small batteries. If the Rail were to provide power it would immediately become the de facto electrical distribution network and battery recharging facility so needed if any electric car fleet is to be implemented. As well, the need for high-density, fast-charge batteries would be reduced.

Propulsion might also be provided by the Rail. Several PRT studies have called for electromagnetic drives on the rails with reactive motors on the cars. Bombardier's light rail cars operate with such a reactive motor. Propulsion by the Rail eliminates a major component in the Car, reducing Car costs and conceivably reducing overall costs.

The Rails would also be the logical place to position monitoring technology. Monitoring functions would be those of an intelligent highway, including a determination of precise positions for adjacent Cars, and tracking of individual Cars in transit. Communication hardware would also need conduit on the Rail.

Metal is the obvious choice for the Rail. Metal possibly could be extruded with the complete cross section required to support the Cars, encapsulate all conduit, and secure the power supply strip. Electrical power could be routed through the structure. Metal will easily accommodate the connections required for support and integration. Metal is durable and will provide a superior rolling surface for Car wheels. Many metals provide a

surface suitable for weather. A metal skin cladding might further enhance protection.

The Rail is also one of the most conspicuous mechanical elements of the Roadway. Smaller cross-sections will enhance aesthetics and enable the Roadway to be an acceptable member of the urban scene. As we examine the mechanism which clings to the Rail, we will begin to appreciate the constraints which limit the minimum size of the Rail and appreciate those mechanisms which securely attach vehicles while allowing slender Rails.

CLINGING TO THE RAIL

Exactly how do the Rails securely support the Cars? And exactly how are the Cars switched from Rail to Rail? What sort of rack, wheels, and drive mechanisms mate the Cars with the Rails? Rail design is beyond the scope and consequent content of this book, but a look at the general categories conceivable, as well as the resultant switching configurations, is illustrative. A reader could easily skip this section, especially if he assumes it's a solvable problem or wishes to avoid the engineer's pain in achieving such.

Let's conceptually divide the most easily conceived Rail configurations into three categories. The first should be that which trains have used on the railroad network for two centuries and supports railroad cars with the same 4-wheel, 2-axle geometry used by oxcarts to skateboards to automobiles. So dominant is this geometry that the world was forced to coin a new word for our second category: monorail. To support a vehicle with a single rail, a fairly complex mechanism is required. And we must spend time examining that mechanism. The third geometry might be considered a monorail upside-down with the vehicle hanging from the rail. Perhaps thinking of this category using one's memory of a ski lift chair is most apt. We will explore two different mechanisms to hang our "ski lift chair" from the Rail. Other categories for support by a rail may need to be considered in other studies.

Chief among the advantages of the monorail configuration when compared to that of the ski lift are two. Comparably the Rail is placed closer to the vehicle's center of mass, and consequently the stresses exerted upon the mating mechanism are reduced. Second, accidents involving obstructions incurred by vehicles on an elevated Rail would seemingly be less likely. No truck parked under a Rail on a quiet night, nor, say, an individual carrying a ladder, will cause an accident. Chief among the advantages of the ski lift configuration appears to be the ease with which switching can be affected.

Some basic physics drives our conversation. Any 3-dimensional object in our 3-dimensional world must have its 6 degrees of spatial freedom—3 translational and 3 rotational—controlled to fully constrain its movement in space. Obviously in our case we want smooth and easy translation down the Rail while maintaining a sufficient connection to allow propulsion and braking. A rubber or steel wheel with bearings is the usual solution. Discussion here will center on controlling the other 5 degrees of freedom.

The Railroad

The common railroad dual rail and car configuration is quite clever. The arrangement includes a steel wheel with a single chamfered flange, which if positioned to the right of a rail, constrains the wheel from moving to the left. Held by a rigid axle connected to a similar wheel on another rail, both wheels are now captured within the interior region of the dual rail. Gravity pulls the wheels down onto the rails and constrains the 2nd translational degree of freedom. As many a train wreck will attest, it is only gravity employed for this 2nd degree of constraint. Rotation (roll in aviation speak) in the plain of the page is constrained by the torque achieved by separating the two rails a minimal distance, while constraint is achieved for the other two rotational degrees of freedom (yaw and pitch in aviation speak) by employing a second axle and wheel set at the other end of the car. Controlling yaw forces the car to point in the same direction as the rail; and controlling pitch forces the car to follow whatever incline the rail takes. Thus all three of the rotational and two of the translational degrees of freedom are controlled. The sixth, and unfixed, degree of freedom lets the train roll down the track. See Figure 4-12.

FIGURE 4–12 illustrates the capture of a railroad axle by means of two rails.

For our application a serious flaw in the railroad design is quickly apparent. The capture well is small; the wheels can bounce! Since our vehicle is extremely light and will be buffeted by cross winds, the flaw is worrisome at a minimum. In its classic form to ensure stability of the vehicle, the individual rails must be separated by a substantial distance. The wide separation needed leads to, in effect, a very large Rail—witness wide gauge railroads. And large Rails are to be avoided for aesthetic reasons. If we choose to use extra wheels to further capture our vehicle, then narrow the separation between the two rails, we mitigate the flaw. But our solution now resembles that for the monorail. And thus we will defer discussion to that approach in the next section.

The Monorail

A monorail supports the weight of a vehicle with single wheels placed at the centerline, one fore and one aft. But nothing in that basic configuration guides the wheels down the center of the single rail or keeps the vehicle from rotating (aka rolling or tipping over). The added machinery to constrain such motion usually and affectionately goes by the railroad name: “Doobie”. Along the sides of the monorail, two smaller wheels are positioned—one on the right and one on the left—and, as they are attached via a rigid bar to the main wheel, constrain the main wheel to roll down the center of the rail. A second wheel on each side must be placed at a large distance from the 1st two to achieve good leverage resisting any vehicle rotation (roll). Fortuitously a monorail typically has this large dimension already available since it has to have a large moment of mechanical inertia to withstand vehicle weight. This arrangement is shown in Figure 4-13a and 4-13b. Unfortunately with 2 Doobies required, 10 wheels are needed to support the vehicle. Given the light weight of the Rail Car vehicles proposed in this book, 8 of the wheels will fortunately more resemble skateboard wheels of polyurethane in size if not sophistication.

The Ski Lift I

So what about the ski lift configuration? Let’s put the Rail above and hang the Car below. Setting out to avoid the swinging typical of a ski chair, let’s try to keep what appears as two intrinsic advantages: reliable attachment to the Rail, and lack of major clearance issues when changing Rails. As objectives we want a connection controlling 5 degrees of freedom, a mechanism

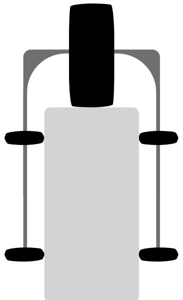


FIGURE 4–13A illustrates the 5 wheels of a single Doobie which constrain 3 degrees of freedom. FIGURE 4–13B is a photograph of a vehicle on Seattle's monorail secured by such Doobies to a concrete rail.

with a low profile on the Car's roof, a small cross-section to be demanded of the the Rail, and facility to switch individually selected Cars between the Rails.

The following is proposed. Design the Rail in the shape of an "I" beam. The top of the lower horizontal element of the "I" will act as the support surface for the 4 load bearing wheels of the Doobie set, and 4 side wheels will be employed on the vertical edge of this piece to keep the vehicle centered on the Rail. The edge of this lower flange must be designed sufficiently wide for the purpose. As we want a narrow Rail which unfortunately will insufficiently inhibit tipping (rolling), a third wheel on each side, lightly rotating against the upper surface of the "I" beam, will be added. The third wheel, securely attached with a triangular piece to the loaded wheels, will not only control any vehicle tendency to roll, but also resists the vehicle bouncing up or pitching under unusual conditions. Not surprisingly, again there are 10 wheels in all. See Figure 4-14 for a cross-section illustrating one end. Barely visible are the two wheels employed to inhibit tipping but are out of the plane of the drawing.

The Ski Lift II

A second configuration with some heritage encapsulates the Doobie and its large rollers within the the Rail and supports the large rollers with two Rail flanges underneath. The Car is attached to the roller assembly through a slot in the Rail. The width of the roller employed controls rotation (roll) and using two rollers controls swinging (pitch). Side-to-side position and direction of travel (yaw) for the Doobie is controlled by the smaller rollers

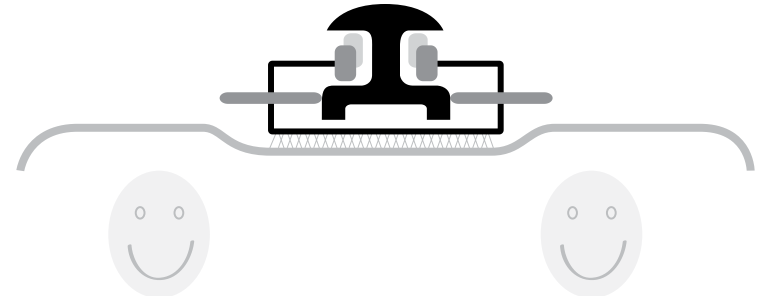

FIGURE 4–14 depicts a Rail Car attached to a Rail from the roof using the mechanism described in the text.

shown with vertical axles. Two such mini-rollers touch the left side of the rail slot and two touch the right. With this arrangement two rollers are always rotating in one direction if the Car attempts slide sideways. If the Car attempts to rotate (yaw), one of the other set of two will restrain the motion. The configuration is shown in Figure 4-15a. Figure 4-15b shows hardware developed by an unknown vendor.

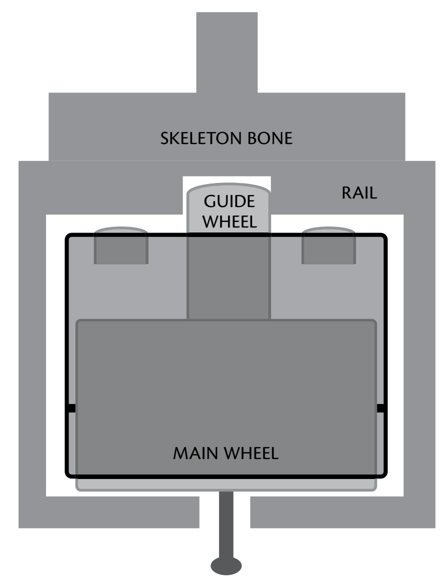

FIGURE 4–15A illustrates a Doobie interior to a hollow rectangular rail guided by a wheel rolling on the vertical surfaces of a groove in the rail. FIGURE 4–15B is a photograph of such a mechanism fabricated by ______, using a single wheel that slides into position.

SWITCHING RAILS

But how does a Car go from one Rail to the next? Changing Rails is necessary as one merges from an on ramp or exits a line, and Rails must be changed twice as one makes a right or left hand turn on any conceivable interchange. For the Roadway to maintain its high vehicular capacity, changing Rails must be done at speed—either at a relatively low speed on the local Roadway or at high speed on the metropolitan line. Obviously, how a Rail Car is switched from one Rail to another depends on the geometry of the Rail and how the Rail Car is attached to the Rail.

Railroad Switching

The genius of the dual rail used by the freight train is the conceptual simplicity of switching between rail lines. Since only two wheel flanges are used to faithfully follow the rails, if a narrow tapered element is inserted between the rail and the flange on one side and a gap is left in the other rail, the wheels will follow the tapered element. Figure 4-16 illustrates a railroad switch from above as a set of wheels approaches the switch configured to turn a train. The chamfered flanges, moving at the same angular velocity but at a higher speed than the wheel flat, will guide the train as they scrape the sides of the curving rails. Upon this simple system, the world has for centuries safely passed vehicles of monstrous weight.

But again, for our application, another design drawback becomes apparent. To accommodate a single turning Car the tapered rail segments must be switched to the secondary, i.e. turning, position. But for the preceding and next trailing Car the tapered segments must be in the primary

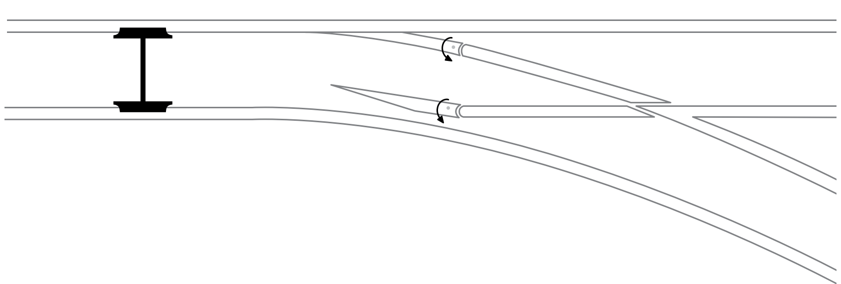

FIGURE 4–16. depicts the wheels, tracks, and switching scheme of the ubiquitous railroad.

position! Remember, headway (the separation in time between consecutive vehicles) is over 60 seconds for trains and as short as 0.05 s for Rail Cars. Car separation can be minimal, and even for low speed lines, switching times well under 0.1 s are required. A difficult do, if the switch elements are large mechanical pieces.

Monorail Switching

Networks to switch monorail vehicles exist today. But switching speed is not evident, and obstacles to successful designs for roadway purposes appear to abound. Principal among them appear as two. Monorail vehicles typically, in order to lower their center of mass, allow the rail to run within the frame of the vehicle. In our case the Rail Car, in order to be switched from one Rail to another, would be required to somehow clear its frame and wheels over the Rail from which it is leaving. Second, if switching requires a substantial piece of Rail to be moved, the process will be slow. The Roadway Rail of this book needs to select individual Cars for routing and, again, have switching times well below a tenth of a second.

Some automated guideways, employed for PRT systems, couple to a Doobie centered underneath the vehicle, while the vehicle's weight is supported by ordinary rubber tires upon the wide guideway. Similarly, concealed in the belly of a Rail Car for operation on surface streets, a Doobie could extend downward and lock into place as the Rail is entered. Conceptually, the Doobie could have an actuator sufficiently strong to lift the entire Car, and do so only for switching. In either case, switching Rails below the Car would then proceed as an upside down version of the Ski lift switch described below.

Ski Lift I Switching

The ski lift configuration allows, compared to the railroad, a very different switching sequence. The switch is associated with the Car, and to great advantage, the Car's switch is activated in anticipation of turning or merging. The Rail's structure is simplified and the Car's switch need not have any rapidly actuated mechanisms. No accommodation of adjacent Cars is required.

Side wheels have been employed to guide the vehicle down the Rail's center. To initiate a turn these side wheels can be realigned to a flange associated with the turning Rail. The realignment has no effect until the Car arrives at the Rails' intersection; at which time the side wheels pull the vehicle onto the curved Rail's path. See Figure 4-17. The kinematics of the turn will be discussed later in the sections on interchanges.

The clearance issues incurred during the turn involve only the Rail and the Doobie. The Car is safely below. The individual scenarios for both turning and non-turning Cars must be considered. To accommodate a turning Car, a large cutout in the main—straight—Rail allows the left two load bearing wheels to slip through. Additionally, the wheels' support strut must slip through a narrow slot in the horizontal alignment surface of the main rail. That surface must remain for non-turning Cars whose alignment wheels will continue straight and bump over the slot. Only the top of the "I" beam remains to hold the Rail together. To accommodate a non-turning Car, only one modification is needed—a narrow slot in the turning Rail to pass the non-turning strut. The diameter of the alignment wheel has been increased so as to better roll over the slot, and while doing such effectively widens the Doobie on the Car roof, a low profile is maintained, and the impact is small. For fail-safe operation, the four alignment wheels must be designed to travel in unison to bi static operating positions.

Chief among the advantages of the ski lift configuration is a robust solution to the twin problems of clearance and switch speeds. The Doobies need only to realign themselves in anticipation of a turn, and no switching occurs on the Car or the Rail during the Car's turn nor does anything have to happen to accommodate the following Car.

Chief among the disadvantages of the scheme is more equipment associated with the Car. Although the public Roadway has been relieved from developing and deploying sophisticated and possibly very expensive

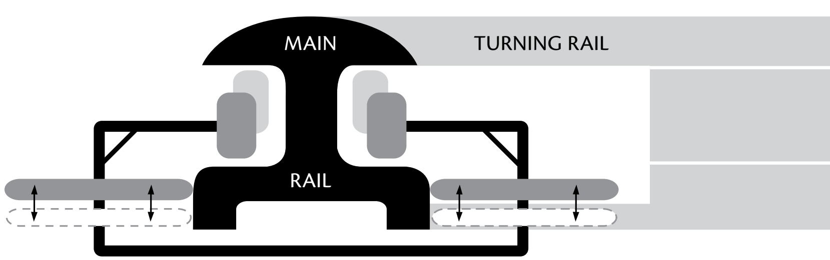

FIGURE 4–17 depicts a look down a main Rail and views the profile of a turning Rail whose flange only engages the side wheel when the wheel is in the dotted position so as to initiate a turn.

switches, the private Car has assumed the responsibility. And while a fully developed U.S. 3rd Generation Roadway would require 20,000 switched interchanges, Roadway users might purchase 75,000,000 Cars. The Cars, on the other hand, have a far easier switch, and the Interchanges are both more complicated and would have at least 16 switches each.

Ski Lift II Switching

Exploring the switching characteristics of the rail enclosed roller, we see a number of intriguing capabilities. Remember that to exit a Rail support, a vehicle has to clear any support mechanism for those other Cars not destined to exit. In our second "ski chair" geometry that feat amounts to clearing the bars that extend from the Doobie down through the Rail to the Car. We will support our discussion with a diagram detailing three cross-sections of a single Rail which progresses to diverge into three Rails. The three diagrams are depicted in Figure 4-18.

In the first diagram one should notice the addition of a set of two smaller mini-rollers which augment the main rollers at the Doobie's centerline.

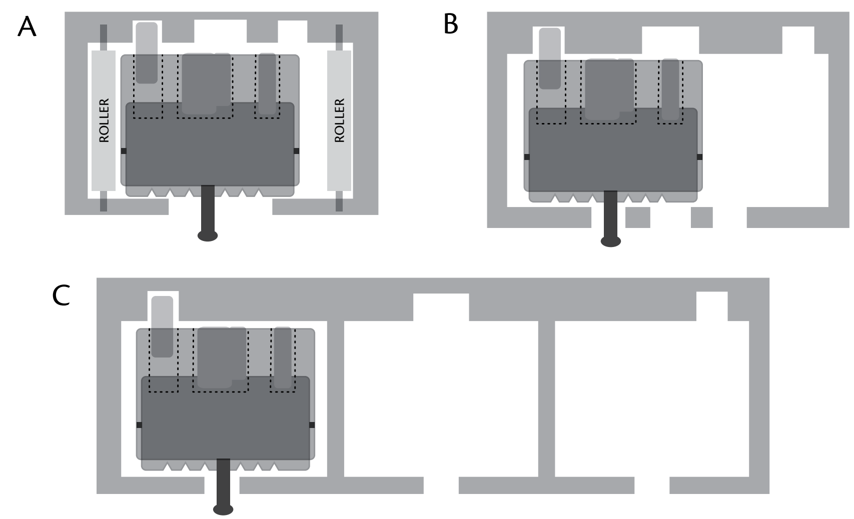

FIGURE 4–18. Cross-sections of Rail and Interior Doobie FIGURE 4–18A illustrates a left turn roller guide actuated, with rollers on the rail's interior to aid alignment as the break-before-make transition of the guide rollers takes place. FIGURE 4–18B illustrates the new rail fork blades that are now providing support to the right side of the Doobie. FIGURE 4–18C shows the new Rail sidewalls at the cross-section where three complete, separate Rails exist.

These smaller wheels with vertical axes of rotation will guide the Doobie and Car around a turn or down the off ramp. To be used briefly and at lower speeds they are smaller than the centerline set and are but two wheels. Two wheels, unlike the more expensive set of four, may have to endure sudden reversals of rotation as the vehicle attempts to yaw left or right of the Rail's path, but their usage is both only temporary and occasional. The Doobie is constrained to pop up one, and only one, set of rollers at any one time. If failure occurs and no mini-rollers are up, the Car will continue straight ahead.

In the second diagram, the Car's guidance rollers for a left hand turn has been actuated, the other two sets are withdrawn. The positions of the three roller guides, that is the slots in the Rail, are diverging and one has pulled the Car to the left. Thus the bars attached to the Car can now clear the ends of two fork blade-like beams that appears in the second diagram as the Rail begins to announce a support structure to accommodate Cars that are not turning. Because the main rollers are so wide at no time are they not supported on both the left and right side of the bars attached to the Car's weight. As the Rail cross-section widens, the wide rollers can clear a new Rail wall which is dropped to the right of the roller shown in the third diagram. The three paths are now free to diverge independently.

An alternative Doobie, of course, could have only one set of guidance wheels instead of three, and move these guidance wheels sideways to appropriate positions in anticipation of a turn. To maintain the Car's alignment during the time of this movement, the Rail would be augmented with the rollers illustrated to the sides of the Doobie on the interior wall of the Rail. The piece of actual hardware previously shown in Figure 4-17b operates in this alternate mode.

LOOK MA, NO WHEELS!

The Rail and Doobie are among the most important elements of the Roadway, and research here should be aggressive. One design, which looks good on paper, is attractive in that the size of the Rail can be greatly reduced relative to that of the previous design, and that the Doobie has no moving parts—well, almost none.

If the Doobie could glide, not roll, along an enclosing Rail and the gliding surface were to belong to a thin body, then the Rail could have a very low profile. Since two such gliding elements are needed for the Car's lateral stability, the Rail will still have width. Image in your mind a pair of snow skis gliding on snow. Better yet, imagine the very short skis on the front of a ski mobile. A ski mobile uses a drive wheel in the rear, but that wouldn't be necessary here. Not necessary here if no mechanical traction is needed. And it won't, if the Car is propelled by a linear induction motor, an item we'll explain in a moment. If no mechanical traction is needed, the drive wheel used by the ski mobile can be replaced with two more glides.

The Rail is smooth, the Car is light, the glides can be small. Figure 4-19 shows the cross-section of the Rail and two glides. Two more glides up front complete the Car's stabilization, that is, deny pitch and yaw oscillations. We've shown each glide to have a two-inch width centerlined on an eight-inch separation. The separation width helps control rolling forces—center of mass changes in the Car below, as well as inertial and wind forces—but for safety we'll have to add some further mechanisms later to control possible rocking. The glide bottoms are tapered in the shape of a "V" and thereby help control lateral displacement.

How, you must ask, does one reduce the friction between the two surfaces scraping past each other? After all we've thrown away the wheel! Mag-Lev bullet trains reduce friction by floating the entire train above the track with magnetic levitation. Air troughs, a common presence in Physics 101 laboratories, float objects by pumping air up out the table at them. It's not the wind and air's momentum that levitates the weight but rather air pressure. Air has viscosity and, if the surface shapes are matched, takes some time to get out of the crack. The longer it takes, with air constantly being pumped in, the more air is trapped, and the higher the object floats.

For fun, and to illustrate a point, let's spend a paragraph to explore this later technique for our Doobie. First, the Car has its own power source, and as opposed to the Physics 101 lab trough which is excited with pressurized air along its entire length to float its passive slug, it would seem efficient to

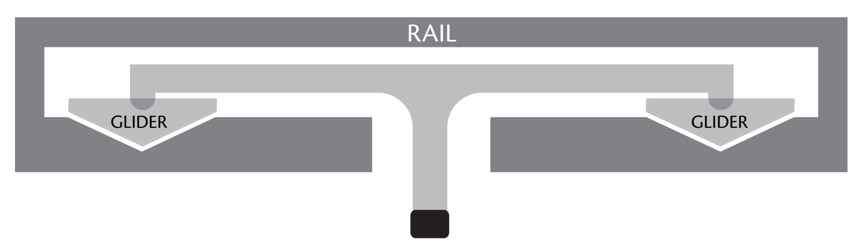

FIGURE 4–19 illustrates the Rail enclosure and Doobie on two of its four floating gliders.

excite the Doobie's gliders with air working against the passive Rail. How high can we lift our gliders? Using how much power? While it will take a fluid flow specialist within the Aerodynamics Department to provide a precise answer, let's make an estimate. Let's design our 2 inch wide gliders to be 3 inches long—we said they were small! As such they collectively have 24 sq. in. of bottom surface area, and we'll need a minimum of 42 psi to lift the maximum Car weight of 1,000 Ib. Using two hp (1.5kW) from the Car we can deliver 10 liters per second at 42 psi to the gliders. Since air can escape from the perimeter at no greater velocity than the speed of sound, the perimeter's length is only 48 inches, and the speed of sound 1,070 ft/s, the resultant vertical lift must be greater than 0.025 mm. (Excuse the mixed units !@*) About the same tiny distance between the plates of glass on a plasma TV display. But not enough.

But the Car is levitated and will glide with two hp. If the slider's surface were flexible, its surface could better conform to that of the Rail's. Surfaces that occasionally scrape do survive well if one surface is very hard and the other softer. The relatively soft Rail might meet with a hard slider. Cost wise, a slider skin of artificial diamond or SiC film is not out of the question. Obviously techniques exist to increase separation. Slowing the air's exit would help, possibly with an abrasion resistant forest of "peach fuzz" fibers designed to skim the surface and used to fill the gap. If the slider's perimeter were a shirt of flexible segmented elements, the rest of the glider would float higher. Somehow we need an order of magnitude. And yes, although we've explored the problem and learned, all this is speculation.

Let's try another mechanism.

Magnetic Levitation

Magnetic levitation and linear induction motors for the Roadway offer a number of exciting advantages. Levitation would allow smooth and very quiet operation optimizing both the driver's and the street observer's experience. Linear induction could propel the Cars down the Rail. No sliding contacts for power transfer are needed , as they are for today's street trolleys. Versions of both technologies are used by many of today's transportation systems.

