

BUS RAPID TRANSIT & MANAGED LANES:

Low-Cost, High-Quality
Transportation Solutions
for the 21st Century

By Baruch Feigenbaum



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By Baruch Feigenbaum

Executive Summary

Transit is important to the economic performance of America's metropolitan regions because it affects the number of jobs a person can access within a certain period of time. The greater the number of accessible jobs, the better labor markets can match people to opportunities, and the more productive a region's economy will be.

Yet despite transit's importance, most metropolitan transit systems are inadequate. In no major metropolitan area, for example, are more than 12.6% of jobs accessible within a 45-minute, one-way commute via transit. This is particularly problematic for poorer metropolitan-area residents, who are most likely to be transit-dependent.

Why is transit so inadequate? One reason is that while many metropolitan areas maintain "radial" transit networks designed to transport workers to and from a traditional central business district, patterns of economic activity have actually become increasingly decentralized. Research shows that nearly half the jobs in the nation's largest metropolitan areas are located more than 10 miles from the edge of the central business district, while only 20% of jobs are located within three miles of downtown. In this context, "grid" transit networks—which do a much better job of connecting suburbs with one another—are more effective than radial ones.

To make transit more effective, policymakers must do more than simply switch from radial to grid networks, however. First, they must abandon the false dichotomy that dominates most contemporary debates about surface transportation, and says you can have *either* better transit *or* highway improvements, but not both. This is misguided: there is a coherent policy

approach available to legislators and officials that would improve both the highway network *and* the transit network—and cost less than traditional improvements to only one of them. That approach is the focus of this study.

Managed lanes are the first of two transportation guideways that are central to this approach. Managed lanes are grade-separated, limited-access highway lanes, which are dynamically priced to manage demand. In busy periods the toll price for using these lanes rises, discouraging congestion and allowing faster, more consistent travel times. Transit vehicles (as well as some carpoolers) can use these lanes free of charge, making service speedier and more reliable—a huge boon for transit users. Moreover, research and experience suggest that the tolls collected on managed lanes can provide a large portion of the funds needed to build and maintain them. This makes managed lanes a notably cost-effective way to improve urban transportation for paying motorists and transit users alike.

Managed arterials are the second type of transportation guideway outlined in this study. Arterials are high-capacity roads that primarily connect freeway and collector roads at the highest level of service. Because they feature multiple intersections with side roads, shopping centers and businesses, reliable travel times can be hard to achieve; intersection capacity is the single biggest congestion factor on arterial roads. Managed arterials deal with this problem by using priced underpasses and overpasses at major intersections. Transit vehicles—and drivers paying a small toll, which can be adjusted based on demand—can use these passes to avoid stopping at intersections, leading to uninterrupted traffic flow and correspondingly faster and more reliable journey times. Selected arterials may also give transit vehicles *traffic signal priority* and allow them to use *queue jumps*, thereby ensuring the speediest possible progress through signalized intersections. Like managed lanes, managed arterials can be largely funded through toll revenue.

The three transit components of the approach outlined in this study are *express bus*, *bus rapid transit* (BRT), and *local bus*. Express bus is a less costly, more flexible alternative to commuter rail, and is already used in many major U.S. metropolitan areas. It provides point-to-point service from one of many park-and-ride lots in the suburbs to business districts throughout the city. This study suggests expanding express bus service, running it five days a week with short headways. Express buses should run on networks of managed lanes, allowing for fast journeys and dependable departure and arrival times.

BRT is an enhanced bus service serving multiple origin and destination pairs, which operates mainly on arterial roads with frequent stops along the route (every quarter- to half-mile). It differs from traditional local bus service because

it operates with the characteristics of a dedicated guideway system: traffic signal prioritization, dedicated lanes at intersections and expedited fare collection. This study goes further and envisions BRT running on managed arterials, using underpasses and overpasses to move straight through busy intersections.

These service enhancements make BRT an attractive alternative to heavy and light rail, which are 16 times more expensive, according to the Government Accountability Office. BRT is also quicker to implement and much more flexible than establishing new rail lines. These three factors make it much easier to create a comprehensive grid network—with high levels of connectivity—with BRT than with rail. Moreover, recent research has shown that per dollar of transit investment, BRT leverages more transit-oriented development investment than light rail.

So, following this study's approach, express buses would run on networks of managed lanes and BRT would run on networks of managed arterials. Taken together, these offer the quick, reliable performance of commuter, heavy and light rail, along with much lower costs (which allow a more comprehensive, connected transit network to be established) *and* benefits for motorists (which obviates much of the political controversy surrounding transit investment). The glue that holds this transit system together is local bus service, running on local roads and minor arterials with stops typically placed less than every quarter-mile, and connecting residential areas, transit hubs and employment centers. All major metropolitan areas have existing local bus service. (Some areas would supplement local bus service with limited-stop bus service.)

Finally, this study advocates a series of operational best practices to further improve transit service, and make the most of an enhanced, cost-effective network. First, transit operators should consider introducing distance-based and time-of-day pricing, both of which could encourage ridership and increase revenue if implemented effectively. Second, transit agencies should use competitive bidding to guarantee value-for-money in service operation. Third, in the absence of a genuine free market in metropolitan transit, a regional coordinating agency should operate a mobility management center—similar to the one in Denver—to ensure a comprehensive network of service for transit users.

The recommendations contained in this study employ existing transportation innovations that already operate successfully in many jurisdictions, are cost-effective and politically realistic, and can be introduced quickly in response to transit user and motorist demand. As such, the approach outlined here offers a pro-growth, pro-mobility way forward that policymakers would be well-advised to pursue.

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Part 1

Introduction

Transit service is uncompetitive in many U.S. metro areas, particularly in suburban locations whose lower density makes traditional transit less effective. Further, traffic congestion is a continuing problem in U.S. metro areas. As the economy improves, both the need for transit service and traffic congestion are likely to increase. Most major highway and transit projects cost millions of dollars and take more than 10 years to complete. Because of high costs, improving a particular corridor of the transportation system in most major metro areas is usually by road or by transit, but not both. For example, either the city widens First Street or it installs light rail. Such an either-or approach can create dueling political interest groups and a sub-optimal solution. With a reluctance to increase taxes and the need for quick solutions, U.S. policymakers should consider a potentially different approach.