Electrical power would have other extensive advantages. Even if a gasoline engine is the right solution for tooling around town, the Rail instantly converts the Car, and the nation, to an all electric fleet. The Roadway becomes the much desired distribution network. If the Car is all electric, and if the Roadway is

designed for such, the Rail could trickle charge the battery. Trickle charging on the Rail and in the garage should provide sufficient and reliable energy for around town use off the Rail.

If the Rail Car Doobie were equipped with a collection of permanent magnets and a paramagnetic metal strip such as aluminum, the Rail, equipped with printed induction coils and electromagnets, could provide both levitation for gliding and the power for propulsion.

Smooth as glass. Quiet as a whisper. 350 mph bullet trains. Superconducting magnets. Magnetic levitation screams high tech. Screams expensive, too. But time, maturity, and success have a way of reducing new and expensive to just slick and affordable. The magic remains. Examples include electronics and automobiles. Henry Ford created a revolution in low cost by pioneering the assembly line and producing the $600 Model T, but that's still expensive in today's dollars. Today the Tata Nano at $2,000 plus tax and license is many times cheaper and although primitive by today's standards, a way better vehicle than a Model T. Can advances in Mag-Lev allow its use on the 3rd Generation Roadway?

Magnetic Levitation deserves a look. Or at least a poor man's version of a magnetic levitation given the cost goals of the 3rd Generation Roadway. After all, top speed for our vehicle is 100 mph, considerably slower than that proposed for full sized passenger trains. Thus, if one argued that levitation heights needed are proportional to the square of the vehicle speed, smaller levitation heights could do. And smaller levitation goals greatly reduce the strength and size of the required magnets.

Levitation reaches equilibrium when, for very small changes in relative position, the change in magnetic field energy matches that given up to gravity. Magnetic field energy goes as μH2 integrated over the volume; gravitational field energy, of course, goes as mgh. That much is easy. The upper division stuff comes when all the boundary conditions deflecting the magnetic fields need consideration. (Another hard part is assuring yourself all your magnetic calculations are in the same units—there are at least nine sets of units in use—as those you used for gravity.)

In the 1980s researchers at Lawrence Berkeley and Lawrence Livermore National Labs, seeking to store huge values of kinetic energy in a large spinning fly wheel, needed a quality bearing. Klaus Halbach invented a way to configure a stack of permanent magnets in such a way as to concentrate their most intense fields on one edge. That edge was then constructed on the interior side of a circle and the intense fields repelled currents induced in a rotating shaft and body at the center of the circle. Unfurl the circle, or if you will, increase the circle's radius to infinity and you've repelled the body but still allowed it to move down a track. If the force of repulsion is pointed up and greater than gravity's attraction, you levitated the body. All with some permanent magnets and passive copper wire coils.

Now, Livermore has a nasty reputation for aggressively shopping clever solutions looking for a problem—think Edward Teller and Lowell Wood selling X-ray lasers powered by atomic detonations, Ronald Reagan's Star Wars missile defense, and rail gun missile launch—but follow this through. Coined Inductrack, now Inductrack I, and recently improved by sandwiching the repelled coils between two such clever magnet stacks, the idea is presently coined Inductrack II. The two stacks are sequenced such that their fields add in the plane of the coils. If fields are doubled, the induced currents are doubled as the coils are pulled through and the levitating force is quadrupled.

Indeed, performance calculated and data presented are impressive. Using 800 kg/m2 of Neodymium Iron Boron permanent magnets in Halbach Arrays and closely packed track coils, a body weighing 40 metric tons per square meter can be levitated. For our less-than-half metric ton Car, when fully loaded, that translates to 0.0125 square meters and 10 kg of magnets. Four 2¼ inch square surfaces each with 5½ lb of magnets to support the Car. Very low speed (2 to 5 kph) would be needed before the Car levitated; and the constant magnetic drag would be minimal enough that a lift to magnetic drag ratio of 150 would be achieved at 100 kph. This is better than that of a wheel. Development continues at Bendix in San Diego with support from the National Transit Authority.

Linear Electric Motors

If levitation seems like magic, think about the magic of an ordinary electric motor: hold a shaft firmly with two bearings, apply electrical power, and viola, mechanical power appears on the rotating shaft. Propulsion for a Car on a Rail can be achieved by a similar approach that's already here. A Linear Synchronous Motor can be designed by using the physics of an ordinary rotary electric motor and "unrolling" the geometry into a flat surface. In strict analogy to the motor, the magnetic fields of an electromagnet repel a permanent magnet, which then moves in response, and is slightly later repelled by another electromagnet synchronously energized to promote

further movement. The Japanese JR Mag-Lev train uses Linear Synchronous Motor propulsion and has achieved 361 mph.

Alternatively, Linear Induction Motors use a strip of metal in place of the permanent magnet and use the eddy currents induced to repel the two bodies. Linear Induction Motors are used to propel Bombardier's light train product line, e.g. New York's Airtrain, and to pull many roller coasters up their steep inclines, e.g. California Screaming. The linear induction motor, unlike the synchronous motor, no longer requires the vehicle to travel at a known speed.

Figure 4-20 illustrates a cross section of Rail as one set of Doobie feet slides through. The magnets belong to the Doobie which is repelled from the printed coils of the Rail sandwiched between. In addition the Rail is shown with an electromagnet at its centerline as the key piece of the linear induction motor. The Doobie is equipped with a thick metal strip along its entire length and provides the eddy currents as it slides under the magnets. The number and strength of the electromagnets must be sufficient to provide the 15 hp needed by the Car. Although the configuration is stable against rolling forces, a separate mechanism, not shown, is needed to provide lateral stability. Nor is some mechanism shown such as a set of skids or small wheels needed for occasional extreme conditions such as severe cross winds or line failure. Note that the Rail still possesses a very low vertical profile, and if the magnetic repulsive forces provide extreme stability around centerline, the Rail can be as narrow as shown.

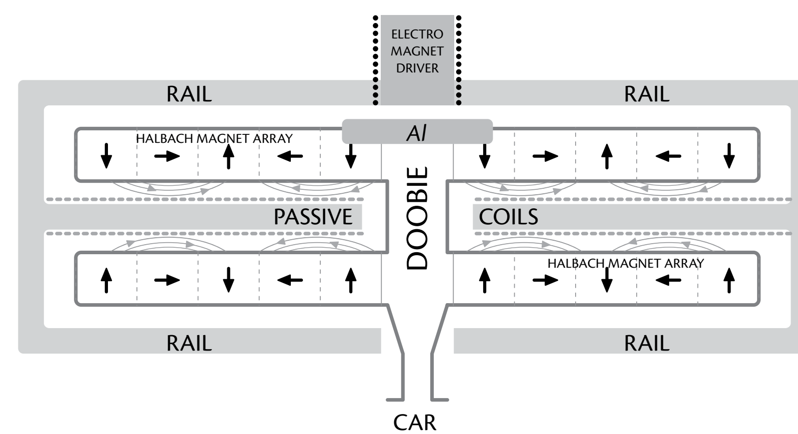

FIGURE 4–20 is an illustration of a magnet-loaded, levitated Doobie nestled within a Rail and being propelled down the Rail, into the page, by electromagnetically-driven diamagnetic currents in the attached strip of Aluminum plate.

INTERCHANGES AND INTERFACES

So, two Rail lines come together, how does one avoid the dreaded intersection? How can vehicles continuously stream through structures that fit above small street intersections? How complex and large will our solution be? How will it perform? This section will address these questions by presenting preliminary designs and their properties.

Our solutions will show designs that easily fit above ordinary intersections while maintaining immense vehicular capacity. Thus the 3rd Generation Roadway grid can penetrate the most dense and most constricted of urban streetscapes. The interchanges enable turns at 25 mph, leading in conjunction with 40 mph speed limits, to average speeds of about 36 mph within urban cores.

Thus everyone has access to high speed lines within 4 minutes, if 5 miles is the high speed grid spacing. While far larger than the inner city interchanges, high speed interchanges configured for turns at 60 mph are still attractive. Such interchanges become crucial components of a high speed network servicing the metropolitan area where speeds approach 100 mph. These high speed interchanges remain tiny when compared to today's 2nd generation freeway interchanges.

Key to its success is the assumption that the 3rd Generation Roadway can be built on existing public right of way. Principally this means built on urban and suburban surface streets, the 1st generation roadway. Included, of course, is the corollary assumption that full interchanges can be built above, and contained within the the footprint of, ordinary street intersections. While we've answered the question whether traffic can flow on 1st and 3rd Generation Roadways along a path without interference, we now need to also answer the question of compatibility at the intersection.

Secondly, high speed lines will need high speed interchanges and we should briefly characterize what such structures would look like. Will they be so large as to break neighborhoods as do freeway interchanges? Will they be small enough to tuck away in some corner of existing freeway interchanges which are monstrous in comparative size? Will the trains be able to maintain sufficient speed in turns so as to allow effective average urban speeds of 80 to 100 mph?

Finally, it has been assumed that traffic can enter and exit the Railed Roadway from and to surface streets without impeding the flow of either. 3rd Generation Roadway traffic control computers will manage the merge

function. On ramps will have the capacity to store a few Cars waiting for traffic gaps, much in the same fashion as today's controlled and signaled freeway on ramps. But the harder question, even assuming some buffer space on exit lines, is whether Rail Cars can unobtrusively exit high capacity Rails onto low capacity streets? How, conceptually, should the interface be handled?

LOCAL INTERCHANGES

Any city street with substantial traffic load is a candidate for a Rail line. Indeed, even a tightly restricted and minimally sized four lane urban street is a candidate for a Rail line. Our narrow street might intersect with a similarly sized street also equipped with a Rail line. Thus their small intersection is a candidate location for an interchange. Assuming both streets have no left turn lanes and no added width for parking or right turns, these minimally sized streets will both have a width of 4 x 12 feet = 48 feet. Can a full Rail Car interchange be built well within the footprint of such a street intersection?

The interchange's architecture is one of the defining elements of the Roadway. Its design must meet a number of demanding specifications. The interchange must allow unimpeded use of the 1st generation street below, perform well with speeding vehicles, be cost effective to implement, and be maintainable over time. So as not to interfere with street use, the structure must have ground clearance for tall vehicles, lack posts within the intersection, and allow signage and lighting for the ordinary intersection below. To be cost effective, it must be fabricated to good measure in a factory setting and require minimal assembly in the field. Aesthetically it must maintain and even enhance the ambiance of a pleasant streetscape. Light, airy, leaving the intersection corners open, it must allow pedestrians to be comfortable walking beneath.

Sixteen feet, about five meters, of ground clearance might be the standard codified to allow full use of the intersection below. Running lower to the ground, street Rail lines will require each Rail to have a transition zone as they approach an intersection. The lower street spans have allowed cars, SUVs, and pedestrians to pass under, but, for cost and aesthetic reasons, may provide no more than about eight feet of clearance. As such the Roadway has prohibited trucks from crossing the street mid-block. Trucks must turn at the intersections. And turn under the interchange.

Spans between the four corner posts, as to be suitably universal for wider streets as well as narrow, must subtend 80 to 100 feet. The upper Rail set's path, which is conceived to be tracing a graceful rise over the lower path, could be considered an arch under a compressive load, supported by a straight element below under tension—a straight beam for instance. In some designs the lower Rail is a standard straight set, in others the Rails are complicated twisted spirals. The skeleton support will be assigned extra loads associated with the turns. A vertical element could tie the upper Rails to the lower Rails at their crossover point. It is the shear strength designed into this vertical tie to which will be assigned the transverse impulses generated by turning Cars.

The Roundabout

The simplest possible configuration for an interchange—let's broadly define an interchange as an intersection with a 100% duty cycle where no one has to come to a stop—is the roundabout, that geometry most Americans associate with European roads. Vehicles driving on the right side of the road enter a roundabout proceeding to drive counter-clockwise on the circle from which the structure gets its name. Right turn, straight through, and left turn paths are executed after a quarter, half, or three quarter circular transit respectively. Conceptually, and many times in practice, a vehicle turning right never completely enters the circle. With that exception, all vehicles from each direction are on the circle for some length of time.

With this in mind, examine again the illustration of SIKA/VisuLogik here in Figure 4-21. First, notice the structure is a single level interchange for two way Roadways entering from all directions. Thus the companion schematic depicts all paths with a solid (———) line which we will use to represent all 1st level Rails in this section. The ability to configure an interchange on one level clearly simplifies the design and construction.

Several limitations in the performance of the structure are readily apparent. While not severe, these limitations will restrict the roundabout interchange to a local type with low vehicular capacity and speed. Low capacity is of course a relative term. Low relative to the tremendous numbers inherent in our low headway Railed Roadway. Capacity limitation results from two causes. First vehicles from all directions on four separate Rails must enter onto the single Rail from which the circle is constructed.

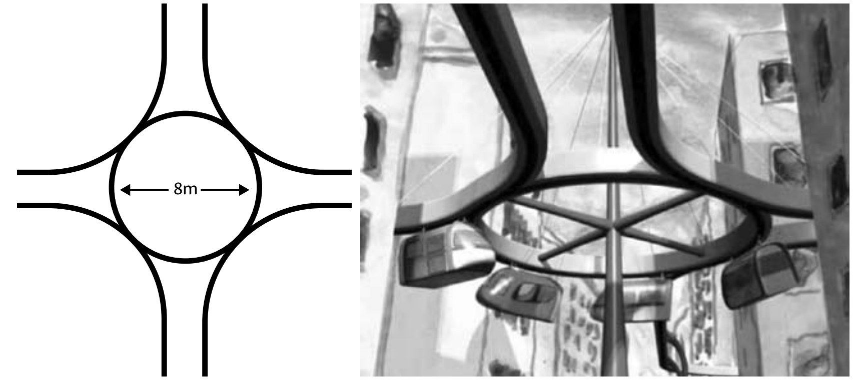

FIGURE 4–21A is a schematic of a roundabout design # 1, illustrated in FIGURE 4–21B, courtesy of SIKA.

Second, they must enter and exit the circle slowly.

Let's discuss vehicle speed through the interchange first. Assumed throughout this discussion is that horizontal accelerations will be limited to 1 g. Thus Cars, attached at their top, in response to the horizontal acceleration, will roll sideways to 45 degrees from their normal up right orientation. The turn is designed for this speed and the Rail will be tilted at 45 degrees to accommodate the expected angle. The same is true for a Car mounted from the bottom. A passenger will feel an apparent 2½ times his/her normal weight pushing directly into the seat. For multilevel structures vertical accelerations will be limited to 0.5 g. In a vertical acceleration up the apparent weight will be slightly more at 1.5 times normal weight; and in vertical acceleration down one will press into the seat with only half one's normal force. With such assumptions, vehicle speed and the Rail's turn radius have a functional relationship.

Speed is constrained by another parameter. Muscles tense and bodies brace themselves against accelerations. And when equilibrium is reached, moderate accelerations are not disagreeable. But changes in accelerations are different. Unpleasant rapid changes in acceleration have an equally unpleasant sounding name: jerk. Unsuspecting muscles and bodies are flailed in one direction or another as unanticipated forces are suddenly incurred. One can sip a cup of coffee at 1 g of acceleration, but react like a rag doll to moderate jerk.

Not only are values of acceleration and jerk important, but their duration is also important. Rocket scientists even have a term for acceleration multiplied by or integrated over the time endured: impulse. When you drop your cell phone on the floor, accelerations and jerk have incredibly high values but the total impulse is small, so the thing survives. Out of concern, the electronic industry always specifies its tiny soldered components and its larger boards for acceleration and impulse. Typical values might be 10^4 g and 0.5 g · s respectively. On a highway, "Curve Ahead" speed signs, set for the most decrepit turnip truck on the road, ask the driver to take the curve at about 0.25 g. The average hot shot driver seems to be willing to take a slightly banked turn at 0.75 g. The NASCAR race driver on a steeply banked turn takes it at 3.5 g. And fighter pilots will pull 9 g. But time of duration is still important. Even the trained fighter pilot, fitted with a special pressure suit and fighting for his life, will have trouble retaining consciousness when his plane, if it can pull 9 g at Mach 2.6, takes a full 30 seconds to make a "U" turn.

To test your reaction to acceleration and jerk, walk into a wall. Ummm, well, remembering that advisement "don't attempt this at home" or "professional driver on a closed test track" let's control the experiment. First, walk slowly! One meter per second ought to do, that's just over 2 miles per hour, a gentle pace. Practice by measuring a 10 meter path and then walking that distance in 10 seconds. Now, walk into a counter top instead, protecting your hipbones with your hands placed on them but cupped outwards at the 36" level so as to easily grab the counter top. Repeating the event a few times, tense your body sufficiently such that, as your hips come to a sudden stop, your head and shoulders bob forward about 2". There, your unsupported head and shoulders have undergone a deceleration of 1 g and jerks greater than 10 g/s! It's not a bad experience, for a short time anyway.

For purposes of discussion we will compare the acceleration and jerk for the Rail interchange designs of this chapter to those of a roller coaster. It is the roller coaster which is the common structure designed to take the average John or Jane Doe to the absolute limit of their tolerance. By the comparison we will be able to note whether the design seems aggressive or not. Worry not, we will achieve good speed on small interchanges and never approach roller coaster values! We choose for our model roller coaster, a nasty one called 'Shock Wave' at the Six Flags over Texas amusement park in Arlington, Texas. Data for the coaster, available on the web, was taken in a small study by Richard L. Taylor from Dallas, Texas. It will be presented at the end of our discussion of four interchanges when the interchanges' accelerations are known. The time duration of the roller coaster ride is 10 seconds but the different interchanges will induce accelerations for far shorter times.

Back to the roundabout! A small street will limit the circle's diameter to approximately 8 m. Limiting horizontal acceleration to 1 g limits speed on the roundabout to 6 m/s or about 14 mph. All vehicles must enter the intersection. About 80% go straight and therefore stay on for a ½ circle as they proceed. Cars turning left will stay on the Rail for fully ¾ circle. Cars turning right, even though they might in some designs stay on a separate Rail, given that we want a compact structure, will interfere with travelers on the circular Rail for about ¼ circle. Thus in heavy traffic, if the computer control can maintain an 80% fill factor, at 14 mph, no more than 8,400 Cars per hour can transit the interchange from all directions, on average 2,100/hour from each direction. All traffic slows to 14 mph. Still, both these numbers are quite attractive for a local interchange.

Another concern with the design involves jerk. A driver making a right turn who does not enter the circle proper incurs a lateral acceleration to the right increasing to 1 g followed by a symmetric lateral decrease in acceleration to 0 g to the left. But driver proceeding straight-through and drivers making a left incur something more complex. Their path goes right, then left, then right, then straight. The Car swings first to the left, then the right, then the left, and then back down. These swings will not go unnoticed. Furthermore, if the circle is truly a circle, the feeding line at best can make contact as a short straight segment, and the Car will be jerked into a 1 g curve as it enters the circle. If the circle is modified, those already on will be jerked. Admittedly any conceivable turn involves two accelerations, and four is not much more than two. But, the majority of travelers are going straight through and they will have to endure four transverse accelerations. In our next design they would endure none.

The Cloverleaf Interchange

If the reflexive design for a European architect is a roundabout, the reflexive, OK cynics, the knee jerk design of an American architect is the Cloverleaf interchange. This is a two-level design. Riders continuing straight ahead on one set of Rails do exactly that. They ride straight ahead; the interchange is transparent to them. The riders on the second set undergo a compound vertical curve to rise about 2 m, 6+ feet, above the first Roadway to pass. When combined with the need to create greater vertical clearance at street intersections for trucks passing below, these vertical curves might start some substantial distance before and therefore be quite gentle.

Riders making a 90 degree right turn can do so at 25 mph at 1 g swinging their Cars toward the center of the interchange if they execute on a curve with a 13 m radius. Cars executing a left turn have a very different scenario. Exiting to the right they complete a full 270-degree turn on a very tight radius dropping or rising six feet at a very steep vertical angle before joining the new Rail. It is estimated that the short Rail Car proposed here could turn on a 2-meter radius. At 1 g it could do so at 10 mph. It would swing out from the structure's center as it did.

With Cars swinging thus, in the effort to keep the design small, a relatively severe problem is incurred. In order to avoid any conceivable head on collision between right turning and left turning vehicles, the right turn Rails need to be moved out as much as four meters. The computer could be assigned of course to time Cars to avoid collisions but the Roadway's fail-safe design would be voided.

Figure 4-22a illustrates as a line drawing a full Rail Car interchange patterned after the classic two-level cloverleaf freeway design. Solid lines are used for Rails on the first level and and a dashed pattern for Rails above on a second level. A Rail Car proceeding straight north or south goes through without interacting with the exchange. Cars proceeding east or west are on a Rail that departs from the primary level and proceed through the intersection on an upper level. Any Car making a left turn goes through the intersection, makes a full 270 degree turn simultaneously with a rise or fall to the next level. Note that in the figure, the loops associated with these left turns are drawn using the dual attach associated the ski lift configuration in, again using an analogy to a track and field relay race, the baton passing zone. Any Car making a right turn simply turns 90 degrees. Figure 4-22b is a photograph of a freeway cloverleaf.

To size the design, two questions need asking. What vehicle speed is allowed? What vehicle accelerations are allowed? For discussion let's assume 25 mph for Cars traveling through or turning right, 10 mph for Cars turning left. Again let's allow a more gentle 0.5 g for vertical accelerations and a more aggressive 1.0 g for horizontal accelerations. With these values 90-degree right turn Rails have a radius of 13 m, the 270 degree left hand turn Rails have a radius of 2 m, and the four vertical curves that define the up, then down, path of the rising straight rail set have a radius of 26 m.

With these numbers the interchange is formed roughly within a diamond, viewed here as a square rotated 45 degrees, with sides of length 12 m = 39 feet. The sidewalk boundaries of our minimally sized street are shown

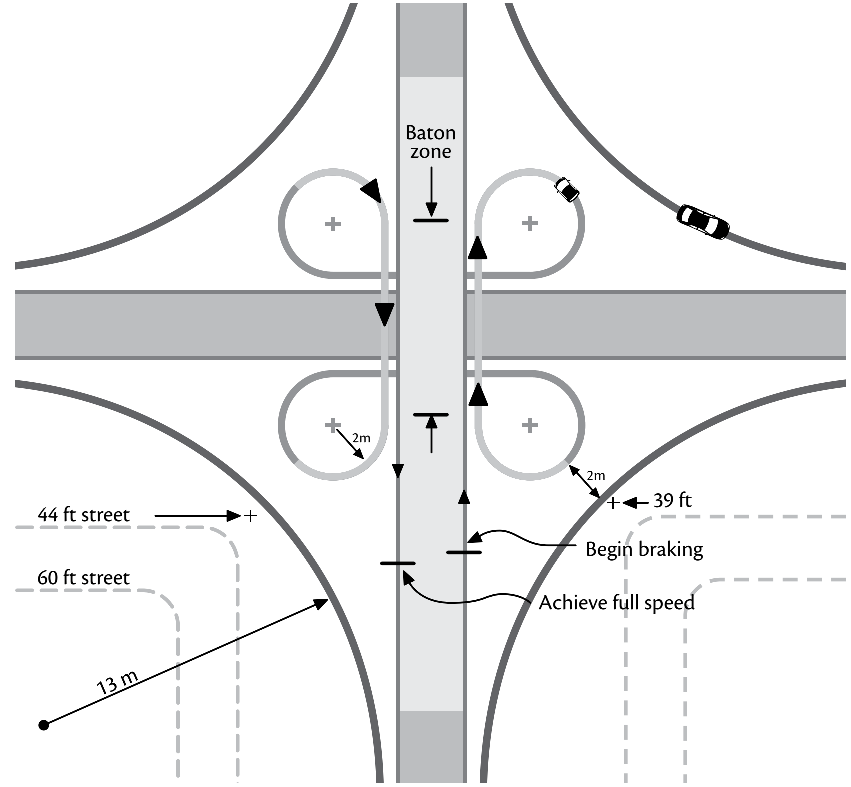

FIGURE 4–22A. Illustrates the geometry of a local interchange, dimensions the interchange given a number of assumptions, and shows the sidewalk positions of a minimally sized street.

FIGURE 4–22B. A Rural Freeway Cloverleaf to be used for Comparison.

at the figure's boundaries for reference. An interchange is a substantial item at the neighborhood corner to be sure, but perhaps not much more than the collection of poles, lighting and signs which are now common.

How tall? Well the number of levels is two. That allows north/south travelers to continue straight ahead without interference from the east/west customers. Two levels need to vertically displace no more than 10 feet, that is, the height of two Cars plus exposed Rail and sufficient clearance. If the interchange takes place over an intersection of two large streets used by trucks, the bottom of the Rail interchange will need to provide 16 feet of road clearance, and the top will crest at 26 feet.

The cloverleaf configuration itself, in at least the hanging Car ski lift conceptualization, consists primarily of a set of two bent Rail segments, which will compliment the two sets of intersecting primary Rail lines. Diagrammatically each bent Rail shape resembles the wire rims for a pair of eye glasses connected with a straight wire for the nose bridge. From above the two are seen as mirror image pieces placed to the left and right of one primary Rail set. Their separate ends, now about 4 meters apart and twisted to the level of the second primary Rail line set, would be then connected by two straight 4-meter-long rail sections, which in turn are attached to that primary Rail set, bolted into place at the appropriate spacing. It is on these two straight 4-meter Rail sections and the two straight "nose bridge" sections that the cars transition from one primary Rail to the other as they make a left turn.