This paper presents a concept that improves both the highway network and the transit network for less than the cost of traditional improvements to only one network. It suggests combining five components, including two different lane management strategies and three different transit technologies, to create a 21st century solution to America's highway and transit needs. The first component is "managed lanes," which uses a variety of tools and techniques including pricing and occupancy requirements to improve freeway efficiency. The second component is "managed arterials," which employs the previously mentioned tools and techniques to improve arterial efficiency. The third component is express bus service operating at least five days a week with short headways in the managed lanes; the fourth component is bus rapid transit (BRT), featuring buses with rail-like properties that transport customers long distances on managed arterials. The final component is local bus service, which will benefit from the increased number of express bus and BRT users.

Highway and arterial users will benefit from new optional lanes and bypasses providing a guaranteed reliable trip. Transit vehicles will gain access to improved guideways and facilities without transit users necessarily paying for this new infrastructure. (In some cities, such as Tampa, transit agencies provide funding to build managed lanes and use revenue to support service.)

Part 2

Background

A. The Current State of Transit

Transit patronage increased between 2000 and 2010, reaching all-time record highs. The increase in transit patronage shows the substantial demand for transit service. Unfortunately, the current percentage of commuters who use transit are still far below 1960s and 1970s numbers, primarily because even as land use patterns and economic activity have become far more decentralized, most transit service has remained core city-focused. Legacy transit systems move passengers efficiently within core cities or from suburban origins to central city destinations, and from central city origins to suburban destinations, but not from suburb to suburb, which now accounts for a significant percentage of urban trip-making—46%.¹ This poor suburban service is transit’s biggest weakness.

Table 1: U.S. Commuting Patterns, 1960–2010

Commute Mode	1960	1970	1980	1990	2000	2005	2010
Drove Total	64.0%	77.0%	84.1%	86.5%	87.9%	87.7%	86.3%
Drove Alone	N/A	N/A	64.4%	73.2%	75.7%	77.0%	76.6%
Carpooled	N/A	N/A	19.7%	13.4%	12.2%	10.7%	9.7%
Used Public Transit	12.1%	8.5%	6.2%	5.1%	4.6%	4.7%	4.9%
Walked	9.9%	7.4%	5.6%	3.9%	2.9%	2.5%	2.8%
Biked	N/A	N/A	0.5%	0.4%	0.4%	0.4%	0.5%
Telecommuted	N/A	N/A	2.3%	3.0%	3.3%	3.6%	4.3%

Source: U.S. Census Bureau, American FactFinder

Research from the Brookings Institution has underlined the extent to which decentralization remains a fact of life in urban America, regardless of its associated positives and negatives. Robert Puentes, for example, has studied Washington D.C., which has one of the larger core-oriented concentrations of population in the country. Despite some reinvestment occurring in the core and the renewed health of some parts of the District as well as the inner suburban areas, decentralization continues to be the number one development trend affecting the metropolitan area today. In fact, the Washington metropolitan economy is already more decentralized than the national average:

- Only 19% of the jobs are located within three miles of the central business district.²
- And only half of all jobs are located within 10 miles of the central business district.
- As a result, 59% of the commutes in the region are between suburbs and only 21% are the traditional commute from suburb to city.

Three trends suggest the U.S. will continue to decentralize. Firstly, metro areas are expanding. Some new suburbs are forming at the edge of metro areas and existing suburbs are becoming more densely populated. Secondly, employment is continuing to decentralize. This is occurring in all metro areas including traditionally dense core metro areas such as New York City and Chicago. Recent research finds that nearly half of all jobs in the nation's largest metro areas are located more than 10 miles from the edge of downtown.³ And only 20% of jobs are located within three miles of downtown. More people may choose to live in core cities, but if their jobs are in the suburbs they face the same distance commute as residents who live in suburbs and commute to core cities. Thirdly, lower income individuals are much more likely to live in the suburbs today than in the past. During the 2000s, poverty in suburbs grew five times faster than in cities.⁴ This is partly a result of central city governments giving developers tax breaks and financial incentives to redevelop inner city neighborhoods. Directly affected are lower income residents whose housing has been demolished. Indirectly affected are lower income residents living in the area who cannot afford the higher rents. This gentrification forces lower income residents to move to the suburbs. Transit options in the suburbs are much more limited than in inner cities. As a result, many lower income residents who live in the suburbs struggle to maintain cars or have trouble finding a job accessible by transit.

Many metro areas design their transit systems in a downtown-centered-development pattern more appropriate for European cities or New York City rather than a gridlike pattern more suited to U.S. metro areas, which have seen their most rapid growth after World War II. The increase in car ownership allows people to live where they prefer, rather than where their jobs are, and suburban centers are increasingly becoming business centers. U.S. cities will continue to change and transit must keep up with that evolution to adequately serve the travelling public. The two basic transit network designs in the U.S. are “radial” and “grid.” Using a side-by-side comparison, let's look at how each of these operates.

B. Radial and Grid Networks: A Tale of Two Cities

Research conducted into the best way to build and operate new transit service suggests that transit ridership is low because U.S. systems are failing to adapt to the evolving distribution of travel in metro areas. One major component of transit network design is geographical orientation of service. In several landmark studies conducted over the last decade, Thompson and Brown found that multi-destination transit networks (grid networks) are more efficient in attracting passengers and cheaper to operate than downtown-based systems (radial networks).

The authors studied 45 U.S. metro areas to determine whether radial or grid networks offer better transit service.⁵ They also separated the metro areas into rail and bus, and bus only. The grid or multi-destination areas performed better in both instances. The radial approach connected neighborhoods to the central business district but made reaching jobs outside of the CBD difficult. The multi-destination approach, while not as good at connecting neighborhoods to the central business district, was much better overall because it offered reliable transit service to more parts of the metro areas.

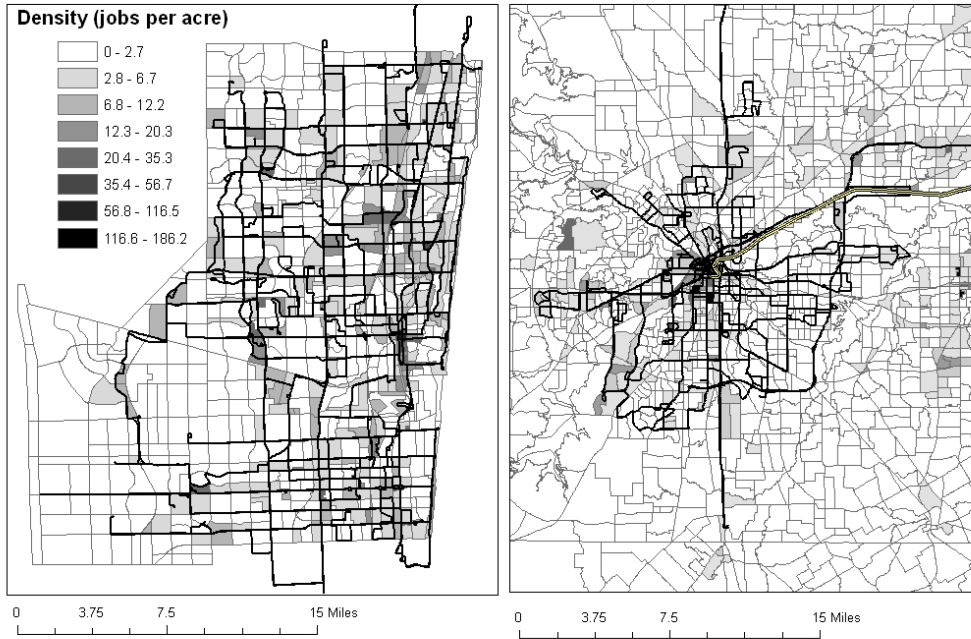
Further, between 1984 and 2004 the grid metro areas experienced much smaller productivity declines (14%) than the radial metros (26%). There was also a smaller increase in per capita costs for the grid service (19%) compared to the radial service (46%).

Thompson and Brown focused on two local bus-only systems in more detail—Broward County Transit (BCT) in FL (Fort Lauderdale) and the T in Tarrant County, TX (Fort Worth). These systems serve areas with similar populations and growth patterns. While the T has a radial pattern, BCT has a grid focus. BCT had 31.72 boardings per hour, which was substantially higher than the T's 16.45. Operating expenses for BCT were substantially lower while load factor was substantially higher.

The study shows that while certain older metro areas may be effectively served by hub and spoke networks, the vast majority of U.S. metro areas would be better served by a grid network.

The following map shows the difference in service between Broward County's grid service on the left and Tarrant County's radial service on the right. Admittedly, geography, roadway networks patterns and activity/ employment distribution patterns can influence the appropriateness of various network configurations.

**Figure 1: Transit and Employment Access
Broward County, FL and Tarrant County, TX**



Source: Brown and Thompson, *Hubs, Spokes, the Grid*

These development trends clearly have implications for transit policy—there is little point doubling down on outdated transit systems that reflect long-passed patterns of land use and economic activity. Until transit better reflects how people live, work and play in the 21st century, attempts to encourage transit usage are likely to prove unsuccessful.

C. Transit’s Role in the Economy

Robert Puentes testified before the District of Columbia Committee on Public Services in 2004 on the importance transit plays in supporting an economically competitive region.⁶ He discussed how development:

... [W]hich is facilitated and supported by a functioning transit system plays a fundamental role in attracting highly skilled labor and talent, which we know is so important in 21st century metropolitan America.

More broadly, a quality transit service supports economic activity in metro regions in the same way as reduced traffic congestion. Both factors serve to increase the employment shed, which is the number of jobs that a person can access within a certain period of time. The larger a person’s employment shed,

the more employment opportunities are available to him. And the larger the number of people who can reach a specific job, the better the chance that the company can select the most ideal candidate.

The employment shed is measured in time because most people will not spend more than a particular amount of time each day commuting to work. As congestion increases, the number of miles a commuter can reach within the same amount of time decreases. Imagine a person's home as the center and a range of employers—some five miles away, some 10 miles away and some 20 miles away. When transit service is effective and congestion is low or zero commuters can reach every point on a 20-mile circle, but in highly congested regions, some people can reach only the 10-mile circle and others only the five-mile circle. According to basic geometry, the area of a 20-mile radius circle is four times that of a 10-mile radius circle. If work possibilities are randomly distributed across the landscape, the 20-mile circle will include four times as many job opportunities as the 10-mile circle. And the same applies in reverse for an employer: four times as many potential employees live within a 20-mile circle as a 10-mile circle.

A larger employment shed leads to an increase in growth of personal income. In a large and diverse metro area, economic productivity depends on matching skilled employees with employers who can make the best use of their abilities. Remy Prud'homme and Chang-Woon Lee studied this question using data on travel times and labor productivity for French cities.⁷ They found a robust relationship between the effective labor market size (the size of the available circle, as defined by acceptable travel time) and the productivity of that city. Specifically, when the effective labor market size increased by 10%, productivity (and hence economic output) increased by 1.8%.

Several studies have attempted to quantify the economic impacts of a larger employment shed. Wendell Cox and Alan Pisarski applied the Prud'homme and Lee analysis to Atlanta in 2004.⁸ They found that a congestion reduction scenario that prevented the Travel Time Index from worsening between then and 2030 would lead to a 2.4% increase in gross personal income in the Atlanta area. Improving transit service could lead to a similar increase in income.

D. Transit in U.S. Metropolitan Regions

In 2011 Puentes, Adie Tomer, Elizabeth Kneebone and Alan Berube wrote *Missed Opportunity: Transit and Jobs in Metropolitan America*. The report studies transit's effectiveness at connecting people and jobs. Specifically, the

report examines transit service in the nation’s 100 largest metro areas, which are the center of the U.S. economy.⁹ While there is considerable variation in transit’s effectiveness, the overall U.S. transit network grossly underperforms in these 100 metro areas. Perhaps this accounts for why such a small share of workers—7 %, or 6.5 million people—rely on some type of transit. Transit’s share for lower income residents is 11%. Larger metro areas tend to have slightly better transit access than metro areas as a whole.

Overall, transit service in most U.S. metro areas is deficient. While nearly 70% of metro residents live in neighborhoods with access to transit service, service is not particularly frequent. Morning rush hour service occurs about every 10 minutes. And, most troubling, the typical resident can reach only about 13% of jobs via transit in 60 minutes and 7% of jobs via transit in 45 minutes.

The following tables show transit coverage and jobs available via transit in the 12 largest metro areas. Much of the data is measured in block groups as defined by the U.S. Census. Coverage is the percentage of working age residents living in block groups that have access to at least one transit stop within ¾ of a mile (straight line distance) of the block group’s center.¹⁰ Transit Service Headway is the time between successive buses or trains during morning rush hour transit service in a census block group. Job Access is the percentage of jobs that a typical working age resident can reach via transit. Metro-wide job access is calculated as the average share of jobs reachable within 90 minutes across all block groups with transit coverage, weighted by block group working age population.