What's the capacity of this second, low speed, local interchange? After all, Cars have to slow before entering the minimally sized left turn lanes, and they have to accelerate after completing the turn, and these requirements will limit capacity. How much Rail length has to be cleared for the merging or exiting Car? The answer is 6 m. This length assumes we'll brake from 25 mph to 10 mph at 0.4 g and of course the Car can only accelerate at about this rate. Thus, worst case, if every other Car is turning, we need 6 m clearance plus 2 m Car length per Car. 8 m per Car at 25 mph is 8,000 cars/hour for each direction—about the average freeway capacity! Of course, we know from our anecdotal analysis of one Manhattan Beach intersection only about 1 in 10 cars turn left—with the rest going straight through or turning right—and so the capacity of a small local interchange is substantially higher. All assuming, of course, that traffic control is up to the task!

The Double Helix and Barrel Roll

A huge advantage for the vertically stacked Roadway will be exploited here in another two-level interchange design. With a vertical set of Rails, vehicles are free to exit left or right from either Rail and thus execute simple 90-degree turns. Rail Cars on the top going, say, north would be free to leave to the left and join Cars going west on the top. Or leave to the right and proceed east. Likewise, Cars going east on the bottom would be free to take a right and join Cars going south on the bottom.

Unfortunately a very nasty problem is now apparent. The poor Car going west on the top, should it choose to turn right and go south, will meet traffic head-on going north! A second problem is also incurred with the straight through Rails. That is, for the two sets of vertically stacked rails to miss each other, four levels of Cars are required; rather than the more compact 2 x 2 configuration associated with horizontal stacking. Thus visually at least the apparent size of the structure would be doubled.

Both problems are solved with one trick. If each of the two Rail sets twist 90 degrees in relative orientation, that is they go from a vertical stack to a horizontal one as they approach the center of the interchange, the sets will cross as a two level structure of four rails. If the rails continue to twist another 90 degrees in the same direction, they will return to a vertical stack, only with the top and bottom Cars in reversed positions. Exactly what our poor Car going west needed! A quick check will convince the reader that all combinations are satisfied.

Through the entire 180 degree process the Rail continues to orient the Cars in an upright position. The Cars rotate around a central axis as if on a double helix with a slow pitch. The Cars are on a double helix, the Rails in a barrel roll! See Figure 4-23 depicting the progressive cross-sections over 40 meters of a Rail Car as it travels away from us and meets on coming traffic as well as the crossing Rail line. Note the Car's helical path.

For 25 mph turns, the 13 m radius right and left turn Rails can start and finish on the center line of the approaching vertically stacked Roadways.

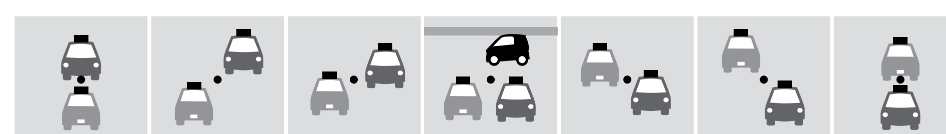

FIGURE 4–23. Progressive cross-sections depict a Rail Car traveling on a barrel roll at an interchange and meeting on occasional coming traffic and cross traffic.

The entire structure is therefore very compact. Half way through the turn the Rail is 5.5 m from the center point and the Roadway largely fits into a 8 m by 8 m square directly above the center of the street intersection below. The Rail Cars rejoin the main Rail some 13 to 20 meters down the Rail merging into their awaiting slot as their horizontal acceleration decreases as gradually as desired. A schematic is shown in Figure 4-24.

Figure 4-24b is a computer rendering of a barrel roll interchange at the intersection of two 3rd Generation lines. The illustrator has taken Roadway built using Design #3 and which are aligned along the medians of two streets. As shown both streets have approximate widths of 60 feet, and the structure easily fits within street boundaries. Ground clearance shown is about 16 feet. The illustration is to scale. The ability to incorporate full interchanges above ordinary major urban streets is a major goal of the 3rd Generation Roadway as the feature allows full penetration of the urban landscape without unduly disrupting the city.

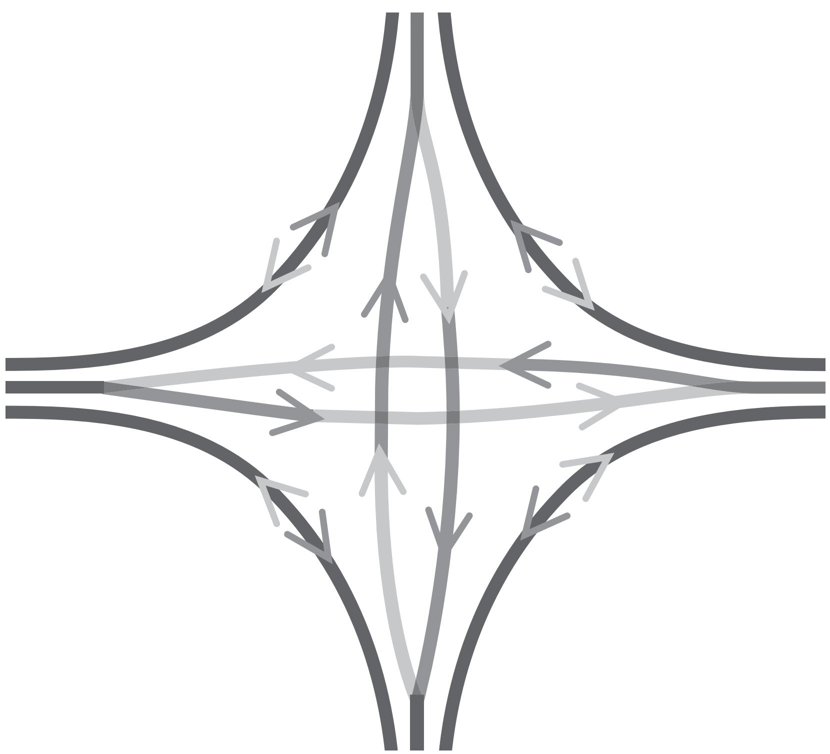

FIGURE 4–24 schematically illustrates traffic flow directions using a vertically stacked 2 Rail Roadway which barrel rolls through the interchange.

FIGURE 4–24B illustrates a full, high-capacity, 25 mph interchange above a common street intersection.

Vehicle capacity for each Rail in each of the four directions is unconstrained by the interchange's speed if the street approaches are at 25 mph. Only the merge functions reduce capacity. If we assume a non-synchronous system, the Aerospace study indicates functionality can be maintained up to a fully 80% solid train. At 25 mph our 7-foot-long vehicles can operate bumper-to-bumper with a headway of 0.19 s or 19,000 vehicles per hour. At 80% that's 15,000 vehicles an hour each way—about twice what a big, high speed, stacked, four level freeway interchange can do.

When the interchange is operating near full capacity, solid trains of Rail Cars will be asked to slow to 25 mph as Cars exit to the right or left. But for the vast majority of time the interchange will see small trains unimpeded by individual Cars slowing and executing a turn. Setting a speed limit of 40 mph for street segments of Roadway with all turns at 25 mph establishes a highly attractive network.

Can Rail Cars traverse the Barrel Roll segment of the interchange at 40 mph? How fast can a Rail Car roll though the interchange? The Rail's barrel roll begins 20 m before the center point of the interchange, at the same point the turn Rails begin, and ends 20 m after the center point. This beginning point has been extended down the street so that the turns, and the barrel roll, can begin gently, thereby minimizing the jerk values of the ride and maximizing passenger comfort. We needn't worry whether Cars tilt right or left since all are in their exclusive time/position slots.

Horizontal accelerations in the barrel roll are complex but small in value. Relative to a straight line, horizontally, the Car will first move out, slow, stop, move in, and then stop. Vertically, the Car will simply leave its level path by accelerating downward and then slow to another level path. Thus, vertical accelerations will be simpler, rising to some value, dropping to zero and reversing to some value, before dropping in magnitude to zero. We have committed throughout to allowing no vertical accelerations greater than 0.5 g. As a consequence the horizontal accelerations will never approach our imposed limit, 1.0 g. Only horizontal jerk will be of concern.

Vertical acceleration, if the pitch of the barrel roll were held constant, would be a cosine function of argument 0 to π, starting and ending at maximum absolute values. This is unacceptable. However, if we pick a maximum jerk value, allow the acceleration to rise at that rate to 0.5 g, and then fall sinusoidally to 0.0 g, we will arrive at a travel half-time with acceptable passenger comfort. That is, the minimum time to transit half way, or 20 m. Minimum time to travel a set distance implies a maximum speed. Picking

2 g/s for maximum vertical jerk, the pitch decreases and the acceleration increases to 0.5 g during a ¼ s. In this ¼ s the Rail has moved over 18 cm and down only 5 cm given the barrel's 1 m radius. The horizontal jerk has been high, 3 g/s. But the Car is now accelerating downward at full value, 0.5 g. It will take only 0.56 s for the Car to drop the remaining 95 cm as its acceleration sinusoidally drops to zero . Total time is ¼ s + 0.56 seconds to traverse the 20 m path. Our answer is 55 mph.

Interchange components are few. One primary component are the eight turn pieces which conceptually are identical although, if exit and entrance hardware are different, they would consist of two sets of four pieces. There are two barrel roll bent sets. These might be complicated but they are only two. There are eight 1-to-3 rail switch guides, and eight 3-to-1 guides. Numerous connecting and bracing pieces will be needed.

Various Accelerations

At this point it is appropriate to compare the accelerations imposed upon Roadway riders as they traverse the various interchanges that have been discussed. It is also appropriate to compare these interchange accelerations with that of a well known event designed to stress the adventuresome: the roller coaster ride. Throughout the text the reader has already been asked to contemplate the acceleration of everyday driving, NASCAR driving, and challenges to a jet fighter pilot.

Figure 4-25 plots acceleration vs time occurring during transit of three different structures. Units of acceleration are in g (1g is the acceleration in free fall under the influence of earth's gravity) and time is in seconds. The first plot is data taken by Richard L. Taylor for the Shock Wave roller coaster at the Six Flags over Texas and plots the absolute value of the vector sum of accelerations for the 10 second trip. Accelerations of up to 5 g, as well as jerks of 8 g/s are incurred. These accelerations, combined with a 3-dimensional path obviously promote an impending sense of doom.

The second set of data is calculated for transit on the Double Helix Interchange just discussed. Horizontal accelerations have been designed to be 1 g for a 25 mph turn on the tapered curve with minimum radius of 13 meters. Tapering the ends of the turns has limited the initial and final jerks to 2 g/s. Right and left have the same absolute values as the turns are mirror images. Also plotted are the vertical and horizontal accelerations incurred for traffic that does not turn and goes straight through the interchange.

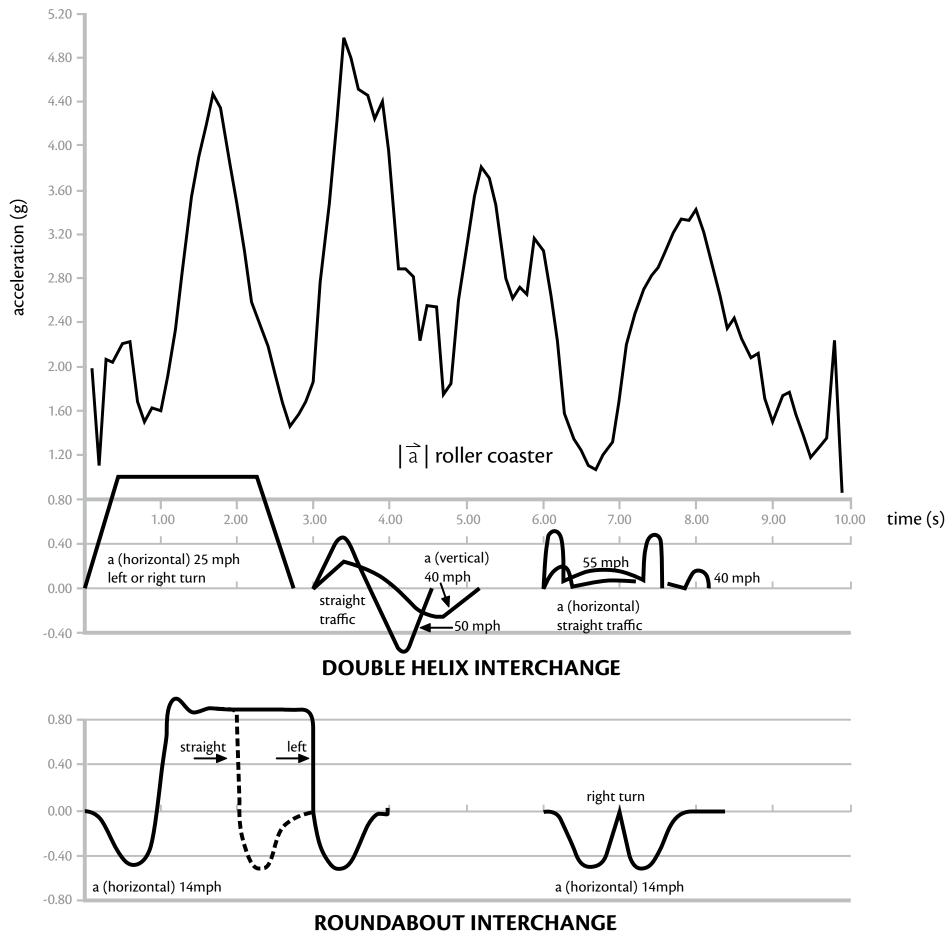

FIGURE 4–25 plots accelerations for a roller coaster ride, transit on a Double Helix interchange, and transit on a round-about interchange.

Plotting at two different speeds allows the illustration of several points. One, traveling through at a speed of 55 mph is possible at acceptable accelerations. Two, traveling through at 40 mph, required in relatively heavy traffic to facilitate easier merging with slower traffic turning at 25 mph, achieves very benign disturbances for a traveler. Also the careful observer will notice that the tapered ends of the helix, designed in the text for minimum vertical jerk, are not optimum when considering horizontal acceleration—witness the rabbit ears at beginning and end—and a redesign is warranted.

Finally, the third design for which data are plotted, is the the roundabout interchange. Several problems noted in the text are apparent. Note that the speed, 14 mph, is lower than in the Double Helix. Note the absolute accelerations and the several reversals incurred by the straight through driver. The theoretical jerk incurred as one transitions from a right turning entrance (in right hand drive countries!) to a left turning circle is infinite. Obviously the sway of the Car will reduce that value but jerk will still be considerable. One approach is to flatten the right turn Rail at its tangential point, and the effect of that flattening is apparent in the zero at the center of the acceleration curve for a right handed turn. But note, as the most local of interchanges, the circle has use.

HIGH SPEED INTERCHANGES

The Double Helix with High Speed Turns

The speed limit for Cars approaching the Barrel Roll interchange will be set well below 55 mph for a very basic reason. For the vast majority of time, the interchange will be operating with moderate traffic, and Cars making right and left turns must slow. While a Rail Car can easily and quickly slow from 55 to 25 mph, requiring only 18 m of rear clearance at -0.5 g before exiting, Cars will take considerably longer to accelerate back to speed. We have now paid a price for achieving superb fuel economy in the previous chapter. By specifying a Car with a small motor, speed limits will need to be reduced to accommodate the slower Car on small urban interchanges.

The interchange can be modified for high speed by allowing high speed turns. Increasing the turn radius from 13 m to 62 m will increase allowable turn speeds from 25 to 55 mph. A simple modification, yes, but one resulting in a structure no longer fitting above an urban street. The main body of the interchange now occupies a 50 m x 50 m square and of course extends further down the Rail.

While the design grows substantially as the turning speeds specified increase, the Double Helix interchange remains small when compared to the freeway interchanges we know today. The main body of our 55 mph interchange occupies somewhat more than a half acre. The comparable number for a freeway is 40 acres.

Elsewhere, 60 mph interchanges will be discussed. Comparable numbers are 74m turning radii, a 60m x 60m main body and 0.92 acres or 0.37 hectares of space occupied.

A Four Level Rail Design

For high speed Rail lines, intended for extremely high traffic flows and using a side-by-side configuration for the Cars, high speed interchanges configured as four level stack may be desirable. Using two shades of gray for the 1st and 2nd level Rails and adding ▪ ▪ ▪ ▪ ▪ for 3rd level and ◆◆◆◆◆ for 4th levels, Figure 4-26a illustrates a 4 level high speed interchange employing only right handed exits and left handed merge sequences. This configuration allows all turns to be nominally 90 degrees in extent and removes the requirement to substantially slow Cars wishing to make a left hand turn. Cars making a left exit to the right, achieve clearance with elevation, and turn left in nominally 90 degrees, finally merging with new traffic from their right. Figure 4-26b is a photograph of the interchange connecting the I-10 and I-15 Interstate Freeways.

What is required if we wish all traffic to proceed through an interchange at full speed? And let's define full speed to be 60 mph. Each turn lane servicing rush hour traffic to or from an urban center can now handle a full capacity of 40,000 cars per hour. Thus no delay or slowing would be incurred even if all traffic wanted to make a left hand turn. This unusual traffic flow might occur, for instance in our example of Manhattan Island, if everyone leaving work and going south on the East Side of the island

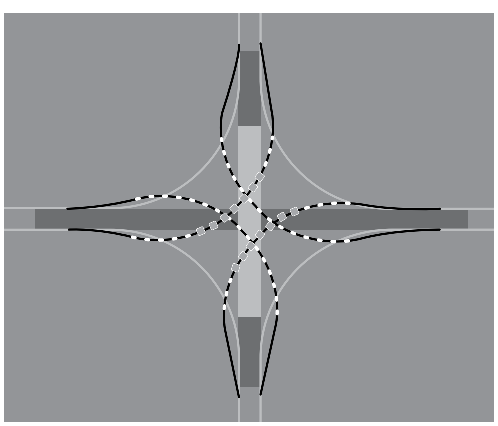

FIGURE 4–26A illustrates the layout of an interchange that requires only 90 degree turns, but requires 4 levels of roadway. FIGURE 4–26B is the equivalent used by the Interstate freeway system.

decides to turn toward Brooklyn. See Figure 4-27.

How much real estate is used? How big are those sweeping curves? Well, the answers are 2.6 acres—that's just over a hectare if you're not in the States—using sweeping curves of radius 74m. This rather large structure allows all cars to proceed through at 60 mph with those making turns undergoing no more than 1g of transverse acceleration. Note in Figure 4-27 how narrow the approaching Rail lines are compared to the spacings required at the interchange.

Before one despairs at the size of the high speed interchange, one must consider the structure that it replaces. High speed interchanges for freeways of today are huge in comparison. Typical numbers for area consumed are 40 acres, fully 15 times the size proposed.

We conclude the writing of this low and high speed discussion with the following note. While local 3rd Generation Roadway interchanges in tight urban area restrict travelers to moderate speed, their vehicle capacity is

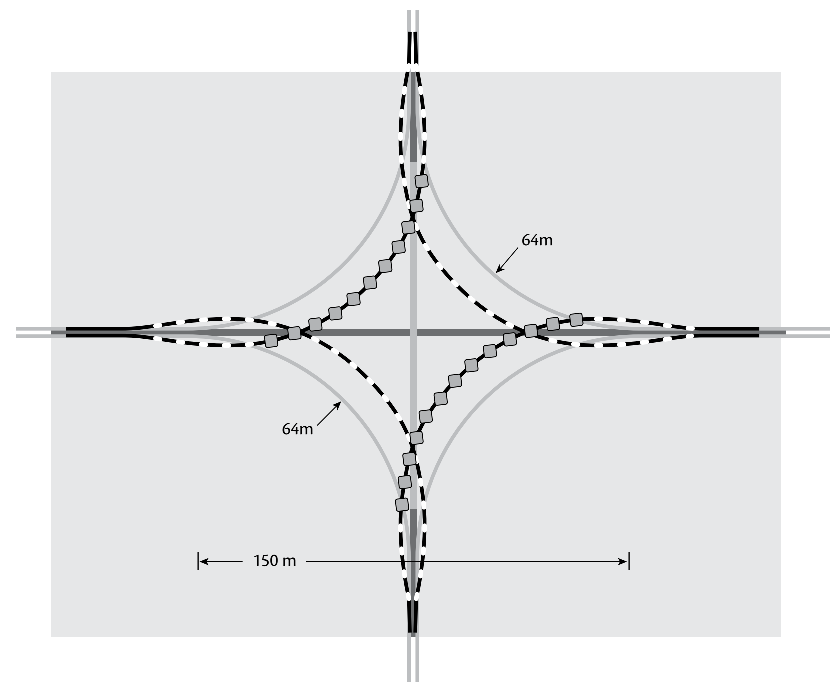

FIGURE 4–27. The High Speed Interchange Pattern is illustrated to scale with the large sweeping curves required to route the Rail Cars through at 60 mph. Note the footprint is huge compared to the narrow side by side Rail lines approaching the interchange.

twice that of the largest 2nd generation structure. They will readily handle the heavy urban traffic load. Note also that if our previous Los Angeles freeway statement is universal, in a major urban area one is never further than 2.5 miles from a freeway. Extend that statement to say that one will never be further that 2.5 miles from a high speed Rail line in any urban area, and the following is true. Restricted in a dense urban core to 40 mph on local Rail lines, one is never further than 4 minutes from high speed transit approaching 100 mph.

We also end here with a photograph of a four level, modern, stacked freeway interchange in Beijing. The disruption of the previous neighborhood caused by the freeway is obvious. Superimposed onto the photograph, carefully scaled so as to accurately represent its true design size, is a drawing of a 3rd Generation Interchange of the type we have just designed. Although our structure could not carry the trucks which travel the freeway, if those trucks could use surface streets, the freeway would not have been built. The Rail line interchange is capable of carrying twice the vehicles than is the freeway's. Examine Figure 4-28 and see if you can find it!

FIGURE 4–28 is a photograph of a high speed freeway interchange within an urban landscape. Superimposed to scale is a low speed 3rd Generation Interchange using an intersection nearby.

INTERFACES

Question #2 is how can Rail Cars be exited, dumped, spit out, onto city streets without clogging up those low capacity roadways. Remember a Rail line can deliver 50 times the vehicles to a destination that a city street can handle. And city streets must still carry much of their normal load—cars, buses, and trucks. Will large numbers of Rail Cars, perhaps entering from the center lanes, merge and not overwhelm regular traffic?

Add to the problem presented by this question. Rail lines proceeding along a center median cannot have exits terminating to a street's far right—the parking lane—without first ascending to considerable height allowing tall trucks unfettered use of the street. Exits as configured in this book also require a parallel track for descent and, if built outside the center median, will interfere with a lane of street traffic.

A preliminary design, useful as a starting point, would be to have median right-of-way wide enough for an extra Rail. Cars wishing to exit would switch to this Rail, and descend. Opposing traffic could have alternate exit areas, never requiring more than two Rails in one direction and one in the other. After the immediate exiting geometry, the extra Rail could curve so as to align itself with the center line of the Rails above, and deposit a Car in the street median. Several Cars would presumably be simultaneously allowed in the area before exiting to the right onto the street proper.

It is important to note that exiting rates for Rail Cars at different off ramps will vary greatly. Exits to residential areas or a neighborhood coffee shop need to and can be built differently than, say, the one to a major parking garage or to the baseball stadium that might host the 7th game of the world series tonight at 6:30. The former type might interface with the Roadway using ordinary streets. The latter type might have high capacity lines directly entering the parking facility.

Alternatively, off and on ramps might be developed exclusively at intersections. High above the ground, exit ramps could immediately begin with a right turn descending into the parking lane of the crossing street. Trucks and automobiles would not be affected at the intersections, and the Rail Cars would merge out of the parking lane into the right lane down the street. Entrance Ramps would use the reverse procedure.

5

PARKING STRUCTURES

The previous chapter outlines a Roadway to move vehicles with speed and convenience, in very large numbers, through areas with dense population. Cities of a few million inhabitants can now be crossed in five minutes. But the benefits of speed will be lost if the driver cannot easily transition to a pedestrian, and it is as a pedestrian that we reach our final destination. If one can't easily park his vehicle, the journey has not gone well. If neither the city nor private entrepreneur can provide parking "close in", within the constraints of a dense, high-cost, urban landscape, much will be lost. If driving is a 5–10 minute task, "close in" means parking and walking is a 1–2 minute task.

This chapter attacks the problem created by the dense traffic now able to flow into selected areas on the new Roadway. Or traffic created as people more easily travel longer distances. Or traffic densities created as population densities freely evolve and presumably increase. How will everyone find a parking spot? Find a parking spot close to their destination? And find one convenient to use?

In residential areas, the ordinary street we know today will ably deliver vehicles the last few hundred yards. Locations that attract many vehicles will have parking lots directly connected to a Rail line — no street use at all. Where Rail Cars exit onto busy boulevards, care must be taken that 3rd Generation Roadway traffic not clog the 1st generation street.

Parking density — that is, Cars parked per unit area or volume — must be increased dramatically from what we know today. Robotic valet service would be useful. Useful as well would be street design allowing Rail Cars to park as conventional automobiles. Two Rail Cars should be able to park where one automobile is able.

One might be tempted to read this short chapter as a footnote: "Good, there's parking, close in, automated, how sweet." But if, as Donald Shoup writes in the book *The High Cost of Free Parking*, the cost of an average parking spot today (to society) is greater than that of an average car, and that the sum total of our national subsidies for parking roughly equal that for Medicare or the defense budget, read again. This chapter will outline the potential of increasing parking density by a factor of ten. Thus Professor Shoup might conclude that the savings in parking expenses would roughly equal the cost of the Rail Cars — or equal the expense of the entire public Roadway.

The next time you drive into a parking structure, think about what you see: the big pillars, the broad turning areas, the two way "streets," those fantastic movie scenes — just kidding — and all that wasted space! The modern parking structure with its characteristic street-like spiral ramps, entrances, exits, and allowances for long vehicles, the 8-foot-tall vehicles, and space required to open your door as you squeeze out, achieves a fairly dismal "packing density" — that is to say, the number of vehicles for a given volume is small.