Table 2: Share of Working Age Residents with Access to Transit in the 12 Largest Metro Areas

Metro Area	Coverage (%)	Transit Service Headway (minutes)	Job Access (%)	Overall Rank of 100 Metro Areas
Atlanta	37.8	10.2	21.7	91
Boston	69.4	8.9	30.2	34
Chicago	78.8	7.2	23.9	46
Dallas	46.3	11.0	19.0	89
Detroit	59.7	11.4	21.9	73
Houston	44.2	7.3	29.6	72
Los Angeles	96.0	6.2	25.6	24
Miami	88.8	10.6	16.2	63
New York City	89.6	4.5	36.6	13
Philadelphia	76.9	9.8	24.0	50
San Francisco	91.7	8.5	34.8	16
Washington D.C.	82.5	6.6	36.6	17

Source: Brookings Institution, *Missed Opportunity: Transit and Jobs in Metropolitan America*

Table 2 details different metrics used to assess transit service. The percentage of residents with transit coverage should be as high as possible. Anything below 80% significantly limits ridership. Transit headways, particularly during morning rush hour should be as low as possible. Any average above 10 minutes limits ridership. Job access should be at least 50%. No metro area comes close to this number. The perception is that larger metro areas have better transit service, yet four of the 12 largest metro areas rank in the bottom 30% in transit effectiveness of all metro areas regardless of size. Finally, common transit stereotypes are often incorrect. Popular media is quick to label L.A. as a transit disaster and Boston a transit mecca. But L.A. actually has by far the best transit coverage of any of the largest cities and the second lowest headways after New York City, while Boston is 8th out of the 12 largest metro areas in coverage and 7th in headway.

Table 3: Share of Jobs Accessible by Transit in the 12 Largest Metro Areas

Metro Area	Jobs Accessible in 45 Minutes (%)	Jobs Accessible in 60 Minutes (%)	Jobs Accessible in 90 Minutes (%)
Atlanta	3.6	8.4	16.4
Boston	12.6	18.7	30.2
Chicago	6.3	12.2	23.9
Dallas	2.3	6.3	19.0
Detroit	2.4	6.6	21.9
Houston	4.6	11.2	29.6
Los Angeles	3.7	9.0	25.6
Miami	2.0	5.1	16.2
New York City	9.8	18.1	36.6
Philadelphia	6.5	11.0	24.0
San Francisco	10.5	16.6	34.8
Washington D.C.	8.8	17.1	36.6

Source: Brookings Institution, *Missed Opportunity: Transit and Jobs in Metropolitan America*

Table 3 details how few jobs are accessible to transit regardless of the commute time. Even within 90 minutes, in the most transit-friendly of the large metro areas only slightly over 1/3 of jobs are accessible.

Table 4 displays the number of people who drive to work alone, carpool, and use all forms of public transit including trains and buses. The last column displays the time ratio between taking transit and driving alone. For example, the ratio in Detroit is 2.02 meaning it takes more than twice as long to take transit as drive alone.

Table 4: Mean Travel Time to Work (One-Way)

Metro Area	Drove Alone (in minutes)	Carpooled (in minutes)	Used Public Transit (in minutes)	Transit/Drive Alone (ratio)
Atlanta	29.3	32.8	52.8	1.80
Boston	27.0	28.5	43.8	1.62
Chicago	28.7	30.8	49.7	1.73
Dallas	25.8	29.3	48.0	1.86
Detroit	25.6	27.6	51.6	2.02
Houston	27.3	31.0	49.9	1.83
Los Angeles	27.1	30.1	47.8	1.76
Miami	26.9	29.7	47.7	1.77
New York City	27.8	32.2	51.0	1.83
Philadelphia	26.5	28.3	47.1	1.78
San Francisco	26.0	30.1	43.3	1.67
Washington D.C.	30.9	35.8	47.0	1.52

Source: U.S. Census Bureau

The average time ratio of driving alone to transit ranges from 1.52 to 2.02. Even in transit-friendly D.C. with the smallest difference of any major city between drive alone time and transit time, a trip that could be made by a car in 40 minutes would require 60 minutes by transit. This equals an extra 40 minutes per day or 3 hours and 20 minutes per week commuting. A transit trip in Detroit takes twice as long. This 40-minute car trip would require 80 minutes by transit or an extra 6 hours and 40 minutes per week. Such disparities are likely a main reason why transit’s share of the travel market is so small. Commuters have little incentive to pay for a ride that takes so long compared to car travel.

Other Transit Considerations

1. Linking Up People and Jobs

Many central city politicians support programs that increase access to jobs. But there is little evidence that traditional programs aimed at enhanced job accessibility have worked.¹¹ These include urban reinvestment programs that bring jobs closer to inner city residents, housing mobility programs that support suburban low-income housing, and transit-oriented development.

Improving transit service could succeed where these job enhancement strategies have failed, especially for low-income individuals. Better transit could connect low-income individuals to jobs. While owning a car may not be affordable for all, vehicle ownership, more than any other factor, improves a person’s ability to find and keep employment.¹² Since it is not realistic for everybody to own a vehicle, and since some people may choose not to own one, quality, dependable transit service could provide an alternative to car ownership.

2. But Won’t Declining Car Travel Increase Transit Usage?

Much attention has been paid to the decline in vehicle-miles-traveled (VMT) between 2005 and 2012, with some transit advocates claiming this heralds a resurgence in transit. Yet the decline in VMT has been relatively minor and its effect on transit has been very slight. Several recent studies have examined what

caused the VMT reduction and whether this reduction will be permanent. The Volpe National Transportation Systems Center's David Pace and Dr. Don Pickrell found that decreases in driving are not uniform.¹³ While men are driving less, women age 35+ are driving more. The study found five potential causes. Firstly, the fraction of population holding jobs is down significantly, particularly for young Americans. Secondly, recent income declines have affected working class households that drive more miles than average but have lower than average salaries.

Thirdly, gasoline prices have become more volatile over the last five years. (Previously gas prices increased in late spring and decreased in late fall. Now gasoline prices rise and fall regardless of the season.)¹⁴ Fourthly, as a result of stagnating income and college loan debt, most young adults have less discretionary income. Finally, many recent college graduates are having trouble finding high-paying jobs. Evelyn Blumenberg and Brian Taylor of the University of California Transportation Center researched the decline in VMT and found that economic factors, such as higher unemployment, are the major reason that VMT has declined. Transportation researcher Alan Pisarski also found that graduated licensing, where teenagers can drive only during certain hours or must drive for longer on a learner's permit, internet shopping and changing demographics play a part.¹⁵

Overall, the decrease of VMT is small and is not translating into large gains for transit. All three reports found that many of the popular explanations are not supported by facts. Overall, transit can account for only a 1% decline in automobile travel. Even for light vehicles in urban areas, transit can explain only 5% of the decrease.¹⁶ And this level assumes that all new transit ridership is from former auto users. Bicycling and walking trips also account for a very minor change because they transport very few total commuters. The back-to-the-city movement, where much of the transit ridership gains are concentrated, comprises a small percentage of the population, mostly young and elderly high-income earners. Census figures show that the rest of the population is continuing to disperse.¹⁷ Further, additional research from Brian Taylor shows that the mostly white, upper-middle class, back-to-the-city folks use transit far less than the lower-income, mostly minority residents they replace.¹⁸

In summary, metropolitan regions are responsible for most economic activity. And as the U.S. continues to urbanize they will be even more important in the future. But most metro areas' transit systems have big problems. Many metro areas are spending resources developing a transit system designed for pre-World War II urban scenarios rather than for current or future urban scenarios. As long as policy makers continue building systems that connect only central city regions to other central city regions or connect suburbs with the central city, the nation's transit systems will not be achieving their full and needed potential. Having only 7% of jobs accessible by transit within 45 minutes is unacceptable. New systems must connect suburbs to suburbs and encourage more reverse commuting between cities as origins, and suburbs as destinations.

Part 3

Transit Options and How They Work

We have established that cities are important economic engines, that current transit systems are struggling to effectively move people from A to B—if B is not the central business district—and that changes in car travel have not noticeably increased transit usage. The problem is our current transit system is not designed for 21st century U.S. development patterns. This section will:

- Detail the different types of bus-based transit,
- Explain why bus and BRT-based transit systems are promising solutions for 21st century transportation needs,
- Outline the most effective way to operate transit systems, and
- Suggest transit best operating procedures.

A. Types of Bus-Based Transit

Transit plays an important role in metro areas, but different types of transit serve varying needs in different regions. While some metro areas across the U.S. use one or more rail-based transit technologies,¹⁹ this study focuses on the potential of bus-based systems. There are four types of bus-based systems:

Local Bus (MB)

A bus service with stops spaced typically less than every ¼ mile focused on transporting people short distances. Local bus is the most widespread service with hundreds of lines in major metro areas. Because of the large number of designated stops on local roads, MB is also the slowest service and the foundation of the transit network particularly for the transit-dependent market. All metro areas have local bus service.

Local bus service can be subdivided into three types of service. The primary grid operates on major corridors linking activity centers and transit hubs. The secondary grid operates on lesser-traveled arterial streets connecting with high-density housing or employment hubs. Feeder service provides basic service from residential locations to transit centers or activity centers.

Advantages

- Is applicable in most medium and high-density locations
- Has large coverage area
- Uses multiple vehicle types

Disadvantages

- Service is slow
- Is not designed to transport customers long distances
- Needs large subsidies

Limited-Stop Bus

A bus service with stops spaced typically farther apart than every $\frac{1}{4}$ mile.

Limited-stop service skips certain stops to provide faster travel times. Limited-stop service is mostly used during rush hour. Some limited-stop buses such as M1 Limited (Manhattan New York) will skip every other stop in residential areas. Others will skip the quieter stations, stopping only at busier stations. Many metro areas have limited-stop buses.

Advantages

- Faster than local service
- Easy to add during high-usage time period
- Relatively cost-effective

Disadvantages

- Effective only in large, dense metro areas
- Realistic only at certain times of the day
- Not designed to transport customers long distances

Express Bus

A bus service that provides point-to-point service from one of many park-and-ride lots in the suburbs to business districts throughout the city. Many metro areas such as Atlanta and Houston have several different bus routes serving a park-and-ride area or have intermediate stops where commuters can transfer from one bus to another. Express bus service is used most during rush hour when choice ridership is higher. Since express buses use existing right-of-way, capital costs are limited mostly to the purchase of buses. As express buses use existing roadways including managed lanes, express bus costs are limited to the cost of buying and maintaining the bus fleet. Express bus mainly operates on freeways or expressways, making its service characteristics similar to commuter

rail. Examples include Brooklyn, New York BM2 or Cobb County, GA 100. Most metro areas have express bus.

Advantages

- Relatively cost-effective
- Uses managed lanes to provide fast service
- Can operate at shorter headways in suburban areas more effectively than commuter rail

Disadvantages

- Much less effective without managed lanes/shoulders
- Has capacity constraints

Bus Rapid Transit (BRT)

An enhanced bus service that operates with characteristics of a dedicated guideway including signal prioritization, dedicated lanes at intersections and expedited fare collection systems.²⁰ As a result BRT operates at faster speeds, provides greater service reliability and increased customer convenience.²¹ BRT mainly operates on arterials, has frequent stops along the transit line every ¼ to ½ mile, and serves multiple origin and destination pairs. Its service characteristics are similar to heavy or light rail. Boston, Cleveland, Las Vegas, Los Angeles, Nashville, New York City and Pittsburgh all have BRT lines. Many metro areas are studying or implementing some form of BRT service.

Advantages

- Relatively cost-effective
- Uses managed arterials/queue jumpers and right-turn lanes to provide fast service
- Requires fewer people to operate at shorter headways
- Transportation/land-use benefits

Disadvantages

- Much less effective without traffic signal priority/managed arterials
- Has capacity constraints

B. How BRT Works

BRT has been used throughout the world for 20 years. However, as the U.S. has just started to embrace BRT, commuters are less familiar with it than comparable rail services.

Some of the most successful BRT systems operate in South America. Curitiba, Brazil and Bogota, Columbia have two of the most extensive systems. Curitiba operates six BRT corridors that carry more passengers than many comparable LRT and HRT systems.²² Bogota's TransMilenio carries two million passengers per day.²³ Two new trunkways are scheduled to open on the TransMilenio in 2013; a total of 43 miles of BRT expansion is expected between 2013 and 2015.

A Transit Cooperative Research Study examined BRT service in Europe, focusing on Leeds and Runcorn in the United Kingdom and Rouen in France.²⁴ The European cities implemented BRT because it had lower costs and greater operating flexibility. BRT also had economic development benefits. The system in Runcorn operates in a busway (dedicated lane) while the Leeds system operates in mixed traffic with queue bypasses.