Typically, standard designs allocate a width of 8½ feet for each automobile and a full 84-foot-wide path for the two-lane driveways with face-in parking on both sides. Such spacing allows only 125 cars per acre per floor. And the number of floors is limited by several factors. First, one's patience is quickly tried by the onerous task to navigate the many spiral turns between levels. Another is the design and expense of ever taller buildings. And finally, the large floor spacings, typically 12 feet or more, soon produce a building whose height violates community standards. Prefabrication, it should be noted, has greatly aided low-cost versions of the multi-storied lot.

The suburban parking lot packs cars somewhat better, about 175 cars per acre. Better because no posts are needed and designers make use of one way driveways. Land is the major cost. And as the lot is intrinsically one level, walking time quickly grows in proportion to the venue size. Even finding your car is sometimes problematic.

THE PUBLIC PARKING GARAGE

The next time you drive into a parking garage, also think about how you would park your Rail Car. Think about valet parking. But think a robotic valet! Furthermore superimpose another image in your mind: that of your dry cleaners! Remember giving a number to your cleaner, and after she punches the number in, a giant carousel holding hundreds of hangers on a rack begins to rotate until yours is up front, allowing her to pull it off the rack. Now imagine your car on that rack!

Imagine. Drive in, hop out, take a number, watch your Car loaded onto a Rail, watch it packed into a virtually solid array of Rail Cars many stories high. The garage owner has packed 10 times as many vehicles into his facility as the guy with an automobile parking garage of the same size across the street. You're happy because the price is right and the owner's small structure is next door to your destination. Hours later, you'll come back, feed your parking stub into the machine, and while it debits your account, your Car will rotate out and down. A new meaning to the phrase, "waiting for the elevator".

Let's explore one possible garage design. The parking structure crudely depicted in Figure 5-1 moves Rail Cars in a unit cell comprised of a long, narrow carousel. The carousel carries Cars on an ordinary straight Rail to the end of the building, orchestrates the Cars into a sharp u-turn of 180 degrees, and completes a loop at the near end with another 180. By placing unit cells side-by-side and stacking them vertically, the architect will fill large rectangular buildings of arbitrary dimensions to fit the location.

To connect the carousels to the street on incoming Rail, several concepts seem tractable. A hoist, actually looking more like an open elevator, might address 10 or more such unit cells stacked vertically to the top of the building. Many such elevators could stand along the street lane on which you approached. Alternatively one elevator could address several stacks if a short horizontal Rail or guideway connected each corresponding story. A very different scheme might have the Cars climb a Railed ramp on the perimeter of the building's exterior. The ramp could climb one carousel

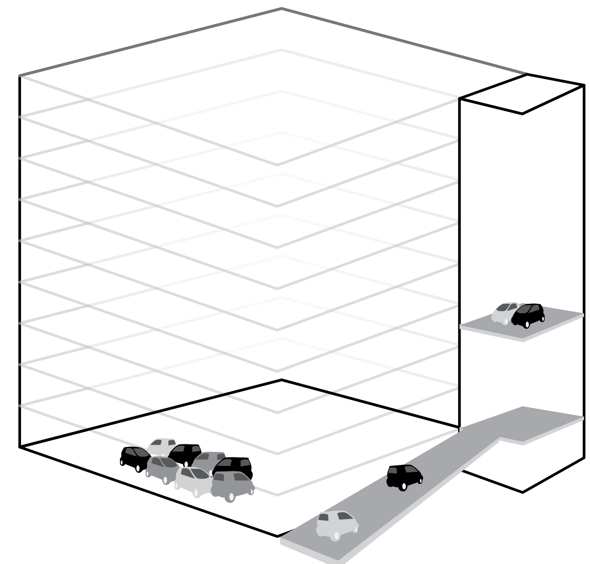

FIGURE 5–1 illustrates a ten story parking cube featuring a 10 x 8 set of Rail Car carousels. This Rail Car Parking Garage has ten conveyor belts to deliver Cars to an elevator set.

height on, say, both the building's north and south walls, thus climbing two stories every circumlocution. From this ramp Cars would load onto the structure for, say, even floors on the west, and odd floors on the east. Even floors would unload on the east onto a descending ramp. The descending ramp would descend on wall floors left open by the up-ramp, also at a rate of two carousel heights per circumlocution.

A 100-foot-long dual Rail built on a 50-foot by 120-foot lot would house 28 7' x 5' Cars in two rows of 14, and allow 20 feet at the end for the drive in/drive out. If the dual Rail is 12 feet wide to allow 2 feet for support posts, four such dual Rails would fit per floor. Thus a ten-floor structure would house 1,120 Cars or 8,200 Cars per acre. The building's height would be about 80 feet.

To conceive of the fantastic densities that many cities will achieve in the next century, visualize today's New York—the island of Manhattan. An island that almost denies the use of today's automobile. As we noted before, if everyone in Manhattan today—in the U.S. today there are almost as many cars as people—drove to work or lived there and kept an auto for the weekend, or, say, to go grocery shopping at Trader Joe's downtown and Ikea/Costco in New Jersey, the daytime automobile population on the island would be approximately 2,500,000 (3,000,000 daytime people times the national average of 0.83 cars/person). Assuming the parking structures employed there today, and arguing that they'd all be 10 stories tall, 3.1 square miles of parking would be required on this island of 22.7 square miles, 14% of the whole place! The "Dry Cleaner's" solution to parking Rail Cars would take 1/2 of a square mile, about 2%! Still a huge item, but more than conceivable.

Stated in very different terms, the Dodger baseball stadium in Los Angeles is presently surrounded by approximately 150 acres of prime real estate used solely as a parking lot with about 23,000 parking spots. Assuming owner Frank McCourt put in a 10-story Rail Car parking garage, he'd need only 3 acres, and everyone would have close-in parking. Consider the amazing concept that the ball park would be far larger than its garage. As the remaining 147 acres would be worth a pretty penny, this is a concept that Frank could get behind.

Los Angeles International Airport (LAX) makes another example. Serviced by 10 traffic lanes in a double deck, the airport is the scene of hideously unpredictable traffic jams that arguably make the 1½ mile service loop the most dreaded stretch of roadway in L.A. Automobiles dropping passengers, automobiles picking up passengers, and taxi cabs compete

FIGURE 5–2. Photographs of a Volkswagen storage facility in Germany. These photos lend credence to the idea that Rail Car storage could be handled by machine.

with a myriad of shuttles and buses servicing the car rental agencies and remote parking lots. Today, prime near-term parking spaces demanding premium prices fill 25 acres inside the eight terminals which are configured in the shape of a big "U". Extensive long-term parking lots some miles away are accessed with the shuttle system. In all there are about 300 acres for 50,000 cars. Real estate in the area is worth many millions per acre.

Rail Car garages could change all that. Even if we assume cheap, easy access to central parking would double the number of vehicles coming to park, if 10-story Rail Car garages were built, housing 8,000 Rail Cars per acre, everyone arriving in Rail Cars could park within feet of the check-in counter. Goodbye shuttle bus. Goodbye remote Car rental. There would even be room within the loop for some grass and parkland.

STREET AND LOT PARKING

THE SUBURBAN LOT

On the street our Rail Car is short and agile. Its seven-foot length is about half that of the average automobile. As we learned in Chapter 3 reading the Car's specifications, its 60-inch wheel base has enabled a turning radius of about half that of the ordinary road car. The Rail Car's proposed width of 59 inches is about ten inches narrower than most cars today. Although the Rail Car is a two door vehicle, unlike today's two door cars, the Rail Car has no need to have an enlarged door capable of servicing the back seats. It has no back seat. Thus the Car's short door can swing wider open with minimal clearance.

Let's list the advantages of these properties in the suburban parking lot. Advantage #1, the Car's seven-foot length will allow face-in parking in slots not much longer than seven feet. This length compares to 15 feet for today's compact parking slots and maybe 20 feet allowing SUV and light truck parking. Advantage #2, the Car's short turning radius allows for a rapid transition from the driving lane to the slot. Thus the driveway can be narrow without the danger of rear-ending the Rail Car parked on the other side. The width of today's driving lane seems driven by that concern rather than the 10 feet or so needed for low-speed navigation. These two advantages together should be sufficient to allow 30-foot parking lanes to replace today's 60-foot architecture. Advantage #3, the slightly narrower Car with short doors can park in a narrower slot. Let's not be aggressive here, but propose an 8-foot or 7½-foot slot compared to today's 8½-foot space. Compared to today's suburban parking lot with 175 road cars per acre, the parking density in the Rail Car section is now 365 Rail Cars per acre. See Figure 5-3 for one possible configuration.

STREET PARKING MIXED WITH ROAD CARS

The Rail Car is, of course, meant to regularly tool around town and park on ordinary streets. Park there without disrupting ordinary life, ordinary road cars, and ordinary meter maids. To say nothing of the guys who have to paint the streets. Figure 5-4 is meant to illustrate a small snapshot of that ordinary scene. Rail Cars park head-in while regular automobiles park

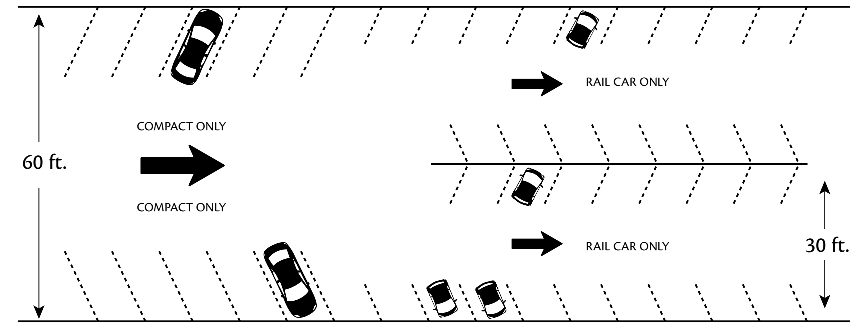

FIGURE 5–3 illustrates the compatibility of Rail Car parking with road cars on the suburban parking lot. Slightly over twice the density is achieved for the slightly narrower, and aggressively foreshortened Rail Car.

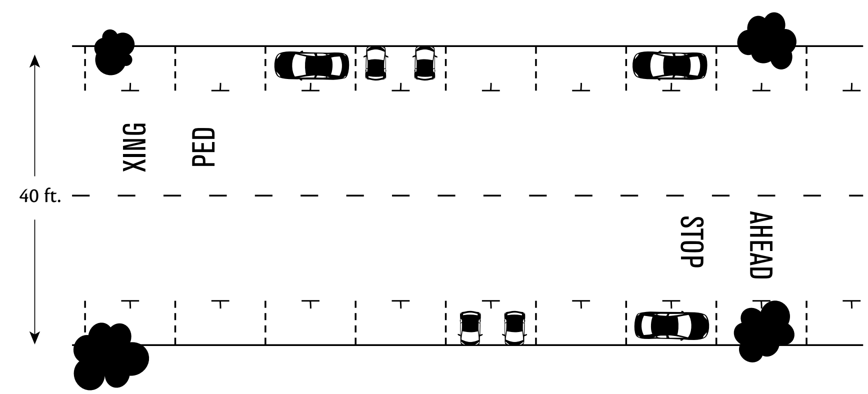

FIGURE 5–4 illustrates head-in parking for Rail Cars at twice today's density on an ordinary street.

parallel to the street. Minimal changes in the street paint inform different users. First come, first served. Equal opportunity to both vehicle types.

The Rail Cars are short enough to park head-in and not stick out into the street. If you like to think inches, when the 84 inch long Rail Car sticks its nose six inches over the curb, and the 68 inch wide road car parks 10 inches from the curb, roadside everything lines up. Well, maybe the side view mirrors of the road cars stick out a little.

Likewise, if street parallel parking spots are 18 feet long—yes, they do vary atrociously—the 9-foot width allowed for each Rail Car is more than ample. And, of course, another big plus: head-in parking will allow us all to forget how to parallel park. Another challenged sub-population relieved of duty! The short turning radius of the Rail Car will allow turning to and from the street to be done with ease.

Part of this book's intent is to convince the reader of the real possibilities for the schemes proposed. With that in mind, this short chapter will close with a photograph. The photograph of Figure 5-5 was taken by a major automobile manufacturer who, in matters of parking, agility and convenience, is clearly thinking along the same path as we have just described. The Smart car's length of 98 inches is 14 inches longer than that proposed for the Rail Car.

FIGURE 5–5. A Daimler-Benz photo highlighting the agility and size of its Smart Car when parking on the street.

6

AUTOMATED TRAFFIC CONTROL

Automated control of the Rail Car begins at the gate and continues until the exit is cleared at the programmed destination. The driver takes a vacation.

When we shift the paradigm from a human-operated vehicle to a computer-controlled vehicle, we shift the paradigm value for a safe trailing distance, and hence the vehicular capacity of a Rail line. We shift the margins needed for merging two vehicles and hence interchange capacity. We shift the expectation for the value of a safe speed. We shift the expectation for safety. Earlier we learned that the Rail's control over a Car's path, the Rail's path, and the right architecture for interchanges will achieve spatially compact, efficient and continuous traffic flow. The Rail Car's electric motor, brakes, light weight, and excellent traction to the Rail will assure responsiveness to control. The "computer" must do the rest. It is a cliché, but true to say, this short chapter will give new meaning to the term "traffic control."

On a single line, how is the speed of a Rail Car controlled? How are their relative positions controlled? How are Rail Cars docked with each other to form trains? The Cars need to be efficiently slowed for turns, and prepared for exit. The critical act of merging two Cars traveling on converging lines needs consideration. In general how do we assure collisions never occur?

In developing a construct for the controller architecture needed for our problem, we will make two rough analogies. The first is the architecture for control and responsiveness used by all but the most primitive of living organisms. The second is the architecture used to control and drive today's roads. The computer system of course is a network—no, not quite a cloud—of computers, assigned a hierarchy of responsibilities, with a web of interconnects and sensors to feed it all.

A human being has a highly developed cerebral cortex, a central processor if you will, but retains decision-making in the brain stem for many functions. Examples of brain stem responsibilities include the impulse to breathe and the involuntary signals to initiate a heart beat, as well as the adaptive control of breathing and heart rates during stress, changes during sleep, temperature regulation, motor functions, touch, etc. Further responses are generated in the nervous system itself, most notably in the spinal cord, which controls numerous reflexes and rhythmic motor commands. In more primitive creatures basic functionality is more prominent, and the distribution of intelligence far more pronounced.

All but the simplest beings have sensors to detect status. We usually think of ourselves as having five. All have a communication link, the nervous system, between their sensors and the processors possessing information. To a EE (that's an Electrical Engineer or a double E) the transmission speeds of these links seem incredibly slow, barely faster than 10m/s, versus those of the EE's copper wire at somewhat faster than 108 m/s. One of the advantages to be exploited in the 3rd Generation Roadway is this factor of ten million.

A second analogy can be made to today's highways. The driver of a vehicle on the open road has dominant control over his vehicle. Viewed from the outside all control is centralized within the automobile. Rules are, however, communicated to the driver with paint on the road surface and various signs on the side of the roadway. At an intersection, the traffic light intercedes and exerts considerable control over activity. The light communicates commands by signaling one of three colors. With luck, the driver uses a sensor, his eyes, and responds appropriately. Downtown, the highway department monitors performance and issues sig alerts, freeway messages, and plans future improvements. Finally, the highway patrol officer controls errant behavior: issuing tickets, calling the tow truck, and enforcing "street legal" status for all by issuing mechanical warnings demanding compliance.

We will argue here that the 3rd Generation Roadway should have its intelligence distributed at several nodes. Various sensors, markers, timers, microprocessors, a multitude of PC-like computers and centralized computers will embody this largely electronic intelligence. As with the body where sensors for vision, hearing, smell, touch and pain are wired sequentially—first to the brain, brain stem, or spinal cord and then to muscular responses—Roadway and Rail Car sensor outputs will be communicated through hardwired and wireless routes to various electronic processors and relayed to motors, brakes and the like.

To introduce the concept of distributed control and as a foil to facilitate discussion of how this control might take shape, we should describe one possible construction and distribution of assigned responsibilities. Much of what is now technically possible has been developed in the past 10 to 20 years; and much in the way of improvement can be expected in the next 20. The Roadway system that would not have been possible 30 years ago, may not be possible today, will be possible tomorrow.

As a construct, let's distribute computer control into four nodes. The first node of control is the Car itself. The Rail Car is a ship on its individual journey and should be given as much autonomy as possible. In lieu of the driver, the Rail Car's individual computer will contain the Car's intended itinerary and communicates requests to each interchange and chosen off-

ramp at appropriate moments. The Car and its computer in communication with the Rail will control its individual movement and position itself with respect to adjacent Cars moving on the same Rail. The Rail Car is equipped with a very capable adaptive cruise control used to snuggle up or couple to adjacent Cars. If the Rail is passive, the Car's motor and brakes are of course in many senses the end result of the control process.

The Rail, as our second node, will perform functions similar to those of the Intelligent Highway. The Rail's markers define position. Timed sensors provide information about adjacent traffic. Thus the Rail can provide redundant information on the Car's speed, its proximity to other Cars, and can take control of the Car in certain situations. In analogy to the central nervous system the Rail also incorporates the hardware of both wired and wireless communication links. If the Rail provides propulsion its role increases. If the Rail provides synchronous power, it can also selectively accelerate or brake a Car.

Each interchange will maintain dominant control over travel on its structure. In lieu of the traffic light, this third node's intelligence will regulate Rail Car maneuvers on and near the interchange. The interchange will position Cars on each Rail by assessing the relative timing of approaching Cars, and then calculating the necessary decelerations and accelerations required to create open slots and resolve conflicts. In a rare pinch, the interchange can even deny requests to make a turn.

The fourth node of our control intelligence is a centralized, metropolitan computer which will assess traffic flows, redirect ensemble collections of trains to equalize loads, and generate detour routes to avoid downed lines and malfunctioning Cars. If heavily traveled high-speed lines converge to an urban core, this computer may provide control functions to interface lines. Other functions might include the dispatch of tow trucks, ambulances, etc.

We have argued that the division of responsibility just described is somewhat analogous to roles on today's highways. Roles played today by the responsible driver, the traffic light at a street intersection, and the performance monitoring and sig alert functions performed by the public traffic department and radio station today. But many functions have no analogies on the road. The control of a Rail Car train and a Car's responsibilities within a train have only vague analogs to a driver on a packed freeway. With such dramatically short spacings, the lightning-fast computer and electric motor responses are clearly advantageous to those of a human being. But at the same time, it's not clear that individual Car computers should have sole control of the job. Such a futuristic "freight" train might demand more thought.

Control at the on-ramp does have an analogy today in today's metered on-ramp which attempts to reduce clusters of cars entering onto a freeway. Control of vehicle timing and speed will be needed to merge individual entering Cars. And, like today's highway patrol officer, the on-ramps also may have the responsibility to reject Cars not judged to be "street legal".

SENSORS: A WORLD OF CAPABILITY

Fundamental technology can enable engineering approaches which may have bordered on science fiction in the past. Individual inventions, once soundly reduced to common practice, often can be combined with other solutions to address more complex problems which once were intractable or inconceivable. In our case consider the Aerospace Corporation investigators looking at PRT (Personal Rapid Transit) solutions in the 1970s. Realize that they didn't know what a PC was, had little hope of today's digital communications, and could only discuss the basic physics which promised the sensors outlined in this section—sensors which are now mature technology.

This section will discuss these many sensors. They are all engineered devices which translate observable phenomenon in the world around us into signals we can see, use, or process into useful responses. A human is thought to have five senses, composed of five sensors and a brain which typically evaluates and generates an appropriate response. Out of modesty the engineer must admit that in the description which follows, most available sensors resemble only one of those five senses—that of sight, which is the ability to remotely sense using electromagnetic radiation. Only limited use will be made of magnetic sensors, perhaps analogous to touch. Likewise, with one notable exception, only limited use of acoustic radar, or Sonar, perhaps analogous to hearing, is proposed.

And all evaluation is electronic. This approach will be adopted because, today anyway, signal processors are usually electrical. In digital form, they are fast and they are reliable. The archetypal processor, of course, is the general purpose computer.

In the next section we will use a suite of our sensors, and a distributed electronic brain, to construct viable methods allowing automated control to replace human control. As with any machine, we wish the benefits of precision and speed in place of the variability and slowness of human responses.

The first four sensor types that we will discuss detect the presence of electromagnetic energy emanating from a remote source. Electromagnetic energy, quantized into little particle-like entities called photons, happily propagates through any medium devoid of other particles, principally electrons but especially free electrons, capable of interaction. Air, with its electrons all tightly bound into molecules, allows relatively undistorted propagation as long as particles such as clouds, fog, dust, or smoke are not added. If one says "visibility is 20 miles" he means that 10% of the photons have successfully propagated that distance, and that the scene has 10% of the contrast would have if viewed up close.

OPTICAL SENSORS

Optical sensors are responsive to electromagnetic energy quantized in the same region as that to which the human eye responds. Your eye, cleverly adapted over eons of evolution, responds only to electromagnetic energy quantized into energies that differ by less than an octave—a single factor of two. Clever, given that our local star's radiance is energetically peaked at exactly that same octave! The other sensors of this section, in contrast, respond to energy quantized over a range of about a million.

Because of the relatively high energy of each quantum, optical light can by very accurately focused, allowing the sensor to distinguish, resolve if you will, light coming in from slightly different angles. Thus patterns are easily discerned, and images are generated.

The first optical sensors were invented in the 1830s by Louis Daguerre and William Talbot who noticed that small, colloidal, 100 nm particles of translucent silver halide, when hit by about 1,000 quanta of optical light, could be rendered into black silver oxide. Controlling their size could change the range over which they turned black, and a mixed set of particle sizes could be used to produce gray.

In the 1960s semiconductor physicists demonstrated that photons could transition electrons and thus trap them into microscopic "buckets" whose electrical voltage would radically change in response. Voltages corresponding to only one, two, or three photons could be detected and recorded. In the 1970s, succeeding after hundreds of millions of dollars of R&D were spent for the benefit of the spy vs. spy world of the Cold War, Kodak shocked the technical world in producing four million of these "buckets" in an array complete with ability to "read out" the status of each "bucket" to some other form of memory. In 30 years this technology has been adapted for the commercial world, and focal plane array (FPA) cameras are now advanced and inexpensive. Indeed in time, cameras with arrays of four million devices cost $1,000, then $400, and are now but one cheap feature on your cell phone.

INFRARED SENSORS

Semiconductor sensors for infrared energy can be made in much the same fashion as those for optical FPAs. They cannot resolve the elements of a scene into pixels with the same finesse as an optical sensor; but they have at least one huge advantage. They respond to photons that the eye cannot. Whereas only solid surfaces at extremely hot temperatures emit substantial numbers of optical photons, solid surfaces at room, or anything close to room, temperatures primarily emit infrared photons. Thus while optical sensors must detect light, usually reflected off surfaces, that originated from an extremely hot body—and there is only one large such natural body within four light years of so from us—an infrared sensor can detect direct emanations from earthbound sources. It can see in the dark.

So-called Forward Looking InfraRed, FLIR, instruments are well developed for numerous applications. Autoliv, an international auto parts supplier headquartered in Sweden and incorporated in Delaware, vends a night vision aid said to have a range of 500 m. Although Autoliv's unit is passive, competitors vend active systems to illuminate the scene and enhance the image with reflections. FLIR Systems Inc. has an active system used by BMW. The system allows drivers to "see" further ahead without visible illumination blinding the oncoming driver. A number of other high-end model cars offer the systems as an extra.

RADAR

Initially developed during WWII, primarily at MIT, RAdio Detection And Ranging, or Radar, has found many diverse applications. As with an optical sensor, Radar detects a signal reflected from an object. But unlike an optical sensor which waits for the sun to rise, the Radar's unit generates the signal to be reflected. Thus Radar can measure a "target's" range by measuring the time required for its signal to return after it bounces off the target. By measuring often, recording change in the range, it can also measure the target's velocity relative to the sensor.

An uncooperative target can be shaped to reduce its reflected signal many orders of magnitude if it wants to move with stealth. A cooperative target can employ shaped surfaces, the inside corner of a cube works very well, to enhance its return signal and/or to identify itself. Images can be created using Radar by sending out sequential focused signals in slightly different directions and sequentially recording the reflections in two or three dimensions. Moving the sensor can be employed to increase the image's resolution. This last technique is known as synthetic aperture Radar.

Advances in electronics have enabled very small units to preform admirably. Witness the hand-held unit by which your local police officer monitors your passing speed. Notice the accuracy with which the roadside unit posts your speed as you drive by. Or the speed of Tim Lincecum's slider and Roger Federer's serve.

The auto parts supplier, Hella, known for its lighting systems, has developed a radar which detects objects approaching rapidly from behind for distances of up to 200 feet. Another Hella unit warns a driver of objects in the adjacent traffic lanes to help avoid collisions. Hella uses a 24 GHz signal. A number of manufacturers have customized similar units for both applications.

LIDAR

Light Detection And Ranging, or Lidar, works by many of the same principles as Radar, only at nominally optical frequencies. Lidar can achieve spatial resolution of a scene approaching that of an optical camera. Lidar's relative speed readings are accurate as well. Advances in semiconductor chip lasers now allow small inexpensive units. Light emitting diodes (LEDs) and lasers, discoveries for which several Nobel Prizes have been awarded, are now available for your flashlight or household light socket. Then again, the incandescent light bulb would probably have won a Nobel if it had been invented later.

If a light beam is modulated, either in amplitude or wavelength, and either in analog or digital format, the beam can be coded with respect to time. Since light travels about a foot every nanosecond, if the beam can be coded to within a tenth of a nanosecond, the path length to and from a target can be measured to within one half inch. Such is possible today.

SONAR

One should note that Radar has trouble reading signals when the target is very close. In basic terms, the transmitted signal comes back too fast—like at the speed of light. Sonar, which reflects an acoustic signal off its target, has a major advantage for close-in detection and ranging. Using sound waves traveling in air, the receiving microphone has a million times longer to wait for the return signal. (Sound travels at roughly 300 m/s, light at 300 x 106 m/s.)

Toyota, in an optional extra offered for its Lexus luxury vehicle, uses Sonar as an automated parking aid. Autonomous vehicle control at distances on the order of a foot is readily achievable. As a candidate for docking, train assemblage, and dis-assemblage, this sensor has great promise.

UPC/RFID

The Universal Product Code, or UPC, has allowed the identification of millions of individual product types by using black and white bars as a code and an optical reader as a scanning sensor. As anyone in a grocery store check-out line can tell you, a direct line of sight is needed to identify. But UPC is inexpensive and has a very low false ID rate.

Radio Frequency Identification, or RFID, does not require line of sight access, and is widely used to track packages. A semiconductor chip can produce an identifying response to a pulsed radio frequency probe. Pulsed probes work even if dust, mud, another package, or plastic encapsulation covers the chip. Recent successful efforts to reduce chip costs to below a

penny means RFID on a box of cereal is not far off. Means of attaching a small antenna as a coupler to the chip drives what costs remain. Such RFID would continue to operate nicely as mud splattered on the vehicle's bumper.

GPS/RINGERS

The Global Positioning System, or GPS, is a well known approach enabling a set of electronics to determine its own position almost anywhere on the face of the earth. The unit's position can be tracked by sending that determination by wireless means to an appropriate website. The accuracy with which that position is determined varies with the number of satellites in view, the time allowed during determination, the sophistication of the electronics employed, and the coding used by the satellites. The idea and the satellite systems were developed in the '60s and '70s while many of the best known commercial applications were developed in the '90s and '00s. Units are now deployed in automobiles.

"Ringer" is not a term for a major type of fundamental sensor but rather a term used here for a type of sensor which might be used on a Rail line. Placed on a Rail line, a Ringer would briefly record how long it had been since the last Rail Car went by. An optical or magnetic switch would do. Conceptually a communication would begin if a passing Car rang a conceptual bell whose decaying amplitude or frequency chirp would record the headway available to the next Car passing. The communication would be completed when the next Car read the headway time available. The concept is completely analogous to the way a red light alerts a freight train today that another is ahead.

DISTRIBUTED CONTROL: CHECKS AND BALANCES

Now armed with some knowledge of sensor characteristics and the state of the art, we are now equipped to discuss how they might be employed in controlling Rail Car traffic. This section will discuss the use of individual sensors in the many functions required. The discussion must lead to a description of the overall performance and reliability of an integrated metropolitan 3rd Generation system.

We should begin by discussing the control of traffic proceeding down a single line. To do so, we will employ three independent sensor systems: the first an asset of the Rail Car, the second a co-operation between Rail Car and Rail based sensors, and the third an asset of the Rail itself. Safety will be assured by some redundant combination of these three sensors.

Radar should be one's first choice for collision avoidance. Radar can sense the range or distance, between the sensor and a reflecting object. Radar can also sense how quickly range is changing. Think of it as the Rail Car's sensor for adaptive cruise control. Sensing a cooperative Rail Car with a reflector embedded in its license plate ahead on a straight Rail is a relatively simple task compared to today's highway problem. Radars do have troubles at very close range, and for train docking and separation sequences other sensors might be preferred. An optical digital camera could be employed along with patterns for recognition again placed on the license plate. The size of the measured image would determine range. Following Toyota's lead would lead to the use of a sonar system for docking.

For redundancy aimed at achieving zero failures, the Rail itself would signal headways (in time) with a Ringer, and its output compared with that of the Car's range sensors. To grossly misuse a phrase that has taken on some weight in technical jargon, consider this electronic conversation in "Machine Language" using redundant control.

Ringer on Rail (R on R): "You have Car in front by 0.2 s. Speed equals yours."

Car: "Roger—my radar reads same."

R on R: "Green Light."

or

R on R: "Car in front by 0.2 s. Speed approaching -0.5 ft/s. Please brake."

Car: "My radar sees no Car!"

R on R: "We are taking control. You are programmed to exit."

If the two sensors simply disagree on the separation distance or speed differential, different protocols might be used. Arbitration becomes possible with a third sensor and, given the critical nature of collision avoidance, this would be good. If the Rail is providing synchronous power, it can also selectively brake. (The Rail giveth, and the Rail taketh.) Thus the Rail itself, might become an independent source of adaptive cruise control for individual Cars. If synchronous power is not used, it is more difficult to see how the Rail demands control, other than to reduce power.

Earlier we suggested that the Rail provide a laser-based guide line to aid the Rail Car's suspension system. Providing path information between adjacent posts in a very straight line, the laser can also provide distance information. If an intelligence node on the Rail wishes to determine the position of every Car between two posts, the laser can act in a Lidar mode with each Car reflecting a small fraction of the beam. In the optical community, it would be said that each Car placed a "half-silvered mirror" in the beam's path. A small mirror set on today's side view mirror would do. If the posts held a curved section of Rail, the laser would need to be scanned. Thus the Rail, independently, would be able to determine the position of each Car to within an inch.

The interchange has its own intelligence. At interchanges the responsible controller would need knowledge indicating which direction each approaching Car is programmed to choose as its exit. In addition the interchange computer needs to know each Car's precise position and the timing of its trajectory. To obtain this information the interchange computer can (1) communicate with the approaching Car for the information, (2) make inquiries using UPC or RFID tags on individual Cars, and (3) augment that information using a ranging radar/lidar of its own. With the determination and communication of such information achieved, a Car can be turned. The steps within such turns will be discussed in the next section.

UPC or RFID can also be used for counting Cars and that information sent to the metropolitan control network, our fourth node of intelligence. Congestion control, detours, damage assessment could be affected with the information available.

If you have emotional problems with governmental control, regulations, licensing, and permits in general, imagine this concept. Remember today's little yellow "check engine" light, the little light that seems to turn on capriciously when something might, or might not, be wrong. The light we all ignore. If it turns on in your Rail Car, you're out of here! No doubt spat out of the Roadway on the wrong side of town! An approach to assure all Rail Cars are operating "street legal" to be sure, but if the yellow light isn't more reliable than today's, howls of protest will be heard.

TRAFFIC ON A SINGLE LINE

The control functions for traffic flowing along a single Rail are principally those of collision avoidance and the assemblage, management, and dis-assemblage of trains.

To recount a driver's four primary responsibilities on the familiar landscape of a freeway, let's list them, in no particular order: (1) Avoid collisions when changing lanes. (2) Stay on the road and in your lane. (3) Don't hit the car in front of you. And (4) Maintain speed. Actually these responsibilities do have a particular order. When applied to an automated Rail, they are arguably in order of easiest to hardest.

(1) Lane Changes. There are no lane change maneuvers envisioned. Simply stated that's because all Rail lines are envisioned as single track. There are merging and exiting functions required, but they occur only at specific points and will be considered separately. Lines which are single-track should have sufficient capacity, 30 to 80 thousand Cars per hour, for any location. Other lines may have to be built in fairly close proximity, but would assuredly be using separate right of way.

(2) Stay on the road. As a task for the control computer and centralized system this requirement represents only minimal difficulty. As a mechanical requirement for the "hook" on the Cars and the design of the Rail, the task obviously merits some careful thought. But once a safe, utterly reliable, and cost-effective mating solution is in place, Cars won't be "drifting off the road" as they are today.

(3) Don't hit the car in front of you. Collision avoidance radar is an actively researched topic for today's road cars. Difficulties arise given the wide set of scenarios incurred while driving an open road. Stationary

objects, say, a bridge abutment which appears dead ahead of the car before the driver initiates a turn on an unknown road presents a typically difficult scenario. By contrast all objects on the Rail are cooperative "targets" in radar terms, and the vehicle is following a known path either in a straight line or on a standardized-radius curve. The Radar's task is to measure relative speed and distance and to allow the appropriate adjustment. Adaptive cruise control for today's highways is very close to what is needed here.

Snuggling up to the next Car, the maneuver called "docking", is an essential function in the formation of a train. The maneuver as seen by the engineer is similar to collision avoidance, albeit slower and more delicate. Related devices are presently in limited commercial production for automated parking assistance. These short-range Doppler radar and acoustic schemes are sensitive and could be low-cost.

Docking requires a number of technologies. But a chief attribute of the overall approach must be a very rapid response time of the motors and the Car's acceleration executing a decision to slow or speed. Any excessive delay will increase the difficulty of docking. (A B747 engine at idle has an awe-inspiring seven second delay from the controls, and if you ever get a chance to spend time on a flight simulator and "fly" a big jet—do so. But don't expect to land successfully!) So it might be wise to make all the electronics for docking a unit on the Car. Ranging radar, closing algorithms, and electric motors all respond rapidly. Electric motors typically have high torque; the Car is light; and thus the Car's movement should be responsive. Ranging radar and Sonar are technologies approaching some maturity as an automobile parking aid. A note of caution should be raised by those who know the delicacy and difficulty of docking spacecraft.

(4) Maintain Speed. Well, the computer controls that. Uh, whoa! Not so fast. In normal conditions Rail speeds will be set and Cars will follow that speed with a system akin to today's cruise control. But three scenarios involving failure must be considered. And we will consider these scenarios in the three paragraphs to follow.

What if a Car just stops? How is the thorny issue of a Car's mechanical breakdown handled? And being on a Rail line really redefines the term "stuck in the middle of traffic". A worse case may occur in the light traffic scenario, in which example a Car might come to a complete stop before the next Car comes upon the scene. If this were to happen, the control feature for the oncoming Car, or several Cars depending on timing and traffic density, would be tasked to slow almost to a stop, dock, and push the disabled vehicle to the nearest exit. Remember the Cars are designed for this bumper mode as part of their train compatibility, and the system is not dependent on a particular driver's skill. The computer automatically handles it in this unusual situation.

What if a Car gets stuck? A particularly difficult scenario occurs if the Rail or Rail coupling mechanism is damaged and freezes a Car. Here the damaged Car will need to be plucked from the line. Something akin to a tow truck would need to arrive. Only a tow truck with a small crane. Or a so-called cherry-picker or bucket with a 1,000 lb capacity. It should arrive with the alacrity of today's paramedics or fire department. Also keep in mind that the metropolitan computer has tremendous re-routing capabilities while this action is occurring. Again the desirability of completely reliable methods of Rail attachment is emphasized.

The danger of actual collision occurs if a Car can't maintain speed and the following Car has a coincidental failure of its radar. The reason to maintain a redundant Ringer sensor for this scenario is clear. In the safety discussion elsewhere in this book, the effects of such collisions are discussed.

The control of a train will involve several considerations. Principal is the requirement to maintain stability within the contiguous configuration of the Cars. That is, in all probability, a statement that positive pressure must be maintained at all times on each set of couplers connecting the Cars. Remember that the trains we know today are pulled or pushed from one end, have passive railroad cars, and have couplers between cars whose multiple functions include maintaining proper separation. Carefully regulated power coming from each Car may be required to avoid momentary jostling between Cars. Careful power-control and coupler designs may be needed to insure the smooth flow and ride that drivers will expect. For the first Car, and to a lesser extent, for the first few Cars, active control isn't necessary as wind resistance will require an additional push to achieve the higher speeds inherent in the train's configuration. In practice the sum of the powers added by the Cars in the rear may be sufficient to maintain train cohesiveness. Short trains might limit the potential problem.

Braking a train presents the complementary problem. Think of a train going downhill. Remember the Rail has a very low coefficient of friction, the long thin train a very low wind resistance, and thus the train will need braking on even modest downgrades. Braking of only the front Car would lead to tremendous pressure on the bumpers of the front Cars, and braking

protocol may demand distributed braking action throughout the train length. On positive notes, a 10-Car train weighs no more than a large SUV today, and will incur forces no larger. The braking power available from the sum of all the Cars is more than adequate for the task—and far superior to the relative braking power of a conventional railroad train. Obviously, estimates had better be below the acceptable, and the more the better.

MERGING TRAFFIC

The merging of two automobiles as they approach a single lane is a carefully orchestrated dance. Anticipation, coordination, adjustment, timing, and speed all come into play. For two drivers at a freeway on-ramp the dance proceeds sequentially and the protocol is understood by both drivers. The entering driver is immediately pressured to achieve freeway speeds. The driver already on the freeway anticipates the merging requirements and executes one or more of many options. Sometimes he scoots over to another lane, a maneuver we can't achieve on the Rail. Assuming he doesn't scoot over, one or both freeway drivers now make several adjustments, all of which involve adjusting vehicle speed. If speed is adjusted early enough it affects the relative positions of the two cars at the eventual point of merging. With skill the new relative positions are appropriate. With better skill, or luck, the two vehicles are now traveling at the same speed and no further adjustments are necessary.

For Rail Car traffic, a gap in traffic is smoothly created by either advancing or holding back one or more Cars. Whole trains might be moved. The merging Car must be presented where the Rails merge at the time the gap appears. The exact relative positions have been known, and the adjustments made, before the merging zone has been entered. With automation, precision and 7-foot-long Rail Cars, the gap created might be no more than nine feet.

Before we begin, it is important to note that all maneuvers to be characterized require speed changes using relatively underpowered vehicles, and we should review. In general the local lines are proposed to operate at 40 mph, the local interchanges at 25 mph. The metropolitan lines operate to 100 mph but slow to 80 mph near interchanges. Metropolitan interchange turns occur at 60 mph. At these high speeds, individual Cars can decelerate rapidly, but must mate with a train before accelerating back to speed.

Rail line merging will occur at on-ramps, off-ramps and at interchanges. All three sequences occur on local lines at low speed but only one sequence occurs on the metropolitan high speed lines. Thus four scenarios need consideration.

Simplest first. In order for a Car to exit a line when configured as part of a train, it must first be separated front and rear from the others. If on a local line, it must also be slowed to 25 mph. If in a train, or if another car is trailing closely, the trailing Cars need to be slowed as well. For most local lines, operating in most conditions well under capacity, these two requirements will be rare. If the controller slows a Car on a 40 mph line to 25 mph at some graceful deceleration, say -0.5 g, 15 feet needs to be cleared to the rear. At an aggressive -1.0 g, only one Rail Car length needs clearing. Further deceleration to a full stop at -0.5 g requires an exit Rail length of only 80 feet.

Over what minimum length does merging occur? How disruptive is merging to through-traffic going straight? The simplest example is that of a Car at an on-ramp which wishes to gain sufficient speed to join the line. Let's presume the speed for local lines near on-ramps and interchanges to be 35 mph. As powered, the Rail Car takes 3.5 s to accelerate from 0 to 30 mph, or approximately 4.8 s to 35 mph. Possessing this acceleration the Car will take approximately 75 m to merge at exactly 35 mph. During its acceleration the car will lose about 25 m to a car steadily progressing at 35 mph, and would require a lead of that distance if it were placed on the line at a dead stop. Thus the on-ramp designer has three variables in play: various approach lengths up to a full 75 m; gating any Car at the on-ramp so as to improve the timing of each merge; and slowing traffic at all on-ramps. Some combination of the three approaches would probably be optimum. Simply gating Cars at short on-ramps would be adequate for most traffic loads.

The same analysis also works for interchanges. Cars must exit a line as they enter an interchange or exit an interchange to enter a new line. Obviously the most problematic is the Car entering a line from an interchange at 25 mph. In heavy traffic, Cars could be slowed to near 25 mph at each local interchange. In all cases it should be noted that the separations required are somewhat longer than quoted in that the Cars have finite width and the two Rails have to separate somewhat before clearance is achieved.

Merging operations create another difference between the operation of local and metropolitan lines. As conceived here metropolitan lines have

buffer zones facilitating merging functions. At interchanges these functions include acceleration and slowing of Cars before and after the turn. But merging zones also provide time to adjust the position of Cars on both the receiving line and the merge lane. They possess latency (the ability to hold a few Cars) should that maneuver be advantageous when a long train is passing. Without merging lanes available on local lines there may be a bias against forming long trains. Although technically it is just as feasible to create a gap in a long train as in a short one, more Cars are involved in the maneuver. It should be noted that long trains are not needed at local line speeds and density. In fact, trains provide little aerodynamic advantage at low speed, and might not be used at all.

A single Car's maximum speed is 60 mph, and as single Cars are certain to request turns at metropolitan interchanges, the speed limit for through trains could be set at 60 mph at interchanges. It will take 16 s and 1,700 feet for 10-Car-long trains to re-accelerate to 80 mph at which time they will have been delayed 2 s on their journey—an acceptable delay every five miles or so.

TURNING TRAFFIC AT INTERCHANGES

The steps required to turn a single Car are several. The Car must be decoupled if in a train. It must be slowed to an appropriate speed, in concert with any Car or set of Cars behind. The Car itself presumably has a pre-programmed Doobie positioned to transition the Car to the right- or left-turn Rail. The Car will follow a designed speed profile on each standard interchange. But for individual scenario the interchange computer will command further slowing if required to match a slot on the second line. Meanwhile, if necessary also on a case-by-case basis, the interchange has slowed travelers on the second line.

Armed with a working knowledge of the procedures required for exiting and merging, we are prepared to examine the many maneuvers occurring at Roadway interchanges. First, realize that all eight turning maneuvers, four left and four right, involve an exit and a subsequent merge. These eight routines must be coordinated with the traffic flowing on the four straight through lanes—one each, north/south/east/west.

Thus control extends over the 12 possible paths a Rail Car might take. Fortunately coordination primarily involves the timing of Cars on paths taken two at a time—that is, timing two Cars about to merge as their paths converge. There are eight such paths of interest. But secondary problems are incurred by other merge sequences which are affected by the primary merging sequence under control. The simplest such scenario involves the timing of trailing Cars which are slowed before entering the interchange but are proceeding straight. Thus preparation for the first merging affects the second set of mergings at a different location on the interchange.

Consider the details of one of the eight pairs. The interchange will begin the necessary maneuvers by instructing the turning Car to decelerate to an appropriate speed. If the Car is closely followed by others, they, too, may be instructed to slow. If the Car is in a train, the Car will be instructed to decouple and, to comply, Cars following will slow. The timing of the deceleration is such that the Car is delayed into an open slot as it merges onto the second line. If the second line has a solid train passing, some Cars on that train or the entire train might be slowed. Remember trains are limited to five to ten vehicles in length, and so the number of Cars asked to delay even in heavy traffic is few. Delays will also be measured in fractions of a second.

CONGESTION CONTROL

While the elimination of congestion as we know it today is a strong motivator for the 3rd Generation Roadway, the reader should realize that its capacity is indeed finite. Some of today's urban areas are fantastically dense, and if they were to adopt the Roadway, these areas might immediately incur congestion. Other areas of the world will adapt, grow, and pressure whatever new transportation limits exist. Thus, it would be good to plan. Grid density needs consideration. Interface schemes need consideration. The routing skills of a centralized metropolitan controller should be characterized. Within limits a controller could distribute loads onto alternative paths with minimal delay. That distribution would be a compromise between equalized loads and the small delays experienced by those on alternative paths.

7

ANTICIPATING THE COST

Estimating the price of a proposed product — one yet to be developed and yet to be precisely defined — is a difficult task. This chapter will examine metrics for pricing a product which is a U.S. national 3rd Generation Roadway servicing half the U.S. population. It will do so from as many angles as possible thereby illustrating both the uncertainty in the estimate as well as its most probable value.

Specifically, as major categories, both acceptable price and estimated cost will be examined. Maximum acceptable price will be defined using four different metrics, each aimed at answering what society should reasonably pay. What price still promotes the common good? At what price will bond issues still be passed? At what price will the politician still get reelected? Estimated costs typically come from the contractor, the engineer, or the architect. Give me a quote! With the many unknowns and ill-defined components of the 3rd Generation Roadway, obviously gross estimates are the best that now can be made. But with that caveat in mind, realize that one should shine light on such a vital subject as soon as possible.

An acceptable price for Roadway will be found to be $25 m/mile. Realize that both high-speed Roadway, with more stringent requirements, and more common local Roadway, with more lenient requirements, are averaged into this estimate. $25 m/mile is consistent with high-speed Roadway at $40 m/mile (think freeway costs) and more common local Roadway at $20 m/mile (think boulevard costs).

The chapter will conclude that the most probable expense would be $2.2 trillion in 2010 dollars, of which $1,000 billion would be for 40,000 miles of Roadway at public expense and $1,200 billion would be for the private purchase of 75,000,000 Rail Cars. The Roadway would be built out and expensed over a 30-year period, financed by bonds sold at 6%, with the Cars expensed over 12 years, leading to an attractive, imputed annual Return on Investment of 23%. The value of 23% results from the assumption that return can be expressed as the monetized sum of savings in users' time, gasoline, lives, insurance premiums, and that ½ of all Rail Car buyers forgo purchase of an ordinary road automobile. No account is made for the benefit of reduced parking expenses, or decreased burden on our 1st and 2nd generation infrastructure.

An immediate pressure on one who proposes to develop a concept is that of estimating cost. How much will it cost to own this thing? And for the engineer/scientist this pressure quickly translates to one of developing metrics for estimating cost. That is, the engineer is asked for supporting arguments that his or her team can build the complete, functioning product for the cost quoted. Price quotes from the steel mill, from the subcontractors, estimates of the number of lines of computer code to be written, become, one and all, bases for estimating cost. In parallel, as for this concept, the architects and legislators promoting implementation will be pressured to develop metrics roughly defining acceptable costs. What is the maximum price society should pay for this item? The numbers provided by the engineer and the numbers quoted by the legislator become grist for the debate. Estimates well below the acceptable would be welcome.

Since we already have automobiles, the definition of maximum acceptable price for a Rail Car is relatively easy: no more expensive than what we have today. Of course, this product will be more useful than expected extensions of what we have today, but we'll chalk that up to progress.

For a new automobile, we all can quickly recite the national consensus for acceptable price. It's clear that, when presented with product versus price, Americans find a consensus answer. No one buys a Yugo or Tata and few buy a Ferrari, but 15 million purchases per year are made at prices between. For most, the answer for what's an acceptable price for a new automobile is: $10,000 to $12,000 for something really basic, $30,000 to $40,000 for something substantial and with some luxury.

But what would they pay for a mile of Railed Roadway?!

ACCEPTABLE COST

WHAT'S AN ACCEPTABLE PRICE FOR A MILE OF ROADWAY?

Let's generate a few ways of estimating costs that would be acceptable, and highly competitive to what we're doing today. First, we could make an argument to the individual driver. Today's driver spends a lot of money for transportation using his/her personal car. A roadway, though public, shared by all, and funded by taxes, should have a per-capita cost commensurate with the other items in that driver's budget.

Second, we can compare alternatives, that is, compare the costs of the new Railed Roadway to a proposed freeway somewhere that some community desperately needs. Maybe the Rail could cost upwards of 50% what that freeway would have cost. This latter comparison has at least two flaws. The nation appears not to able to afford many new freeways, and secondly, has no intention of building as densely as the 3rd Generation Roadway would.

Alternatively one could assume that a certain percentage of the nation's transportation budget should be properly assigned to those individuals who will benefit as users of the Rail. Redirect that money to the new system.

A fourth and final look might be to determine what time and money the nation would save. Unfortunately, the savings inherent in a new technology seldom justifies an expense. Society either adsorbs the new approach for higher productivity or adsorbs it into the daily routine with intangible rationale. Thus, yielding to the way the world works, this last method may provide only a gross upper limit to a cost that would actually be funded.

For clarity, since the architect and the politician will be promoting national or regional budgets and the engineer wants to estimate cost per mile of Rail line, we need to ask how many miles the nation needs. To wit, earlier we worked out that the central section of the greater Los Angeles metropolitan area, to be fully serviced, will need slightly over 2,000 miles of line for its 8,000,000 people. We also estimated that Rails should service urban/suburban areas resided in by half of all Americans, or 150,000,000 people, a population 19 times that of L.A. Presumably, as an approximation, an urban America 19 times the size of L.A. will need 19 times the Rail line, or 40,000 miles.

No Long Pole

Let's ask the individual driver. A common method of assigning acceptable cost in any project is to compare the cost of the item in question to the other components within one's total budget. No one item can eat the entire store. No item should be neglected. Each item's cost at maximum must seem reasonable compared to the whole, or its cost should be adjusted. There should be no long pole in the tent.

For instance, given an expected level of family income, 25% seems a reasonable percentage to spend on housing, 20% on food, etc. When building a house the same process should allocate to the kitchen an amount roughly equal to that for all the bathrooms and maybe that special luxury room you always wanted. For the affluent this process might mean compromising between the Sub Zero fridge, the Viking stove, or the granite in the kitchen, eliminating the fourth bathroom, and choosing between the infinity pool or the backyard cabana. For the less well-off, in the wealthy industrialized world anyway, choices will center at a different level—dishwasher or not. In the third world, maybe—running water or not.

The American standard of living has resulted in the aggregate driver setting an a national average per-capita budget needed for his personal transport by automobile. We assume the budget is rational since "everyone does it." One well-established individual expense within a driver's transportation budget is that for the private automobile. The automobile's purchase price is but one component within a total budget which also includes vehicle maintenance, fuel, his or her time, expected losses, and a piece of the roadway to be shared with the public. Average maintenance costs are published, as are fuel costs. The cost of time has been monetized in the introduction to this book. We can monetize his expected losses as covered by private insurance.

In the U.S., the national average price for a new car, SUV or light truck is running at about $28,000. 16 million on average are bought per year. Ignoring the cost of trading these vehicles as they trickle down among the 200 million active U.S. drivers, the average driver is effectively sending $2,240 per year to "Detroit" (2,240 = 28,000 x 16/200).