The U.S. has a number of BRT systems. The best known are Cleveland's Health Line, Los Angeles's Orange Line and the Las Vegas MAX. The Health Line, run by the Greater Cleveland Regional Transit Authority, travels 6.8 miles along Euclid Avenue. The Health Line operates 24 hours a day, seven days a week; the frequency of train service is every five minutes during rush hour, 10 minutes during middays, 15 minutes evenings and weekends and 20 minutes during the night. Los Angeles's 14-mile long Orange Line was built in the corridor of a former railroad line. The service operates every five minutes during rush hour, 10 minutes middays and weekends and 20 minutes during the evening. The Metropolitan Area Express is owned by the Regional Transportation Commission of Southern Nevada and operated by a private contractor. The eight-mile route has a 12-minute daytime frequency and a 20-minute nighttime frequency.

To help define and more fully explain BRT, the Federal Transit Administration is working on a technical definition of BRT. Various technical groups including the BRT subcommittee of the Transportation Research Board (TRB) have been consulted. While the definition is not finalized, it is expected to include six characteristics that are included in the "Characteristics of BRT Manual."²⁵

1) Running ways that give buses priority,



2) Unique station design,



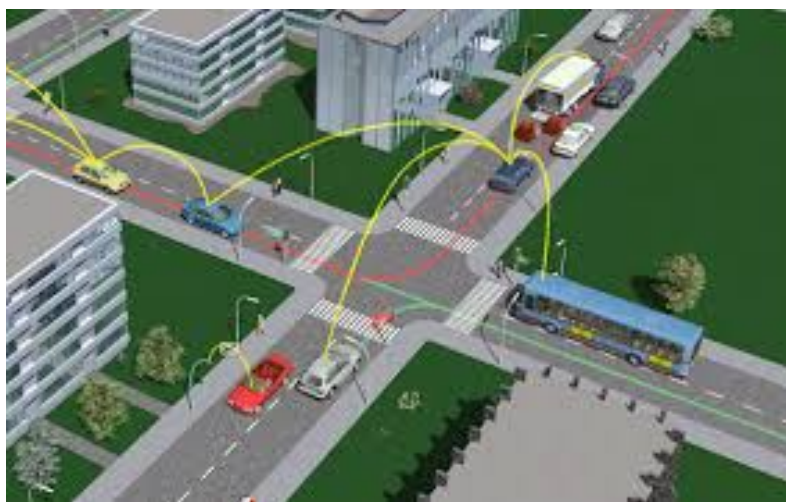
3) Larger vehicles (often 60-seat articulated-buses),



4) Electronic/SMART card/off-board fare collection,



5) Intelligent Transportation Systems such as priority signaling, and



6) More frequent service, typically every 10 minutes or under.

Most analysts also expect the definition will include a seventh characteristic: Branding differentiated from traditional bus service.

Many BRT services also have the following optional components that can improve service. These are:

- 1) Land-use/zoning changes,
- 2) Elevated boarding platforms level with the station, and
- 3) Electronic signage displaying bus arrival times.

C. BRT Types

Transportation researchers typically separate BRT lines into BRT Heavy and BRT Lite.

BRT Heavy service operates in an exclusive lane. As a result, operating the service requires either building a new lane solely for buses or taking away a lane for cars. While BRT Heavy may be the best choice in downtown cities, such as New York City and Chicago, with a high number of transit users, a lower level of automobile use and a short frequency between buses, it cannot be economically justified in many U.S. suburban locations. While providing quality service is vital, many BRT lines do not have short enough headways to require a dedicated travel lane.

BRT Lite, which operates in lanes shared with cars, is the better choice for most U.S. municipalities. BRT Lite has many but not necessarily all of the seven features, listed above, although future BRT operators should try to include all seven features. These features allow it to offer service superior to traditional buses.

The Los Angeles Metro Orange Line, which operates on an exclusive busway built on the right of way of a former freight railroad line in the San Fernando Valley, is an example of BRT Heavy line.²⁶ The Los Angeles Metro Rapid, which operates on major arterials such as Wilshire Blvd and Ventura Blvd offering 10-minute or less headways during peak periods and limited stops spaced approximately one to one and a half miles apart, is an example of a BRT Lite. The Ventura Blvd line has dedicated bus shelters, specific branding and some traffic signal preferences. A 2007 study comparing the Ventura Blvd and Orange Line services found that travel times were similar but while the capital cost for the Orange line was \$16,800, the capital costs for the Ventura service was only \$1,300. The difference in costs will not be as substantial for all BRT Heavy versus BRT Lite comparisons.

BRT Lite's ability to provide effective service at a much lower cost than BRT Heavy make it the better option in most situations. Low population density and headways of two minutes or more make BRT Lite the better option. BRT Heavy is more appropriate for areas with extremely short bus headways—less than every 120 seconds—such as New York City. BRT Heavy can also be justified on roads with excess capacity where removing a lane for automobiles will not increase capacity.

However, there is one area where all BRT services need a dedicated lane or a lane shared with right-turning traffic only—major surface intersections without grade-separated overpasses or underpasses. The biggest bus delay factor is red lights at intersections. To solve this problem, buses should be able to use the right-turn lane in order to be first in line at the intersection. In this situation, the bus will receive a priority green light, which will allow it to proceed through the intersection and move back into the regular travel lane. Cars turning right would have to wait for the bus to proceed through the intersection. Use of the right-turn lane and priority signaling provide major travel savings to the bus without the expense of adding another lane or removing a lane for car travel. Some intersections may have to be modified to ensure cars turning right do not queue into the bus path. This may include a merge lane on the destination street. Transit signal priority will be discussed in more detail in the “Transit Components of Managed Arterials” section.

D. How Express Bus Service Works

Express Bus offers a type of service comparable to commuter rail. It is an older concept than BRT; the first express bus service went into operation 50 years ago. Today, these buses share space with cars and operate on both freeways and arterials. The highest quality express bus services operate in “managed lanes.” In managed lanes, the highway operator uses pricing, capacity requirements or type of vehicle requirements to proactively manage demand and capacity. The three most common types of managed lanes, which are discussed later in this report, are high occupancy vehicle (HOV), high occupancy toll (HOT) and bus only lanes.