Car maintenance averages $650 per driver per year. Fuel costs roughly $2,000 for the average 650 gallons tabulated by U.S. DOT, assuming we're paying $3 a gallon—which, of course, is anybody's guess by the time you're reading this. Insurance costs roughly $820 as estimated by the National Association of Insurance Commissioners. Our subtotal now is $5,700 per driver and $1.14 trillion nationally per year.

Both of these last numbers are conservative. The Auto Club of Southern California, a unit of the AAA, adding in a number of smaller costs, estimates an even higher cost per driver—$8,120. And of course we will now completely ignore the implied expense of the roughly $12,000 for the driver's 500 hours on the road. But let's settle on $7,500 per driver here which times two hundred million drivers multiplies to the pleasantly round value of $1.5 trillion dollars per year. One should now grasp why many think $100 billion per year for public roads is grossly inadequate. That $100 billion is only $500 per driver. Hey, without a road, no car is going anywhere.

This book proposes a roadway used by about 1/3 of all American drivers for the majority (10,000 of their 14,000 miles) of their driving. If one argues a "no long pole" budget for each driver who will be using the roadway, arguably the roadway could command an additional 30% when they are actually on the Railed Roadway. Thus, the capital fabrication and maintenance budget for the 3rd Generation Roadway would be set at $1,600 per driver per year (30% x 10/14 x $7,500). Given 75 million happy drivers, that's $120 b/year. With a 30-year build-out for the 40,000 miles of Roadway required to service these drivers, we arrive at a budget of $90 m per mile.

What's an urban freeway cost?

Not an easy answer! Huge variations exist. See for example the comprehensive study results from the State of Washington DOT, on line at the time of this writing, summarizing the cost of many freeway and other roadway projects. The Texas Institute of Transportation at Texas A & M also has a multitude of examples.

Where nature is demanding or right-of-way expensive, costs are enormous. Examples of nature-induced cost include Boston's Big Dig at $188 m per mile of lane, Seattle's Hwy 99 freeway at $240 m per mile of lane, and San Francisco's Bay Bridge earthquake-induced redo at $70 m per lane mile. Beware the unit of lane mile. Then go ahead and multiply these dollar values for lane mile by the number of lanes on these freeways for the staggering price per mile of highway!

Two Los Angeles projects exemplify right-of-way expense and civic objections to the devastation. The I-105 Century Freeway just south of Los Angeles for which right-of-way was acquired in the 1980s and was largely constructed in the early 1990s runs 17 miles and cost roughly $2.3 billion. If built today, the 105 would easily cost three times that amount. Its run

includes four major high-speed interchanges, two with a fifth level for "flying ramp" commuter lanes adding to the conventional four-level stacked design. The I-105's roadbed alignment through almost continuous residential housing tracts stirred epic debates and ended up being placed down Imperial Boulevard and not its namesake boulevard. A problematic section subject to flooding was built as a trench to abate noise and placate a hostile neighborhood (3 x $2.3 b/ 17 miles = $406 m/mile).

The completion of the I-710 Long Beach Freeway just east of Los Angeles is presently generating cost estimates at $750 m per mile. Though it is to be routed through relatively flat terrain, it may be built as a tunnel to avoid neighborhood objections. No wonder so little 2nd generation urban roadway continues to be constructed in the 21st Century.

On the open road, with nothing but flat earth, freeways without interchanges cost far less. An example of low-cost road construction is a six-lane project completed for $6.6 m/mile in 2000 improving I-90 in the Paloose region of eastern Washington west of Spokane.

An example of freeway construction in mixed suburban and largely open countryside is provided by the 28-mile extension of I-210 in San Bernardino County just east of Los Angeles. A county-wide ½ cent sales tax largely funded the eight-lane construction undertaken from 1998 to July 2007. The road and three major interchanges cost $714 m. The interchanges still require several high speed flyover ramps to be built. $25.5 m per mile.

Another California project under construction is the Sunny Side Gateway Project, a segment of SR 52, within a fully suburban area of San Diego County. With two major interchanges to connect its ends to existing freeways, the 3-mile long 4-lane freeway has a construction budget of $255 m. It is of note that the middle mile of the freeway, an easy stretch with only two street overpass bridges to complicate construction was contracted out at $27m. Subtracting out the cost of the two bridges (2 x $8m?), construction costs approach the example from the Paloose. But the cost of obtaining right-of-way has been $226 m. This huge number results from the lot by lot purchase of land creating a minimum clearance for the 300 ft. fence-to-fence spacing a freeway typically needs. California must have paid on average $238,000 for an average 50 x 100 foot lot. The present estimated total cost of the entire project including this and that is $600 m. Or $200 m per mile.

Upgrading existing freeways is equally expensive. A typical project cost might be that associated with the conversion of the 4-lane Guadeloupe expressway to the 6-lane Guadeloupe freeway in San Jose, California. In 1998 the 3.1 mile six-lane freeway which includes two interchanges, 3 under-crossings, and some riparian environmental repair was constructed for $225 m or $73 m/mile. In 2010, adding a single HOV commuter lane to the northbound I-405 through Sepulveda Pass, a distance of 10 miles, is projected to cost $1,300 m—or $130 m per mile.

The widening, streamlining, and lighting of major 1st generation streets isn't that cheap either. The just completed conversion of Santa Monica Boulevard into a more efficient 6-lane street was budgeted at $68 m for a 2.5 mile stretch east of the I-405. The upgrade of Rosecrans Avenue, on a 1.5 mile stretch just west of the I-405, all things included, cost $50 m.

Interchange costs also vary according to location. An I-70 interchange in rural countryside near Dayton, Ohio cost $140 m. The recently constructed I-215/60-91 interchange in suburban Riverside, California cost $381 m. The Marquette interchange in urban Milwaukee, Wisconsin cost $810 m.

Numbers from yet another urban source might shed light. Is a light-rail metro line society's substitute for a freeway? A solution for an equivalent need? Go back and review the cost numbers in the section on public transportation. Same ballpark as a freeway.

So, what is the "average" freeway construction cost? Confused? Don't feel bad, metropolitan freeway construction is so idiosyncratic that quoting an average may make no sense. One thing is clear, the cost is almost always driven by right-of-way acquisition and interchange construction. Please note that these are precisely the two cost components the 3rd Generation Roadway promises to minimize. And clearly the 3rd Generation Roadway paths are targeted where freeway construction is most needed, most problematic, and most expensive.

So let's hazard a guess. Amortizing in a high-speed interchange every five miles, an average ten lane freeway incurring expensive suburban right-of-way costs … $200 m/mile. This number will justify a considerably higher cost than the other methods, but probably is more a statement that the nation couldn't afford to build a freeway system at its present cost. But, forge ahead, use our 50% rule for the highest acceptable 3rd Generation Roadway cost, and derive $100 m/mile.

Time, gasoline, lives, and insurance premiums saved

Although time, lives and money saved can never really be used to politically sell a project—the savings are simply adsorbed into society's level of productivity—let's make an estimate. Earlier we estimated that American drivers each spend 10 hours a week on the road expending time worth, nationally, $2,400 billion, and using gasoline costing $400 billion. If 1/3 of them (75/200) use this system, and save half of both their time and the gas they use; the savings per year is $525 billion. If 7,000 lives are saved and lives are worth $5 m each, that's $35 b/year. If insurance drops from $800 each to $400 each for 75 m policies that's $30 b. All told, that's $600 b/year. This amount justifies a capital expenditure of—accountants, quick give me a number!—5 years to pay back—$3.0 trillion. Good luck!! $3.0 trillion for 40,000 miles is $75 m per mile of line.

Redirect some of the budget

Hey, I'm tired of driving in a traffic jam. Please divert 25% of the transportation budget that should properly be directed by me as a citizen to begin developing part of this line. Yeah, and I vote. I vote, and half of all Americans are in the same boat. The estimated U.S. tax revenue raised explicitly for building the infrastructure for surface transportation in 2006 was $100 b. And let's assume 30 years is a reasonable development period with the budget being used for maintenance after that. 25% x ½ x $100 b x 30 years = $375 b. $9.4 m per mile of line.

$9.4 m per mile of Rail line is problematic. It is by far the lowest number that our various methods will generate to define acceptable cost. Perhaps to divert only a quarter of our urban transportation budget is conservative. After all in the city we're only filling pot holes, for the most part.

As well, many consider the present national transportation budget of $100 b to be woefully inadequate. This money is generated with the 18.4 cent Federal tax and any additional State taxes on a gallon of gasoline. California adds 18 cents per gallon and a 7.25% sales tax which generates a sum total of 9-10 b/yr within the state. The number for Federal tax has not changed since 1987. With inflation of course the real number has dropped a factor of two. As a percentage of the cost of gasoline it has dropped even further. And as a social mechanism to discourage the use of a limited natural resource, it is virtually non-existent.

To summarize, what have we learned? To laugh, realize how disparate the numbers are. "Tell me what you value, and I'll give you a number!" Where Roadway is considered a substitute for an urban or suburban freeway, cost above $100 million per mile seems acceptable and politically feasible. Where roadway is deemed to substitute as major boulevards, saving time and resources, maybe $25 to $50 million per mile seems appropriate. If funding is simply diverted from present resources, viable costs are less. Perhaps in this case, to use a very old metaphor, substituting a Cadillac for today's Chevy would loosen purse strings. See Table 7-1.

25% of present budget for cities	$9.4 m
time and gas saved	$75 m
30% of user's total costs	$90 m
50% of freeway cost	$100 m
political guess	$25 m

TABLE 7-1 Acceptable costs using various metrics

Let's focus on a single number. Surveying the four numbers in these paragraphs, let's grandly pick … $25 million per mile.

$25 m/mile. 40,000 miles. Including roughly 20,000 interchanges, maybe 60,000 on ramps, 60,000 off ramps. $1,000 billion total. 7% of a year's GDP. My!

Additionally if the 40,000 miles of 3rd Generation Roadway proposed in this book is to be used by 75,000,000 Rail Cars costing on average, say, $16,000 each, private enterprise will pay $1,200 b for the individually purchased Rail Cars. That is, the total cost of the Cars will amount to $30 million per mile of line available and roughly equal to the government's expenditure for Roadway. Thus the expenditure for Rail and vehicles would be $2.2 trillion total. 15% of a year's GDP. My, my!

Enormous sums without a doubt. But what did it cost to grade and pave the enormous length of our 1st generation streets? Or the 2nd generation freeway system we have today? In the 20th Century what did such items as rural electrification cost? Dams and reservoirs for hydroelectric power, irrigation, flood control and recreation? Or the enormous aggregate municipal networks for clean water supply and sewage on the other end? Civilization only advances when it has the cohesive order and the willpower to seize an opportunity.

The estimated expenditure for a U.S. national system, $2.2 trillion, is of course a staggering sum. But note that $2.2 trillion is close to the annual U.S. expenditure on transportation, and developed over 30 years, the development expenditure could be considered as a mere 3% of the nation's transportation budget. It is fair of course to argue that the 3rd Generation Roadway is for the benefit of only 1/3 (modeled as 75 million of the 200 million licensed drivers) of all travelers, and thus should be considered to be 9% of the expenditure rightly associated with their individual benefit. During the 30 year period, maintenance and Car replacement costs might double this figure, so it might be fair to quote 20% as a percentage of the total transportation costs of the user set.

Return On Investment

An important measure for any investment is something usually referred to as Return on Investment, or ROI for short. Annualized ROI is usually expressed as the yearly free cash flow back to the investor divided by the amount she put in—a percentage. "If I do this, how much will I get back every year?" For any planned investment the expected ROI is the the quantity of interest. And so we ask, what's the expected annualized ROI for society's investment in the 3rd Generation Roadway? All numbers are relative to automobile usage, which, since people do it, we assume to be a rational investment of people's money and lives.

Free cash flow might be simplistically determined by subtracting direct expenses from one's gross revenues. We will define gross "revenues" as time, gasoline, lives, and insurance premiums saved as compared to street automobile use. "Revenues" here are more accurately described as "benefits to society" in that the value of time and lives are only monetized quantities and not actual cash. Gas and insurance premiums, of course, are. Direct expenses, again simplistically, would be the interest expense on money borrowed, the amortization of both the Roadway and the Rail Cars, maintenance costs, and the money saved for the purchase of new Cars. Government interest expense at 6% would be $60 b/year. The Roadway might be expensed over a 30 year period, straight line, and thus Roadway amortization would be $33 b/year. Let's argue that half of all Rail Cars are used in lieu of automobiles, and the remaining half are expensed over 12 years, thus an expense of $50 billion per year. In addition, Rail Car owners must prudently bank savings of $46 b/year preparing for a second batch of new Cars, earning 3% above inflation. Roadway maintenance we'll guess at $40 b/year. Thus the "free cash flow" is $600 billion - ($60 b + $33 b + $50 b + $46 b + $40 b) = $371 b/year. Investment is $1,000 b for the Roadway, and $600 b for half the Rail Cars. Thus our return is $371 b/year on an investment of $1,600 b. Or an annualized ROI of 23%.

But let's be critical and generate another viewpoint from which to decide if we have a reasonable investment opportunity. Here's one my Republican accountant likes. Earlier in the section on today's freeways, we asked what rent the government should reasonably ask for travel on today's typical freeway. The answer was 31 cents a mile or $18.60 an hour. Well then, as an average, what would be fair rent on the 3rd Generation Roadway? Would it less expensive than use of today's suburban/urban freeway?

For simplicity, let's assume on Monday the U.S. auctions a single bond for $1 trillion. On Tuesday, the Chinese buy it at 6% with a cashier's check out of Hong Kong. On Wednesday, a contractor builds the 40,000 miles of Roadway, and on Thursday 75,000,000 Rail Car drivers start by using 27 miles each. What's the cash flow on Friday morning? We now have a going business, with real "cash flow", and solid expectations.

Let's also assume the government takes the real estate lady's advice—set a capitalization rate of 10%, or equivalently, buys at a gross multiplier of no more than X10—given in Chapter #2, and sets rates to collect 10% of its investment every year, which of course is $100 b/year. $60 b pays for interest to the Chinese, and $40 b is used for maintenance and management. The Roadway pays for itself and everybody is happy. But what's the charge per mile?

Well, 75,000,000 Cars each paying for 27 miles a day generate 2,050 million miles of rent a day, 750 billion miles a year. So, to generate $100 b in rent must imply 13 cents a mile. Quite a bit better than a freeway. But maybe not good enough for a boulevard.

Further striving to increase use per mile of Roadway, city planners might reduce the grid's density or eliminate Roadway aligned along streets with lower traffic levels. At some point, of course, the grid would begin to lose usefulness for many drivers and the benefits of eliminating lines would lose any effectiveness. The "sweet zone" of grid density and number of servicing lines would obviously increase if construction costs decreased … or vanish if costs rose.

An example of higher traffic density has been provided in Chapter 2 for the Manhattan borough of New York City. There, 140 miles of Rail lines are needed to service an estimated 1.5 million Rail Car users. The estimated public investment would be $3.8 b, and the purchase price of the Rail Cars $24 b. The resultant use rate stresses even the densely spaced grid and is fully five times the modeled national average. But New York's investment in Roadway would have an immense return.

PROBABLE COST

WHAT'S AN ESTIMATED COST FROM THE ENGINEER/CONTRACTOR?

Let's now flip the conversation, and ask the factory/contractor/engineer for an estimate. An engineer's estimate is usually based on expenses for comparable past work. Sometimes, past honesty is even checked. For instance, Caltrans annually publishes a "report card" which includes the aggregate cost of all construction in the year versus the aggregate bids accepted. That is, how bad were the overruns? Realize in our case, of course, no one has much actual experience that directly relates. And no one has any actual experience in exactly what is proposed. On the other hand, cost estimators are extremely skilled in finding relevant experience for bits and pieces of a project. How much steel and concrete are needed? How much does steel and concrete cost? How much does transport and placement cost for large preforms? What do in-the-street concrete foundations cost? How much does this type of computer code cost? And so on, and so forth.

Adding to the complexity, of course, is that the project is big, public, and complicated. In a very dark book, Megaprojects and Risk, featuring a cover depicting a huge dark shadow looming over a city, the Danish Professor Bent Flyvbjerg, argues that big public works projects are almost predestined to run over budget. All parties have a bias to lie. The politician wants it to happen. The contractor wants the work. His job is to sell. And no one can get enough money for needed studies to understand all the hurdles. Professor Flyvbjerg's examples include the Suez Canal which cost 2,000% of its original proposed cost and 200% of the estimated value the year construction began. The Concorde supersonic airplane cost 1,200%

of the original estimate. The Brooklyn bridge cost 200%. Closer to home in transportation, the Boston tunnel came in at 296% of estimate, the Mexico City metro line at 160%, the Washington, D.C. metro at 185%, and the D.C. to Boston railroad at 230%. With a wry sense of cynicism, in a book named ARAMIS after the French PRT prototype experiment of the 1980s, the well known author, Bruno Latour, depicts PRT as development for the love of technology, an example of technology as the god that failed.

The easiest path here of course would be to quote the answer given in the New Jersey Personal Rapid Transit study mentioned in the introduction. After all, the two-year, well-funded study was written by many of the recognized experts in the field of Personal Rapid Transit and the rail or guideway needed for PRT vehicles is in many ways similar to that needed by the Rail Car. That study's answer is $30 m to $50 m per mile for a dual guideway as the first production articles. Skytran of Irvine, California claims $15 m/mile of PRT guideway.

The New Jersey PRT and Skycab answers are more encouraging than at first glance. The PRT systems are public transportation. The projected costs include the cost of the vehicles, the platform stations for passengers, and facilities for idle cars and cars in repair. The 3rd Generation Roadway assigns vehicle cost to the private sector. Repairs are offline and at the owner's expense. Likewise Rail Car garages are either "public" or private enterprises charging a fee or part of a private dwelling—typically your house. Of the $30 m/mile in the New Jersey study, some substantial fraction is for the vehicles and stations.

The 2.5 mile ULTRA pilot system, shown in the introduction, is being finished at Heathrow by Advanced Transport Systems Ltd. (ATS) for the British Airport Authority (BAA) complete with 18 vehicles at an estimated $30 million. MISTER in Poland is estimating $12.6 m per mile for its 21 miles of track and 100 vehicles. Skycab has a cooperative agreement with the city of Hofors, Sweden to build 5 km of prototype line from the railroad station to the center of town. The cost estimate is $33.5 m.

Attacking a slightly different problem, a major 70-mile light-rail project in Utah, Frontlines 2015, is working with a budget of $2.85 b. That is, construction in years 2008-2015 for track, stations and trains will cost $40 million per mile.

PLACING THE BURDEN ONTO THE CONTRACTOR

The reader must not only understand the impact and promise of the 3rd Generation Roadway but also the challenges to any implementation. The challenges of doing it right. The reader knows the major components needed and therefor has some insight into the rationale used for the engineer's answer. In many ways the following list of the many tasks to be efficiently handled will complement a later discussion entitled "Gifts to the Engineer" which is intended to provide hope that the product here is both possible and will outshine the achievements of previous generations.

Let's start now by cautiously giving the engineer a "low-ball" target budget, complete with targets for each major component. By low-balling the initial requests we've automatically created a reserve to be meted out bit by bit. After all, some of our targets will prove impossible, and at the moment we're probably ignorantly omitting essential tasks. Later we'll break this target budget into as many subcategories as possible. If the materials and/or labor needed within the smaller subcategories become more transparent, the feasibility or absurdity of the preliminary budgets will also become more transparent. Remember the 3rd Generation Roadway is to be made of standardized parts, manufactured in factories, with limited installation tasks in the field.

$10,000,000 per mile. For completed Roadway. Hmm! Let's assign $5 m per mile for straight, standard segments of the Rail line. And allocate $1 m for an interchange, needing on average one per mile of line; and $250 k for an on-ramp or an off-ramp, of which we need four per mile of line. Furthermore, on a prorated basis let's assign $500 k for traffic control software and computer related field hardware, $500 k for R & D over many years, $1 m for overhead and management, and keep the remaining $1 m as reserve.

Realize when reading that by allocating $500,000 per mile for control software, given 40,000 miles of line, we've allocated $20 billion to be spent over time to develop functional software and implement a fielded computerized system. The $500,000 allocated for R&D justifies a $20 billion program of research, conceivably as a program with a $1 billion yearly budget for 20 years.

Line switches, motors, on board computers, docking sensors and electronics are all parts of the Cars—not a problem here. Of course, making the designs for the Rail Cars and the Rails compatible, and adjusting the performance of each, is a problem here.

Now let's go a step further. We've assigned $5 m per mile for the straight Rail line itself. OK, for simplicity let's raise the budget to $5.280 m/mile. That is, $1,000 per foot.

$1,000 per foot. Installed. Let's assign $500 per foot to the factory and $500 per foot to the road crew. The factory must build Rails, posts, beams, and assemble the skeleton. The Rails would include stiff tubes or trusses, extruded rolling surfaces, flanges, fascia and weatherizing finishes, electrical power contacts, wiring, the embedded sensors and passive markers of an intelligent highway, etc. A set of two Rails, please. The beam might be of precast, reinforced concrete. The posts might be as simple as a welded flange, vertical tube, and a spar with attachments for the dual Rails. Some posts would provide conduit for power and communications. One every 80 feet, please. Maybe $350/foot for Rail sets, $70/foot for concrete beams, and $6,400 per post [(350 + 70 + 6,400/80) = 500]. Feel the price squeeze?

The road crew would have a more varied task. Typically, create or modify a narrow median strip, change out various signs and lights, anchor and pour concrete pillows for each post, and finally install the posts and assemble the Rails. Each of these steps themselves of course involve many steps.

$1 million for an interchange. An interchange, as depicted in Figure 4-24B, has six major pieces. Extending to supporting posts about 80 feet apart in both directions, the two major pieces (the barrel roll sets) would be budgeted at more than twice the cost of an equivalent length of straight line, let's say $100,000 each. Let's budget $100,000 each for the four curved right turn sets, $10,000 each for the eight short connecting pieces, and $120,000 for the computing system and sensors. Which leaves … $100,000 for other items or reserve, and $300,000 for the road crew.

And so it goes, the engineers would continue their pricing. Impossible price goals? Only after R&D expenditure will the engineer answer with believable numbers. Only after far more detail is developed, only after far more more discussion by many groups will crisp answers in this section emerge.

PAYING THE PRICE

To most Californians, toll roads remind them of feudal Europe: warlords in their castles above the Rhine, extracting payment from passing travelers. To which we must reply, "I'll pay, just don't nickel and dime me as I move! Bonds, sales tax, gas tax, vehicle tax, per mile tax can all be sold, assessed

and add up to the full bill. Make me pay, just do it efficiently. Put a meter on my Car, make me pay by the mile, but do it yearly or quarterly. Give me an E-pass and bill my debit card. And, by the way, give me a credit, money back, when I use my Rail Car during rush hours. There's no congestion on my Roadway, I'm reducing congestion on the street, there's one less freeway you'll have to build! Hey, read my meter when I get my smog check, add another line to my DMV bill, just make it easy."

8

A THOUSAND WAYS TO DIE

As viewed by the engineer and the social scientist, this book outlines an attractive transportation system promising progress against a multitude of urban problems and one that conceptually seems technically and financially feasible. Viewed by these two groups, implementation should receive a green light. Ha! If it were only so.

Issues involved in implementing the 3rd Generation Roadway are many. Some issues originate from the physical nature of the task and others from the nature of human beings. Human beings with local and national politics. Some aspects of the Roadway should ease the enormous task which such a development will be. Other features will be onerous in implementation.

This chapter will examine the pitfalls anticipated for such an ambitious undertaking. It will look at the difficulties from many different angles. First, the voice of the naysayer of many different stripes will be heard. We listen because the arguments expounded by opponents and the pressure opponents will exert on the political structure need discussion. An examination of political and societal problems will occupy several sections.

Such a monumental development will face many technical challenges. Knowing that the world needs to develop an efficient, fail-safe umbrella design, an attractive cost-effective Rail and skeleton, and a world-class Rail Car, we will study the needs of an R & D program. There are obvious technical problems before the engineer, and flaws will likely result in the initial versions of Roadway. But there will also be problems in funding and user-acceptance problems for leading edge communities as they adopt a new technology.

The initial proofs of an R & D program will include demonstration-neighborhood Rail lines and several will be suggested in this chapter. Caveats are obvious. Cost/benefit ratios will be closely watched and the initial results may be poor. The cost of initial Roadway will be higher. The benefits to single communities using single lines lower.

To end, we will give the reader a basis to hope for a favorable outcome in a section entitled "Gifts to the Engineer". The 3rd Generation Roadway is not an impossible engineering task. Many aspects appear very addressable with a motivated society.

A road map is needed. A road map will define goals, define key milestones in R & D, set time lines, and set expectations. Goals include definition of what the Roadways is, where it will go, how it will be used. A road map will keep all participants focused as "the slings and arrows of outrageous fortune" impede the ultimate goals. The anticipated expenditure within the U.S. for a Roadway servicing the nation's major metropolitan areas and the private Cars to run on it is $2.2 trillion. To expend 5 to 10% of that amount for development is a staggering $110 to $220 billion. Now, although this expenditure is assumed to include all phases of developments including critical area demonstrations, there could be $220 billion spent before a mature, glistening system exists for all to see. And most people require a mature, glistening system to believe something is real.

And no government or collection of governments and industry can be expected to expend that amount on a domestic project in order to initiate it. So the question becomes how to cobble together disparate sources of effort without eviscerating the goal. Without a road map during the cobbling process, the reasons for success or failure of steps will not be fully understood. Lost in "the fog of war," the reasons will seem random. Maybe PRT people movers and guideways at airports will demonstrate key elements. Maybe they won't. Maybe the automobile industry will develop a suitable Rail Car; maybe it won't.

Perhaps developing a road map might be analogous to aiding "Blind men examining the elephant". That is to say, give enough intelligent groups a chance to feel, a facility to analyze impressions, and the characteristics of an elephant, or an attractive Roadway system, will be uncovered. Give one of these groups tools, an optical spectrograph perhaps, and even they will know the elephant's color. The project itself needs a developmental road map and a consistent approach, because, clearly, "1,000 monkeys pounding on a typewriter" is not acceptable.

OPPOSITION: DEATH BY A HUNDRED BLOWS

"Not in my neighborhood, not more traffic here, not more visual blight ... Not in the current fiscal crisis, not with freeways underfunded and in disrepair, not when we want less government ... not with the rural voter left out, not with truckers left out ... it'll be too expensive and suffer inconceivable cost overruns ... We don't need it; we need to drive less ... Suburbia is fine; people shouldn't be forced to buy a second car ... We need to fund public transportation instead... It'll never work."

Any idea can die. New ideas generate opposition. Opposition which is powerful, organized, and well established compared to that for the new idea. This fragility of the new born is particularly true for a complex system to be integrated into the fabric of a society—a system that has to be integrated into many disparate, preexisting communities with disparate politics and at the same time a system that needs massive funding. The history of transportation illustrates this fragility as well as any human endeavor.

Any idea can die under its own weight. That is, any idea can be implemented in a sufficiently awkward way so as to lose attractiveness. Death can come both by contortion to meet competing political objectives and by unimaginative engineering vision. Engineering can produce poor tradeoffs, poor designs for key components, and poor choices for initial lines. Engineering management can fail to deliver. Engineering, with complete freedom and independence, can fail to come up with a good design. Something that people want. Urban freeway revolts are common.

This section will discuss undercurrents which clearly will impede initiation and successful development of urban Rail Car Roadway. The section will do so by category. The first category is largely social and political and will center around (a) those who think society has too many pressing problems to develop something so novel, (b) those who feel they and their constituents will make little use of the system, (c) those who feel the 3rd Generation Roadway isn't a good idea, and (d) those who wish to change the idea or change its thrust.

The second category will be problems with the engineering of the system and problems intrinsic with the idea itself. Engineering problems include a host of difficulties affecting the actual product delivered as well as cost overruns and scheduled completions. The idea itself has some less than positive aspects and these will be discussed as intrinsic problems. The expected cost of the system by using several disparate estimation means has been discussed in its own Chapter.

NOT NOW, WE'RE BUSY.

"Citizens for Reduzed Taxation today announced opposition to the proposed ½ cent State sales tax and a 25 cent gas tax to support funding of area Roadway. In these hard times, the Roadway has less utility for older citizens already under duress. Other groups argued that private funding and control of Rails would yield greater efficiency and that State funding should be denied. Citizens for Responsible Government filed suit in District Court yesterday alleging State funding of such projects violated its responsibility to existing transportation obligations."

Without doubt, focused interest and funding for the system proposed by this book will be difficult to sequester. Reasonable budgets and allocations for Rail Car development can be argued. But it's all too clear that substantially less funding would be a likely outcome. Generating funding for new, non-entitled programs is difficult to sequester. Many groups see new public developments as an expansion of government's role. Tax and spend. Although it can be argued that the developmental model for the 3rd Generation Roadway is identical to those of the 1st and 2nd, many will not see it that way.

Tight government budgets obviously inhibit developments, and particularly inhibit expensive, novel ideas that (1) may not work, and (2) have alternative solutions. The idea of the 3rd Generation Roadway needs substantial study in validating its many precepts and has, of course, an alternative in the existing first and second generation roadways.

Today's roadways have powerful bureaucratic organizations chartered to develop and maintain these existing roadways on limited funding for which they must fight. Caltrans, for instance, has any number of freeway and surface street projects awaiting funding. The 3rd Generation Roadway might not be seen as complementary to the 1st and 2nd and an immediate sense of ownership would be surprising.

Many might see the 3rd Generation Roadway as a form of mass transit, and metropolitan transit authorities also have turf to defend. Authorities within urban rapid transit districts wield substantial clout, and they also live by a number of paradigms which would crush the ideas espoused here.

That is, as designed, the Roadway doesn't fit many MTA paradigms. Light rail cars must mechanically support the push and shove of full trains. The resultant weight is tolerated. Headways must be sufficient to avoid collisions assuming the preceding car "hits a brick wall". French Metro rules require 60 second headways. If full safety isn't guaranteed the system shuts down. The European systems focus on crash avoidance. In contrast, the U.S.'s National Transportation Safety Board (NTSB) focuses instead on strengthening cars so as to ensure the survival of passengers undergoing a crash.

The problem of limited resources and competing ideas is clearly illustrated in another example. The nation's first high speed "bullet" train is presently proposed as a 2½ hour connection between Los Angeles and San Francisco. The California High Speed Rail Authority is aggressively pushing for its development. A $12 billion proposal was approved by the voters of California in a November 2008 ballot initiative as a jump start to the $33 billion project. Some Federal funds have been approved. Should it be built, it obviously will be an alternative to one intercity Rail Car line of the 3rd Generation Roadway. (The primary difference in use would be the availability of quickly getting to and from the terminals within the two metropolitan areas. While the "bullet" train speed over the 390 mile long track would be considerably faster than a train of Rail Cars, "door-to-door" time for the average user of the Rail Car would undoubtedly be less. Adding a car rental on one end, adhering to the scheduled stops, and possible security regulations would negate the train's higher top speed.) Why would the State build both?

Commercial resistance might be reported as follows: *"City business owners and leaders today voiced their objections to reduced street traffic along Main St. They fear reduced walk-in business given that Rail users will cruise-by without stopping given no immediate access to the street. They also objected to proposed routing of delivery trucks down a longer stretch of back alley given the proposed five block restriction for truck crossings of Main St. between 5th and 10th."*

Trucker unions and Freight businesses will only reluctantly quiet their objections. Here is a system that does not directly serve them in any way and will impede them in several. The most obvious impediment is a height limitation. In order to reduce visual impact, post costs and access distances, local lines will probably be developed at minimal elevation—10 foot ground clearance is a baseline. Such clearance will allow pedestrian, bicycle, car, SUV, and small truck traffic to proceed without interference. But large trucks would only be allowed to cross lines at major intersections

where clearances would be increased to 16 feet—the clearance typical of standard road overpasses and underpasses. This added inconvenience to truck traffic might be little noticed by society, but to truckers it might be seen as a major negative.

The automobile industry will feel threatened. Actions might be reported as follows: *"In Washington, D.C. today, Detroit lobbyists promoted two bills introduced by Michigan Congressman, Feed MeMore, to deny federal research funding for the Rail Car and promote alternative fuel and motor development. Researchers in alternate fuel today lobbied to preserve funding by denying line items specifically aimed at Rail system research and development. Earmarked lines are under challenge. A rider on one bill sets minimum weight limits for street legal vehicles at 2,000 lb."*

The paragraphs above illustrate the obvious response of many whose funding will be threatened by the emergence of another priority. Those with strong business interests invested into one approach will oppose a newer approach mandated with uncertain outcome. Viewed by employees of funding agencies, alternative transportation is available, and maybe we should just muddle along. There are more ideas than dollars.

THIS IS A LOUSY IDEA.

There are many reasonable objections to the proposed development. The introduction of an elevated structure to suburban or crowded urban environments is not to be taken lightly. Why replace a quiet, perhaps even quaint, village scene with a Buck Rogers futuristic landscape with flying ships. What are these vehicles buzzing over my local intersection? Are they noisy? Will they drip oil? Will they occasionally crash? Will the computerized traffic control system always work?

Bulky or noisy implementations would be particularly objectionable. Multiple examples exist of suspended systems that would not be acceptable. Look, for instance, at the elevated rail built for the Chicago metropolitan area in the early 1900s. Shown in Figure 8-1 the support structure is extremely large and obtrusive. Ground support is needed far too often. The rail itself is of segmented steel and the thunderous roar of the heavy trains has been used a synonym for the crowning attribute of a bad neighborhood. Such an implementation would be deadly to this idea. Visual blight must be mitigated. The noise abated.

FIGURE 8–1 is a photograph of an elevated light rail system supporting full sized railroad cars of the famed Chicago "L" mass transit network.

The issue of safety is not to be underplayed. While this book makes a point of how dangerous existing roads are, and predicts that many lives will be saved with a controlled Rail system, Roadway injuries and deaths will occur. Pile-ups should the computer systems fail would be impressive. The effects of Roadway damage would need to reduced, mitigated, or eliminated. A single post taken out by an errant truck, a terrorist, or a fallen tree has the potential to derail many Cars.

The system's cost is another concern. Is it really possible to more efficiently transport people with such a sophisticated aerial scheme than it is to use what could be a dirt path?

And finally, that good old assertion, "It'll never work." And, well, a lot of good work had better be completed to prove this simple statement wrong. The computer software performance alone will impress. The design of single spans, the design reduction to standard parts, the manufacturing of components at reasonable cost, and the field projects of street placement will all need demonstration.

This small section is the outlier. It is the only section which might describe the self-absorbed discussion of the earnest engineer/inventor/citizen intelligently and honestly debating himself the relative technical

merits of the idea in front of her. What don't I like? What can't I get rid rid of? What is intrinsically negative?

I CAN'T USE IT.

Many voter blocks will never use a 3rd Generation Roadway. The system is for transportation in dense, urban, affluent, time conscious communities. The poor, the rural, the disabled, the very young and the very old will not be users. Consider the passage of federal or state funding. Why would a representative of poor inner city constituents, who can't afford such a Rail Car, and certainly not one as a second car, vote for Rail Car research and development at the expense of a financially struggling metropolitan bus and mass transit district? What direct advantage for the immobile? Why would a representative with rural constituents vote for rail funding over highway funding?

Rural voters and rural states would seem to have little motivation to support the Roadway. But politics is politics and support may come quid pro quo. Indeed rural states supported the 2nd generation roadway when developed as the Interstate Freeway system. Rural States were connected to more populous areas with state of the art roadway. As inter-metropolitan 3rd Generation Roadway appears competitive to other transportation as described earlier, such approaches might engender political support.

A partially developed Roadway is a lesser Roadway. No individual can use the Roadway until a reasonable network of Rails is in place in her neighborhood. If the state puts one and only one line into your community will you be motivated to buy a Rail Car and use it? Maybe if it goes from near your home to near your office. But what if you have to have go out to dinner or the gym straight from work, or pick your child up? Only at some grid density will the motivation be compelling to buy the Car. Fortunately, carefully chosen pilot lines will be able to demonstrate the value of such systems, motivating communities to accelerate development.

LET'S MUTATE THE IDEA.

Many good ideas are fundamentally sound, are robust and adaptable, and continue to grow as people embrace them with increasing sophistication. They're mutable. But in other cases, Frankensteins result. Clever inspiration can, will, and should refine and improve what is presented here, but the theme of this short chapter is to point to undercurrents which will likely, and negatively, impact development.

One clear threat is the insertion of very local interests intent on serving a community without consideration of any possible detriment to the larger metropolitan area. These interests might force Rail lines to be built in relatively non-productive (as seen by the majority) paths expending available funds. A demand for intense development of a certain area might optimize use by participants there, but leave other areas without any benefit. Conversely, resistance by an individual community or organization might deny service to an important area. A quick trip on the Roadway cross town might then be thwarted by the congested last mile. A peculiar aspect of the Los Angeles light rail system is that it bypasses the Los Angeles International airport.

The concept of Personal Rapid Transit is one of public transportation. The poor, the infirm, and the visitor are included. The public ownership of Cars can increase their utilization to the benefit of all. Walking to frequent stations simply replaces the slightly shorter walk to the garage. Why not develop PRT instead?

The 500-pound weight limit on all Cars will come under attack. First, it will be questioned by manufacturing interests during their development to meet the admittedly difficult requirement. Second, those attempting to provide and those attempting to receive luxury "improvements" to the vehicles will naturally want extra weight allowances. If allowed, the extra weight will increase the difficulty of building light, airy, inexpensive rail lines and impede the development.

Interests seeking to obtain relief from many engineering tasks will be heard. The narrow Rails proposed here will be harder to implement than wider guideways. Guideways are easier but bigger structures. Bigger Doobies are easier. Slower Rails are easier. One dimensional lines are easier than two dimensional grids.

Here is a good point to relate the tale of ARAMIS—the ambitious French automated personal "subway" designed to service the south of Paris.

ARAMIS failed, and failed for many reasons. Some were political—the overlapping jurisdictions conflicted, the Parisian MTA had partial control and really didn't want a competitive system, and it was final killed by the new conservative government of Jacques Chirac. Some were funding—intermittent funding led to the disbanding of three different engineering teams employed by the contractor, Le Garde. Some were due to inadequate R&D, e.g., the project went from idea to prototype in six months.

But the fundamental mechanism which induced failure was the slow mutation of the project goals. Yes, these changes can be traced to weaknesses in the R&D, the various political objectives coming to bear, and the inherent lack of feasibility of the original project, but the mutations—changes in objectives—that came from parochial interests, from ad-hoc fixes, and from engineering obstacles are the signatures of ARAMIS's failure. First the idea of very small cars was abandoned. Then, effectively, the idea of a grid…

THE ENGINEERING IS DIFFICULT

Megaprojects are difficult. New aggressive developments involving structural, electrical, and architectural tasks incur messy complications. Witness the many delays in Boeing's development of its dreamliner, the B787. Software, safety systems, yokes, metal fatigue, default algorithms, component lifetimes, user interfaces, subcontractor supply problems, etc. are terms which could be applied to the B787 or the 3rd Generation Roadway.

As the unexpected problem predictably occurs, opposition groups to a public development are presented with an opportunity. Opportunity seized to delay/mutate/kill a project motivated by reasons totally unrelated to explicitly stated concerns about the unexpected problem. When there is plenty of blame to go around, many get blamed.

Risk is pronounced in R & D as well as in the "first article" stage of production. Risks can be exposed from many sources. Imagine the pressure exerted on the Roadway concept if breaking news were reported as follows:

"Last week it was disclosed that stress fractures in interchange trusses called into question the flying buttress approach to low speed interchange wings. The wings have been a key approach technique to produce a standardized, and hence low cost, mass produced, interchange geometry and structure. The carbon based truss prototype delivery date has been delayed twice in the last eighteen months. The first date slipped when contract negotiations between U.S. DOT and Bechteeel Corp of San Francisco extended the April start date. Later this key date slipped when mode analysis difficulties were incurred by study collaborator Sanferd University.

“A fail-safe architecture was still not evident in the first Critical Design Review. Thus the project will not be authorized to initiate several, long lead time, hardware investigations.

“The truss, post and girder structures proposed will be subject to various resonant vibrational modes exceeding pre-established guidelines and will not be certifiable under this Department of Transportation until fully redesigned with substantially heavier…”, said the County spokesman. “Post structures in city street medians are incompatible with the city’s master plan.”

HOW MUCH IS THIS THING GOING TO COST?

The added expense to the world’s already complicated transportation infrastructure will be considerable. Except where traffic loads are heavy, the complication of a 3rd Generation overlay is not justified. It is far too early to generate strongly supported estimates of the cost of a full 3rd Generation Roadway, and the lack of such estimates will create opposition.

The promoter could show the expense justified given the benefit—the “savings” to society. Earlier in this book we looked at the benefit of the proposed system in saved time and gasoline. Casually, the promoter assumes that one could spend some fraction of that amount. How naive!

The skeptic will come with a recitation of cautionary tales indicating how much can go wrong in the cost equation. The promoters retort rationally why the cost will be manageable.

Several factors lead one to argue that the cost of 3rd Generation Roadway should be “modest” per vehicle mile. Two beneficial factors are immediately clear. The capacity of the line is very high, and if lines are built and full utilization achieved, the number of vehicle miles should be very high per mile of line. Secondly, the width of line needed is small indicating that existing roadbeds will not need to be modified to include the line. This may be an accounting ploy, but that price has already been paid. What is certainly true is that the 3rd Generation Roadway will not destroy whole neighborhoods as has the 2nd—the freeway.

The Roadway itself consists of posts, cables, struts, and the Rail itself. The Rail consists of a stiff inner tube providing stability for the suspension, and a shell providing supporting guidance and power for the Cars. While technology is needed for the Roadway’s appearance, none of these components is intrinsically expensive. It is argued that the key components of the Rail are manufactured in quantity as set number of standard items. The Rail is simply assembled on site as would a pre-fab parking garage or a giant erector set. On site connections to the ground are straightforward and minimal. Concrete pads need to be laid at sparse intervals—approximately100 feet.

Interchanges and on/off ramps demand other components and the high speed switch previously discussed. The number needed will be less than the line’s components, but its cost is more questionable. The interchange requires curved elements with undefined support elements.

CHALLENGES: ROAD MAPS, RESEARCH & PRIMING THE PUMP

Signatures of quality in a research project are many. Yes, the researchers should be the best and the brightest, the facility and its capital 1st class, and the team dedicated to the goal. But other signatures are harder to obtain, especially in a large, difficult, and socially embedded endeavor. Clearly desired are continuity in funding and focus, an appropriate gestation period allowing for sequential development, multiple threads in parallel investigation, and competition and a sense of urgency for teams with different sized chunks of the problem. The best and the brightest in turn should be multi-disciplinary players variously to be profiled as eggheads in their ivory towers, theorists they’re called, proof of principle lab rats, experimentalists they’re called, to the nitty gritty technician types who know the art that exists, what really does work, and all the details that go with that statement.

All too important is defining and staying with what the goals of the research really are. What are the key demonstrations and what can come off the shelf. If you hire a car or motor researcher, he will see the goal as car research or motor research. If the politician or political manager has excessive sway, the photo opportunity and sensational demonstration will dominate.

The quality of management is as important. There are the people who make things happen in appropriate sequence. Define what appropriate sequence is. And required as well is the quality in understanding possessed by those outside the project. Those who can affect funding. Those who must understand what has been demonstrated and what lies ahead. Those who can see what hard times may lie ahead. Those who can see through the hype.

Funding research is a difficult thing. If you were building a house, or say, even a grammar school project, you'd think nothing of spending 5 to 10% of your expected effort in planning and designing the project. And if you were daring, eschewing 2 x 4 studs and drywall and using Frank Gehry or Thom Mayne, you'd think nothing of doubling those percentages. Likewise building a second grade project, if she were your first child, or Ms. Berardo were a stickler, you'd expend extra time selecting your daughter the perfect poster board. Not so in a big public project.

That house, you have faith, you will live in. Ms. Berardo set Friday as a deadline, and she expects 100% compliance. But the public project is huge. The timescale long. People lose faith. People, even people in charge and those who can influence funding and direction, don't understand. Don't understand the risks, what's been demonstrated, what has not. And for good reason they don't understand—it's hard to understand. They say that 90% of the effort remains, after 90% is complete.

Conducting research properly is to prove key assumptions at certain stages of development and to thereby justify and focus the next steps. It's hard, too. Researchers always assume after some pleasant progress that the concept is proved, the article is real. To the developer, that's the guy doing r&D with a big D, not anyone pounding repetitive nails, the concept is still flimsy, the hardware impossibly primitive, and the researcher an idiot. The developer then typically spends ten times that which has been expended by the researchers. To the crew demonstrating a prototype and setting up small scale manufacturing, everyone before was an idiot. And each group, watching their baby in further development, is blown away by the expense needed on the next step. But of course, to the user—that spoiled individual accustomed to slick, low cost, off the shelf manufactured articles with ergonomic contours, utter reliability, and universal GUI displays—it all looks to

be expensive, poorly done, overly hyped crxx from legions of idiots! Only after large scale, low cost, six sigma manufacturing consuming tremendous investment, is everybody happy.

Rather than riot against the individual dramas of people caught in a process, perhaps it is wiser to assume that the natural sequence by which complex technologies are developed is good. That each step allows a judgment as to whether a milestone has been reached. That each judgment allows another element of society to weigh in; be it the engineer, management, the board of directors, the customer, or the green community concerned with sustainability. The 3rd Generation Roadway may reasonably take $110 to $220 billion to fully develop, but it would be insanity today to put a $100 b ballot initiative in front of the voters come November. Perhaps there is a logic to increased funding only after critical judgment opines that promise is exhibited.

To wit, one model is to grandly and simplistically assume that funding should be reduced by a factor of 10 for every step an idea is removed from a manufactured reality. Round numbers for each step are obtained if our developmental road map glibly assumes $111.111 billion is to be cobbled together by industry and government. $100 b can thus be made available in our final development step to fund mature Roadway and Rail Cars in several selected cities. Fully functional grids can be built to fully service metropolitan cities which will use and live with the 3rd Generation Roadway. One might coin a term for these Roadways: Version 3.1 Roadway. In the step before, $10 b is available to fund a beta city grid with relatively mature hardware. Money is reserved during construction at this stage to field-modify components, interchanges, and develop newer ways to operate such hardware. Before this expenditure, there is $1 billion to develop and test demonstration hardware and software in laboratory and field environments. $100 million is available to study concepts, implement tradeoffs, prototype software, some hardware, etc. And before that, $10 million funds conceptual studies, simulated hardware, analysis, simulated visualizations, and target audience receptions. Yes, money is skinny at the front end. Also obvious is the clean separation of these development phases is simplistic.

The item to be developed here includes a set of world class road vehicles from multiple manufacturers, a low cost, smooth, field erectible set of electrified beams and Rails with intelligent highway tags, an awe inspiring software package, methodology to ease street modification and Rail installation, and the politics to gain acceptance of many diverse communities—to name a few. How does one get from a notional design, only hinted at in this book, to a fielded, mature system? How do you go from A to B?

To conclude, a lengthy, government funded research program is clearly required. An understanding of impact, that is to say utility, and approach is needed. Detailed design is needed. Design trade-offs and competition between designers is needed. Test tracks are needed. The PRT projects in progress are needed. And a demonstration of an operational, fully functioning, attractive Roadway segment is needed.

INITIAL ROADWAYS

The issue to which this section addresses itself comes under different nomenclature by different communities of people. To a scientist, the term "proof of principle" means assurance that an effort is on sound theoretical footing and effort further down the road is justified. Beta site testing is a term which would resonate with many. To someone in mass manufacturing "scalability" denotes that a small scale process is ready for a massive increase in scale for production or implementation of a commodity-like product.

What is the ease with which a test case, or small area, of 3rd Generation Roadway could be built and actually be useful to a group of people. And for society as a whole to assess the results? Does the Roadway work as proposed? Did the construction proceed as hoped? What are the refined cost estimates? Does anyone hate it? And most importantly, do people eagerly use it? Do the majority eagerly use it?

Most traffic, as politics, is local. Thus development of a section of Roadway over a relatively small area would have immense demonstration value. The small area could approximate in shape a square. An area occupied by a community similar to our 'hood, which with today's transportation is our local community of 250,000 people or less, within which we can run errands and visit frequently. The example of Manhattan Beach (10 miles of rail servicing 35,000 people) indicates 72 miles of Rail line would fully service 250,000 people, and leads one to believe 20 to 40 miles of Rail line would at least provide meaningful service.

Or the demonstration area could be long and thin such as a commuter route between bedroom and office. 30 miles of Rail line might be sufficient for the fan in (convergence of local lines), high speed segment, and fan out (divergence of local lines) driven by a group of commuters.

Before we start, please realize the benefit to any one of these single communities won't fully justify the expected expenditures. The pilot Roadway will be more expensive per mile than later mass produced versions. The pilot's single pathway will be useful to individuals if we choose correctly but not as useful as a fully deployed network. We'll also degrade Roadway utility somewhat by not including high speed lines in that they may require more mature technology. What we want is community acceptance and then substantial use of the pilot Roadway. Use at some sufficiently intense level that a democratic majority can successfully argue that the Roadway will lead to usage similar to the projections written in this book. The single Roadway has to be a demonstration on the roadmap to success.

Obviously, a small scale development will have start up tasks, associated Research and Development costs, and in general be more difficult, costly, and messy as learning curves are climbed. The global or national society which watches should, in a rational world, provide a subsidy. The simplest case can be made for the purchase price of an individual Rail Car. If a reasonable target price of, say, $12,000 has been set for such a car manufactured in the tens of millions, then the response of the test community needs to be evaluated with $12,000 Rail Cars available. A heavy subsidy is needed. Would an automobile manufacturer volunteer? Likewise the test community itself cannot bear the entire expense of the prototype Roadway with start up glitches, snafus, and generally inefficient first try construction. The magnitude of these subsidies will be an issue. Whether the subsidy, that is, buy-in, comes as private investment from potential vendors and car manufacturers or from government sources is TBD. One could argue for federal or state funding to be tapped for the Roadway itself.

But in summary the message that should be taken from this section is that a relatively mature evaluation of the 3rd Generation Roadway's acceptance by society can be had. Construction of 20 to 40 miles of Rail line and production of, very approximately, 50,000 cars would establish a community transitioned to Rail Car use. Admittedly, utility of a 3rd Generation system will increase as one can use it to cross metropolitan areas to other neighborhoods, and as the quality of the Rail Cars improve; but if a community uses the Roadway with these initial restrictions, surely they will use it in greater numbers when the Roadway comes into full flower. If early production versions of Roadway and Rail Car could be produced at a low multiple of two, compared to large volume production cost goals, the cost to create such an experimental community would be $3 billion. That is 2 x (30 miles x $30 million/mile + 50,000 x $12,000).

CANDIDATE DEMONSTRATIONS

As a demonstration, a successful pilot Roadway can create believers. But the first Roadway faces daunting challenges. Would you buy a car if you could drive it on only one stretch of road? Now of course you can drive your Rail Car around local streets, but what if there was only one pilot line in the city? To be useful, Roadways must go almost everywhere you want to go. Sounds simple. And a single Roadway would be useful only if you go that way almost all the time… Like the road to work.