E. Bus Advantages: Cost, Implementation Time, Connectivity, Flexibility, Transit-Oriented Development

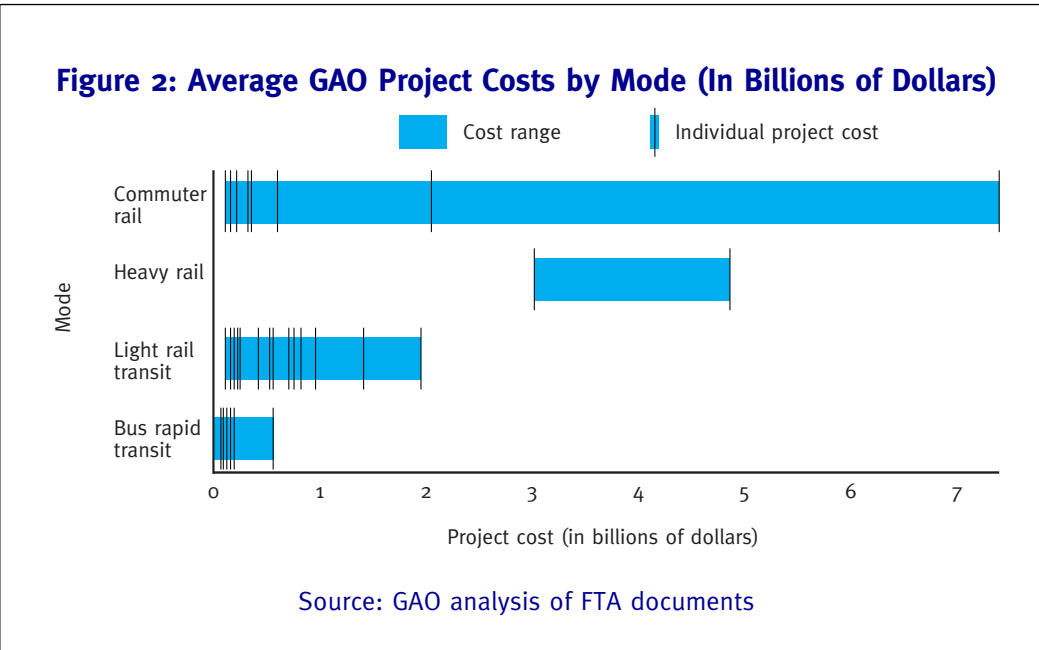
One of the biggest advantages of BRT—and express bus service—is the low relative cost compared to rail. Several comprehensive studies have examined bus versus rail costs. According to the U.S. Government Accountability Office (GAO), capital costs for BRT projects are typically lower than for rail projects and account for a very small percent of the Federal Transit Administration’s New, Small and Very Small Starts’ funding.²⁷ BRT projects range from \$3.5 million to \$567 million while LRT projects range from \$111 million to \$7 billion. The median cost for a BRT project is approximately \$36.1 million while the median for a rail project is \$575.7 million. Therefore, rail projects are on average 16 times more expensive than BRT projects. Even though more than

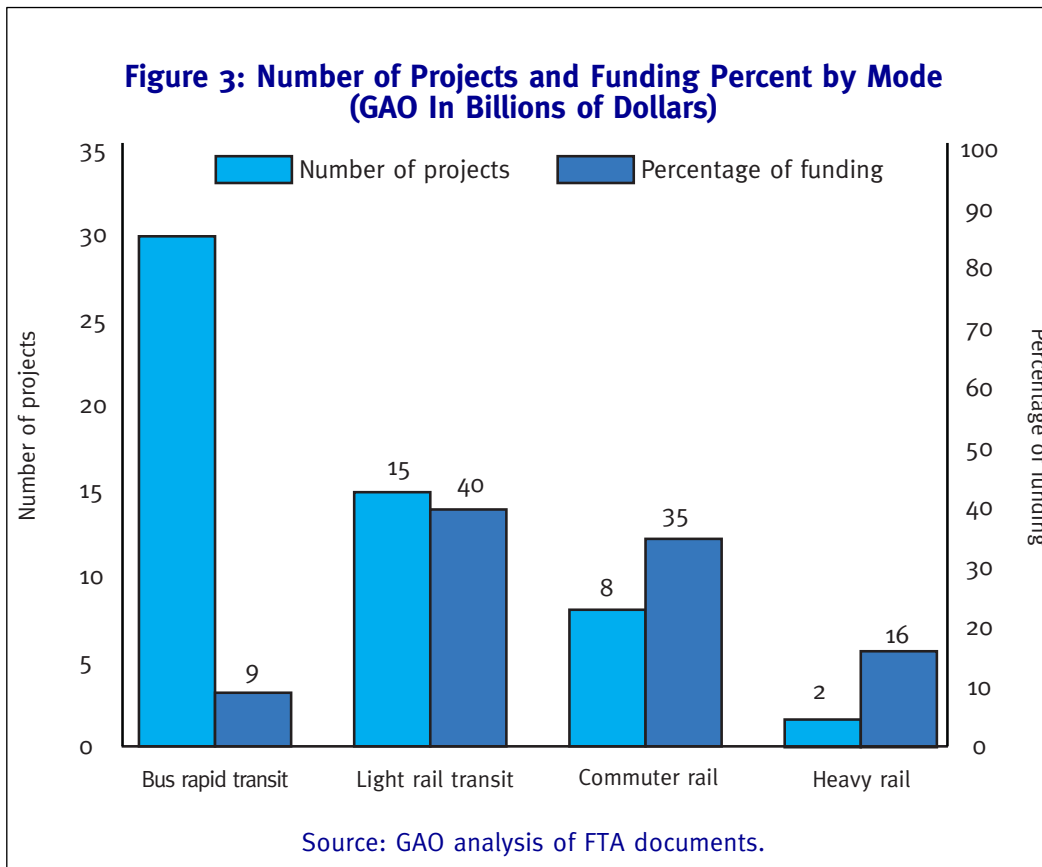
half (30 of 55) of the projects between FY 2005 and FY 2011 have been BRT, those projects account for less than 10% of committed funding. Between FY 2005 and FY 2012 federal transit funding provided \$12.8 billion of capital investment grants. More than 90% of the funding supported rail; only \$1.2 billion of this total supported BRT. Of the 30 BRT projects that GAO studied, only five have higher capital costs than the least expensive rail transit projects. Both the Cleveland Healthline BRT and the Eugene LTD officials chose BRT because of the lower costs. The Healthline costs less than a third of a traditional rail project.