Let's try to generate several routes within the Los Angeles area which might service as successful pilot routes. In L.A., let's pick (1) The Malibu coastline to Santa Monica and east on Wilshire Boulevard to Beverly Hills. (2) Ventura Boulevard on some stretch between Woodland Hills and Studio City. And (3) the historic demonstration route for the 2nd generation of roadway from Pasadena to downtown Los Angeles. Looking elsewhere, realizing that our Los Angeles demonstrations are single lines primarily servicing as commuter alternatives, let's propose a fourth pilot as a minimal grid to service an entire compact urban area. We choose the city of San Francisco. What would be the prognosis for benefits and challenges for each of these four choices? We can build only one.

(1) The Malibu coastline now has a substantial population all the way out to the county line. Traffic density and congestion on the four lane highway has increased dramatically. Movie industry moguls, stars, lawyers, surfers, bikers, sightseers from Omaha, maids, gardeners, and garbage trucks make for a hectic and dangerous mixture. Most urban services for this growing population lie down the coast in the L.A. basin. Commuters from the San Fernando Valley avoiding the 101 and the 405 through Sepulveda Pass add to the morning mayhem by driving the "Z" across the 101, down Malibu or Topanga Canyon, and east on the coast highway. The worst traffic East of Topanga Canyon to Santa Monica, a four mile stretch, averages about 8,000 vehicles in congested conditions during the two hour morning rush going east and barely changes throughout the day. A freeway is unthinkable as the road squeezes between the Santa Monica Mountains

and the Pacific Ocean—landslides coming down on the left, surf eating the houses on the right.

This opportunity for a better commute requires the purchase of a Rail Car. These residents won't have a problem with the expense! They may, however, have an issue finding a 5 x 7 foot space in the garage. Obviously, the Roadway must go to their destination. Or close enough to their destination that completion of the trip on surface streets still makes the overall experience attractive.

Proposed: Build a 3rd Generation Road along the most congested portion of the Coast Highway into Santa Monica and on to Beverly Hills. 17 miles from Surfrider Beach past Topanga, up the California incline though Santa Monica, down Wilshire past UCLA, Westwood, Century City, and ending just east of Rodeo Drive. Driving city streets would allow Rail Cars to access many employment centers. UCLA is 800 yards. Moguls willing to drive city streets for 3 miles might go south to Sony Headquarters in Culver City or north to downtown Hollywood. What large percentage of drivers on the coast highway have those destinations?

If 30% of Malibu's population adopts a Rail Car, the demonstration line would have several evaluations: (a) mechanical performance of the Roadway; (b) performance of the Rail Cars on both city streets and a problematic suburban highway; (c) compatibility of the 3rd Roadway itself with a 1st generation set of various streets, (d) the value of reduced traffic levels on the 1st generation streets, and most importantly (e) satisfaction of the users and of the community.

Again, it is not expected that the pilot line's value to the actual users will justify its expense. If construction costs are double what the expected mass production costs will be, and if usage at 30% is only half that eventually expected—users can only go to selected destinations, the cost/benefit ratio will be off by a factor of four. The five demonstrations are the value; because successful demonstrations allow the next steps.

(2) Ventura Boulevard is suburban shopping heaven. Neighborhoods North and South feed traffic onto the 25 mph street. Traffic winds slowly through intersection lights planted at shockingly frequent intervals for one 15 mile stretch before changing character. The boulevard is paralleled by the Ventura Freeway (101) which subjects drivers to amazing congestion during rush hours. And rush hours are not single hours in L.A. Whether Ventura Boulevard or the Ventura freeway is the subject the Eagle's "Ventura Highway" lyrics is not clear.

A 14 mile pilot 3rd Generation Roadway placed on Ventura Blvd. from Woodland Hills to Studio City/Universal City where Cahuenga Pass begins would be less of a commuter utility test than one of neighborhood mobility, convenience, and acceptance. Extending the line another 10 miles over Cahuenga Pass into Hollywood/Los Angeles would make the route a major commuter test although higher speed might now be considered important. To be tested by the shorter neighborhood Roadway is market penetration—that is, how many bought Rail Cars? How happy is the neighborhood? Is life on Ventura Boulevard improved or disrupted by the Roadway? And of course does the Roadway function as expected?

(3) A third demonstration route would echo the demonstration vehicle for the 2nd generation roadway, that is, the 1940s Pasadena freeway. Build a pilot line to downtown Los Angeles from Pasadena. Feeder lines only two or three blocks long down Glenarm, Fair Oaks, and up Orange Grove on one end in Pasadena and several more on Figueroa and Spring downtown would be sufficient. Ten or eleven miles in total. Again Roadway performance, market penetration, and to a lesser extent reduction of congestion would be key demonstration metrics. Reduction of congestion may be less important as a metric in that it may be clear that if the first two metrics succeed like gangbusters, congestion will be reduced.

(4) San Francisco is a densely populated, compact city constrained into roughly a 7-mile square by water on three sides and from the rest of its peninsula by one political boundary. In the year 2000, it also was the 13th largest U.S. city. (Its population is 800,000, density 17,000 per square mile, and area is almost 72 square miles at 48.05 square miles.)

A conceivable, minimal demonstration grid that would provide some service to the entire city could be constructed with only 22 miles of Roadway. This length would result from one solution configured as a single four-mile square plus a diagonal line from the northeast to the southwest complementing the square. The four-mile square would be roughly centered within the seven-mile square on which the city stands. The diagonal would run from Montgomery Street, down Market to Portola and then Junipero Serra. Starting from the southwest the square Rail line alignment could run north up 19th Avenue to California, east to about Montgomery, south aligned somewhere between Dolores and Third St., and west on Alemany or Ocean in order to complete the loop.

The Roadway would be low-speed lines servicing neighborhoods interrupted by only two grid nodes. 22 miles of line, two low speed interchanges, and nearly 50 on- and off-ramps to provide demonstration to a city of 800,000. No user would be further than 1½ miles at any time from a line, even though the total Roadway length, with one mile per 36,000 citizens, is only 1/10 that baselined for the U.S. as a full system. Unless the Roadway alignment ran south on the 101 or I-280 no high-speed demonstration need be attempted.

Performance of the pilot Roadway could be evaluated in many ways. Mechanical and electrical performance of the components would clearly be in test. Several generations of low speed interchanges could be evaluated by replacing one or another of the two interchanges. But, so too, would average user speeds, congestion relief, use versus user distance from the line, safety, performance of the Cars on the open surface streets, willingness to buy Cars, and general happiness with the Roadway. Average use versus user distance from the line would provide powerful data for planners of grid spacing.

Happiness with the Roadway is also well tested in San Francisco. The community is diverse. It's densely populated, its flavor urban. Its traffic a mess. And San Franciscans are notoriously concerned for the aesthetics of their city and our fourth example would be an acid test for the architect.

AESTHETICS

For all its glory technology is only useful if, in some way, it makes life more livable. Machines that eliminate work or medicines that save lives qualify in ways that are easy to see. We all want to work less at the tasks we don't like and we all want to live. But most products are sold to us for their positive benefits by corporate advertizing empires, and we live with and work around the negative.

Automobiles are a mixed bag. They may provide mobility and freedom, but in addition to using our time, jeopardizing our safety, and wasting resources, they are noisy, stinky, fill space with steel, and demand we blanket the landscape with concrete streets. "There's a truck out on the highway, a mile or two away" may have made songwriter John Denver homesick, but up close a moving truck, car, or their ensemble on a freeway is a negative to the bystander. A city bus may carry many, but it cuts a negative swath as it plows down the street. Long gone is the time when we built our house close to the street so as to be near the action. We mitigate but can't eliminate the noxious fumes that pollute our air, give us cancer, deplete protective ozone, and warm our planet. The brown haze of NOx and the black soot of diesel are simply subtractive from the automobile's benefit.

Described in this book is a technology that promises to reduce pollution, speed our transit, eliminate congestion, improve our safety, and reduce our burden on the earth's resources. Even when used on the street, the Rail Car is a very efficient vehicle. And its small size, Jerry Brown would agree, is better. But one of the negatives we must anticipate is that we commit to place small vehicles and their supporting structures "in the sky". Or at least at elevated heights as to break one's view of the landscape. Now one must endure a view of the vehicle undercarriages. Forced to view moving objects ten or twenty feet in the air. Traffic noise above. The structure there 24/7. How negative will all this be, particularly up close?

Stepping back, let's look at the history of elevated structures and compare that to what we have projected for the 3rd Generation Roadway. What's the prognosis for mitigating the negative? Clearly there is value in continuing to illustrate, as would a building architect, what the projected structure will look like. Whether our structure will be appreciated. Whether we as urban planner have improved the cityscape.

There are historic structures of interest from several eras. Each is classic and well designed with the technology of the era and for the task at hand. But they are also hideously engineered structures, at least when viewed by the goals of this book, unsuitable visually to be compatible with the modern metropolitan street. We hope by looking at these structures we will learn what we must minimally do. And review, like a poker player dealt a new deck of cards, how to best play the opportunity afforded. Played wrong, the 3rd Generation Roadway will die a thousand deaths, played right, life can be more livable.

The railroad trestle is a good place to start. Constructed of wood, configured over various canyons and cliffs, and typically employing multiple triangular trusts, the railroad trestle is designed for the tremendous weight of a freight train. A freight locomotive, remember, can weigh 800,000 pounds over a wheel base of maybe 40 feet. The amount of wood used and the frequency of ground support required both clutters the landscape and would make using any street below difficult.

Built near the end of the 19th and early 20th Centuries, the famed Chicago "L" supports full railroad cars presently designed to weigh many ton, and is supported primarily by steel beams. The "L" is in active use today,

but the frequency of ground supports makes use of the streets beneath difficult, the filming of chase scenes exciting, and gives a generally cluttered visual appearance. It is also physically imposing—not at all a structure suitable for a livable urban landscape. To boot, passing trains are incredibly noisy. Witness the many movie scenes depicting the poor schmuck who lives in its shadow. Like the freeway or most light rail, the Chicago L destroys with noise, grit, and bulk a wide swath of real estate wherever it goes.

In the 1960s, several so called monorail systems were developed. Arguably the most famous is the Seattle World Fair's cross-town monorail. Sleekly designed from a single beam of reinforced concrete, it achieves a frequency of ground support that makes the streets below usable by all. It is sufficiently quiet that street traffic noise below dominates that of a passing train. Posts are still quite large and imposing. But then, the train cars they support weigh many ton and present heavy loads per foot. Figure 8-2 is two photographs of the monorail operating in September 2008.

What would the architect draw for the Rail required for the 3rd Generation Roadway? Its maximum load is 140 lb per foot. Its construction might be reinforced concrete or carbon fiber composite. As for Seattle's monorail, the Roadway must be a two-way path.

GIFTS TO THE ENGINEER

As presented, the elevated 3rd Generation Roadway is composed of lithe, slender, somewhat diminutive elements compared to the massive elevated freeways, elevated city street overpasses, and commuter train trestles we know today. Compatibility with existing streets—from minimal posts to small interchange footprints to acceptable visual appearance—is achieved by use of human-scaled structures which must blend with the neighborhood. Vehicle capacity is huge compared to what we know today. How is this possible? Is it only a dream? How can this book argue that the engineer will develop a new Roadway onto a previously developed landscape, achieve individual control of mass numbers of vehicles, and do so with a finesse that will compliment the urban scene? Why can he/she succeed where so many have taken different approaches?

An engineer is one who builds the simplest, most elegant, and trustworthy solution to the problem presented. His/her craft is valued for providing society with the machines optimized to be full featured, user friendly, low

FIGURE 8–2A and B are photographs of today's monorail operating since 1963 in Seattle.

cost and reliable. Increasingly the product provided has reached a sophistication level suitable to be viewed as a magical black box. From windmills to nano-particles to quantum computers the game is reduction to practice. The engineer has certain tools in the handbag; certain skills learned in the craft; and a problem that is rendered tractable by a set of assumptions. Together these tools, skills, and assumptions make a problem tractable, potentially yielding a useful product.

Gifts are bequeathed by the assumptions inherent to the concept of the 3rd Generation Roadway; gifts are bequeathed by newly advanced technologies of the world today; gifts are bequeathed by the infrastructure that the nation has already developed. We will call these "Gifts to the Engineer".

First, let's examine the assumptions in the problem presented here to the engineer. In comparing the problem to those presented to 1st and 2nd generation Roadway, light rail, heavy rail, or subway engineers, we will note three major advantages inherent in the reduced requirements placed upon the 3rd Generation Roadway designer. Advantages inherent at the starting point and given to the engineer as the problem is addressed.

Gift Number 1 is that the Roadway must support light vehicles only. No trucks or buses need be supported. No railroad-class vehicles are to be supported. Eighteen-wheel trucks weigh upwards 80,000 Ib and 20,000 lb per axle. "Light-rail" vehicles used by many cities weigh 70,000 lb unloaded and 100,000 lb loaded supported by two Doobies. Weight per foot, while nowhere near uniformly distributed, is approximately 2,000 per foot for a truck and 3,000 per foot for the railroad car. The maximum conceptual load presented to our designer is far lighter at 143 lb/ft.—that possessed by a fully loaded Rail Car 7-feet long also with two Doobies.

Gift Number 2 is that of advanced technologies. This road system will go into design after the development of many technologies achieved in the later half of the 20th Century. Its small load allows use of more expensive materials whose superior performance in turn further lightens the structure. One promising design for the rail would use an elliptical tube, possibly of carbon fiber, as the primary element surrounded by an extruded metal skin appropriately shaped for the many functions required.

Arguably chief among technologies is the power of computing and the underlying electronics which drive computing. Complementing this ability to handle data is the new availability of low cost sensors to generate the data. Discussed elsewhere within this book are the complexities of Traffic Control: programming an individual car for routing and exiting, guiding

Cars for approaches and merging, docking and disengaging, as well as spatial contention resolution. The technology of GPS could allow vehicle preparation for rail maneuvers. One rail maneuver, that of docking within train formation, will combine GPS with radar. Interchange overload, while occurring only at very high traffic levels, will need analysis.

Advances in the technology of construction materials will be employable. The earliest elevated trains used wooden trestles. Monorails of the 1960s used reinforced concrete. Some monorails were constructed as hollow beams, with Styrofoam core centers to reduce weight. Carbon fiber elements and steel cable discussed within this book may offer major advantages. Newer fiber filled concrete may as well. The computer may again offer major advances with innovative modeling.

Advances in vehicle technology will allow a variety of advantages. Chief among these may be the resultant vehicle weight. Remember sizing of the spans is driven by vehicle weight. But the possibility of performance and comfort for a hybrid electric vehicle for personal use has certainly achieved reality in the last 10 years. An on board computer now seems almost prosaic. Incorporation of the required features for a 3rd Generation Roadway car will be easier than 10 years ago.

Gift Number 3 is the use of existing right of way. Right of way in most cases is provided by existing surface streets. No underground work is required, save sinking the concrete pillows to support the Rail posts. Surface infrastructure, such as median signs, landscape shrubbery, etc., must obviously be accommodated. But the small size proposed for the Roadway enables use of existing right-of-way. No massive demolition is required as it was for medieval towns to accommodate the automobile, or as it was for modern cities to accommodate the freeway.

But in summary, the gifts inherent in the assumptions of the 3rd Generation Roadway are what may make the engineer's task feasible. Key to these assumptions is the vehicle's weight and size. Capacity of the system is proportional to the length of the car. Dynamic suspension systems can be developed to compensate for the Car's expected short wheel base. The system is designed for only one type of vehicle: a vehicle of minimum weight only four times that of a typical passenger.

Thus it is no accident the design of the 3rd Generation Roadway promises such dramatic progress.

COMMENTARY AND SUGGESTED READING

COMMENTS ABOUT THE TEXT

This book is not intended to settle engineering questions. But rather it is to put possible engineering solutions into play. That is to say, if these items could be successfully engineered, please notice the impact. And is society interested in the payoff? By showing engineering options, the reader is led to believe that engineers will have the ability to deliver attractive solutions. For example, note that the book shows Rail Cars using a "ski chair" attachment to the Rail, as well as Rail Cars attached as they would be on a "monorail". The Doobies discussed will, in all probability, not survive other designs to be implemented in real systems. Open is the configuration of the Rail itself, which clearly would be different for Cars supported above or below. The Rail might provide synchronous power. Rail Cars could be hybrid or all electric. Likewise the key enabling component of the Railed Roadway—the small street local line interchange—is an ill-defined architecture in the sense that it could take several forms, each leading to different performance levels, footprint, and general appearance.

The numbers used in this book are approximate. As presented in different calculations many numbers are even different for nominally the same quantity. While considerable effort has been expended to assure that no datum presented is misleading, for several reasons these apparent discrepancies have been left in the text. Since any implementation of the 3rd Generation Roadway will surely target the slower, denser sections of metropolitan areas, the speed numbers used may indeed have a conservative bias.

It should be realized that even precisely quoted values referenced properly to government and other reputable sources are in fact approximate. Precise values used for discussion many times have imprecisely defined assumptions. Notably the definition of a metropolitan area for which numbers are quoted is imprecise. For simplicity half of all Americans are assumed to live in metropolitan areas (which will make use of the 3rd Generation Roadway), while U.S. DOT estimates 76.8% lived there in 2004. 75% of the book's metropolitan drivers are assumed to participate, yielding 75/200 of all U.S. drivers using the 3rd Generation Roadway. Then again, with pessimistic assumption for urban drivers adopting the Roadway, such as only 1/3 of them using the system, we would conclude a market share of only 33 million Rail Car drivers.

Number of drivers, number of vehicles, number of miles driven—sounds easy doesn't it. But what's a driver? One who has a license to drive?

Or one who sometimes participates? Where possible the U.S. Department of Transportation's Research and Innovative Technology Administration's (U.S. DOT RITA) data are used. RITA Tables 4-11 for instance provides data for automobile numbers, mileage per year, and fuel economy/consumption. But data for SUV, pickups, light trucks, and vans are compiled separately in Table 4-12. What percentage of SUVs, pickups, etc. are merely used as light duty transport for single individuals? Single individuals free to use the Roadway. Mpg for vehicles in both tables on a weighted average basis is 20.4 which of course is not the same as the federally mandated U.S. fleet average. Nor probably is 20.4 mpg the average mpg of those who'll transfer their usage to the 3rd Generation Roadway.

IF YOU WERE KING … AND COULD DREAM

If you were King and able to make the world turn on your fingertips, the planning of the 3rd Generation Roadway would be different. While the writing here cedes to the reality of existing infrastructure, the lure of existing right-of-way, and a democratic world, your Roadway would not be superimposed on that which is owned by others and be told where right-of-way was available. Yeah, your Roadway, your city, and your configuration would start with a blank slate.

Not that any of us are Kings, but in history many urban planners have come close … Pierre L'Enfant, a French urban planner, was given charter to plan Washington, D.C., the new capital of a new nation. Likewise, Brasilia was planned from ground up. The Burgermeisters of Amsterdam, delighted with their small town in the Dutch Golden Age of the early 17th Century, set in motion a plan to expand their semicircular canal scheme, which guided the city for two centuries. These were people with a plan, a vision, and a charter to back it up. They say Robert Moses of New York wanted to assume as much.

As King, you know the 3rd Generation Roadway is what you want. It's mature, it works. You want small streets, virtually free of vehicles. Shops and pedestrians happy. You assume a rectangular grid of paths is best. (Such grids are scalable; planning is simple as your city grows, and the placement of buildings is straightforward. Boring as viewed from above, yes, but understandable by all. In three dimensions there's a reason a box is cubic, and that the room in which you read this is as well.) You plan your grid spacing small, set your streets narrow, plan for pedestrians and set small shops on each side.

At regular intervals Railed Roadway is aligned down slightly wider "boulevards" which run not only as one grid but as two with the second rotated 45 degrees from the first and from the streets. Thus at each "boulevard" intersection a Rail Car may go straight, left or right 90 degrees, or left or right at 45 degrees. Five choices, not the three we are accustomed. Thus a Car at high speed, traveling on a longer journey, can make two sequential 45-degrees turns in order to achieve a 90-degree reorientation. Why? Speed and intersection size is why. A Rail Car negotiating a 90-degree turn in a 50 x 50 foot intersection can do so at 25 mph. Negotiating a 45 degree turn, it can do so at 60 mph. If we ask high speed traffic to incur 2 g of horizontal acceleration in turns, the Car can turn at 85 mph. In an additional advantage, travelers can now better approximate a straight path to their destination.

Let's assume your city is built to a uniform 5-story height, as much of Amsterdam and central Paris are today. The Roadway is now supported by horizontal struts across the narrow "boulevards" from roof line to roof line, not by posts placed in the pavement. The buildings have shops at ground level and are residential on the four floors above.

You allocate 10% of your city's land for streets, 10% for parks and such, 30% for private interior courtyards and such, and the remaining 50% to the 5-story buildings. You decree that on average every citizen should expect about 800 square feet of living space; 2,400 square feet for your kingdom's average household of three. And you plan for a city of 100 million—hey, your Kingdom thinks big! Now, what's the area of your planned city? How long does it take to go across town? Can all citizens call the entire city their personal neighborhood?

Hmmm! … So you want answers! But you're King, you have minions to find the answers. And if I don't tell, I can write a sequel.

{Well, OK. The three answers are: 1,450 sq. mi., 23 minutes, almost—if you live near the center}

SUGGESTED READING

Books

The Fundamentals of Personal Rapid Transit, Jack Irving (Lexington Books) 1978

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Texas Department of Transportation (www.dot.state.tx.us)

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University of Washington PRT (faculty.washington.edu/jbs/itrans/prtquick.htm)

Wikipedia: Freeway Revolts (wikimedia.org/wikipedia/en/wiki/Freeway_revolts)

Wikipedia: Robert Moses (wikimedia.org/wikipedia/en/wiki/Robert_Moses)

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EPILOGUE

We have proposed a system for transporting people with massive capacity, unequaled convenience, and one with safety and ecological efficiency. This is a transportation system that can be viewed as disruptive or as a natural progression in an advancing world. The 3rd Generation Roadway has the potential to save time, energy, and money, and to allow higher density, more efficient cities and metropolitan areas.

As compared to that of 1st generation surface streets and 2nd generation freeways, Rail Car transport on the 3rd Generation Roadway achieves incredible efficiency. Avoiding intersections greatly improves transport speeds. Substituting computer control for human greatly improves vehicle headway times. Vehicle capacity of small Rail lines would be fifty times that of a two lane street. Land use efficiency would be fifty times that of a freeway; and a single two way line would carry seven times the vehicles of a typical ten lane freeway. Narrow, existing right-of-way can be used, either by building above the median strip of freeways and surface streets, above the parking lane of narrow streets, or reassigning existing freeway commuter lanes. Safety is greatly improved and energy consumption greatly reduced.

The growth of cities, requiring a host of technological advances, is a hallmark of modern man. However, today's transportation options for people limit metropolitan areas to districts with limited interactions. With multiple metropolitan centers spreading the urban center, citizens live in neighborhoods and only occasionally sample other areas. After all, one can travel from New York to Los Angeles in a time not much longer than a round trip across either of these cities at the wrong time of day. By increasing urban speeds by two, the 3rd Generation Roadway will allow urban neighborhoods to grow by four. By greatly increasing Road capacity, the Roadway will allow urban neighborhoods with greatly increased density to continue to operate without transit congestion.

As modeled here, for the United States, to service half the population, 75% of whom would take advantage of the Roadway for 10/14's of their surface travel, will require 40,000 miles of Roadway. 40,000 miles is longer that the sum of all urban freeways today, but the real estate area needed for the Roadway is about one tenth that for those freeways, and about one hundredth that of urban streets and surface highways. With an very roughly estimated Roadway construction cost of $1,000 billion, traveled by 75 million private vehicles valued roughly at $1,200 billion, conceivably amortized over 30 and 12 years respectively, the investment would save $450 billion in lost time, $50 billion in spent fuel, and 7,000 lives per year. Accounting crudely, if the monetary savings minus the capital amortization is our return on the national investment, a healthy 23% yearly ROI is imputed.

Wide acceptance is a goal to be challenged by at least three inconvenient realities. Cost is one. While considerable relief of our overburdened surface streets and freeways is promised, society will be obligated to support three types of roadway, and of course, first make room for the new development. Streetscape aesthetics is another. Clutter in elevated positions, minimal as it may be, will face civic scrutiny. Finally, overall convenience to the majority of metropolitan households needs to be proven. While faster, safer, isolated travel will hugely enhance use of small electric vehicles, the large automobile or light truck is dominant today because of its convenient adaptability – no matter what you're doing today, you are equipped to do it. How will the majority handle a choice of two vehicles in the garage—each less than universal?

Significant engineering challenges abound. Chief among these is to create elevated Rails sufficiently graceful and elegant as to be socially commendable. Visually commendable at commendable cost. Design, materials, and factory prefabrication are key. In contrast to the PRT prototype systems in development around the globe, the 3rd Generation Roadway is a futuristic proposal and discussion here is directed toward answering several key questions: what would be the impact of such a Roadway, does it look technically within possibility, and could communities afford it?

ABOUT THE AUTHOR

Roger Davidheiser's career extends over several decades of developing futuristic technologies within an industrial context catering to national defense, NASA, and NSF interests. He has published and lead substantial efforts in superconducting electronics, passive millimeter wave imaging, high speed electronics, developments for the wireless and cell phone industries, and studies of exotic systems such as space-based solar power farms. During the 1990s he managed the space electronics research and development program for what is now Northrup Grumman.

The author is a graduate of the California Institute of Technology with a BS in Physics, and of the University of Southern California with a PhD in Electrical Engineering and a minor in Material Science. Employed by the California Division of Highways, he spent college summers supervising highway construction and soldiering preliminary survey. He lives in Manhattan Beach, California, drives an old Volvo, and sometimes thinks his favorite games are Tetris and Rush Hour.