The GAO reviewed 15 different BRT services and found that 13 reported increases in ridership after one year of service and reduced travel times of 10–35% percent over previous bus services.²⁸ While a BRT system often carries fewer riders compared to a rail system, such systems have typically been implemented in lower-density areas. BRT systems in dense urban areas such as New York City’s M15 BRT line carry equivalent numbers of passengers to rail systems. The M15 line carries 55,000 riders per day.

The Institute for Transportation and Development Policy (ITDP) completed a comprehensive study detailing BRT and LRT and found that LRT projects cost on average three times as much as BRT projects.²⁹ BRT achieves comparable levels of speed, capacity and passenger comfort, but can be built at a fraction of the cost and construction time.³⁰

The second major advantage of BRT is the speed of implementation. The time to plan and implement a BRT line, typically two to four years, can be half the time to plan and implement a rail line, typically seven or more years.





The third major advantage of BRT is network connectivity. Since buses operate on streets, it is cheaper and faster to establish a network using bus-based transit. There are five different components in a bus-based network:

- 1) Local buses offer basic, affordable neighborhood bus service throughout the metro area.
- 2) BRT provides higher-speed service on arterials and other major streets.
- 3) Express bus provides high-speed service connecting suburban park-and-ride areas with major business centers.
- 4) Demand-response bus service can be offered in very low density parts of the metro area where there is not sufficient population density for fixed-route service.
- 5) Finally, demand-response service for the elderly and disabled can be offered throughout the metro area. Modern BRT can offer more one-seat rides than trunk and feeder rail systems.

And since BRT systems are three to 16 times cheaper than LRT systems, for the cost of three LRT lines a metro area can build between 9 and 48 BRT lines. In addition to producing a more comprehensive system, this also eliminates the rail-based system of winners and losers when choosing which area receives the new transit line.

The fourth major advantage is flexibility. U.S. development patterns change over time. In the early 20th century before the automobile, development was much denser because residents needed to walk to work or use the streetcar, not because they chose to live more densely. But today, development patterns are much less dense as most of the population owns a car or can telecommute, and prefers to live less densely. Rail lines cannot be moved to reflect new travel patterns. But BRT networks are flexible. It is unlikely that any line would be eliminated. But service headways can be adjusted based on changes in travel patterns. Routes can be moved to a parallel street based on needs. Transit providers can change and customize service to development changes we cannot imagine today.

And BRT vehicles can serve multiple network roles. BRT vehicles can use any route and serve any neighborhood. For example, a BRT vehicle can make a number of off-system origin stops to pick up passengers. Then the BRT vehicle can use any guideway or roadway for the line-haul trip. Finally, the BRT vehicle can go off-system to make destination stops in an employment area.

The fifth major advantage is the BRT's potential positive effect on transit-oriented development (TOD). Since BRT's inception many transit providers have speculated that rail is more effective at spurring transit-oriented development than bus. But a recent landmark study shattered this perception. The ITDP report found that per dollar of transit investment, and under similar conditions, bus rapid transit leverages more transit-oriented development investment than light rail transit.³¹ And while both LRT and BRT can leverage more TOD than they cost, outside factors such as government support and the strength of the land market are more important than the quality of the transit investment. Specifically, there is no correlation between the level of transit investment and the level of TOD investment. BRT can create more TOD investment because a metro area can build multiple BRT lines for the cost of one light-rail line. In fact the two cities with the most TOD development per transit dollar were both BRT lines—the Cleveland HealthLine at \$115 and the Kansas City MAX line at \$102.

Enhancing Transit System Operations

Developing a transit network using bus- and BRT-based systems is vital for many metro areas. But developing transit best practices can help improve service further. The following section details three methods for enhancing transit systems operations.

1) Distance-Based Pricing and Time-of-Day Pricing

In distance-based pricing the fare is based on how far riders travel. In time-of-day pricing riders' fares are based on how many passengers use the service at a particular time. These market mechanisms help transit providers offer better overall service. While some express buses and BRT offer different fares based on distance traveled, others do not.

Distance-based pricing may substantially increase express bus ridership. Bus A's current fare is \$6.00 for all riders regardless of whether they are commuting 25 miles from the town of Far North at the beginning of the line to the town of Far South at the end of the line or 10 miles from the city of Slightly North, in the middle of the line, to the downtown business district also in the middle of the line. According to federal IRS reimbursement rates, driving 25 miles costs \$14.13 while driving 10 miles cost \$5.65.³² The transit operator is losing money on both routes. Customers traveling 25 miles are getting a bargain. Many would be willing to pay more than \$6.00 to make the trip. The transit agency should consider increasing the 25-mile trip price to \$8.00. Customers traveling 10 miles have little incentive to use the service since it may be cheaper for them to drive. Lowering their price to \$4.00 may induce some to use the express bus.

BRT lines face a similar situation. Bus One currently charges a flat \$2.50 for all riders, a good deal to travel the 18-station, 25-mile trip to the airport, but a terrible deal for those traveling the two-station 1.2 mile trip to the next stop. According to travel reimbursement rates, traveling to the airport by car costs \$14.10. While cars offer more flexible travel times and other advantages, these differences do not equal \$11.60. The transit agency is losing revenue by offering such a low rate on this trip. Contrast that with the trip between the first two stations, which according to standard travel rates, by car costs \$0.67. The bus company is losing substantial ridership by overcharging this route by almost \$2.00.

Bus and BRT operators could also use time-of-day pricing, which varies based on demand. Charging higher prices during rush hour has two benefits. Firstly, the transit agency can operate more buses when the demand is highest, providing better service to customers. Secondly, the increased price will cause some customers to vary their travel times to shoulder times (hours immediately before and after rush hour) to pay a lower fare, which will have the beneficial side effect of relieving crowded vehicles.

Yet, price is not the most important consideration for many system users. Transit passengers value headway (the time between buses on the same line) above all other factors in choosing a transit service. Headway is more important than type of transit vehicle, fare and even travel time.³³ Many bus and BRT lines feature headways of 15 minutes during rush hour. The longer the potential wait, the less likely a customer is to use transit. If the peak period wait time can be reduced from 15 minutes to six minutes, customers are much more likely to use transit. Express bus services typically have longer headways, but the same principle applies.

Headways are often increased because of budget challenges. The problem is that each time headways are increased, fewer passengers use transit. The result is more budget cuts and additional headway increases. This is the never-ending transit service death spiral. Distance-based and time-of-day pricing, while initially complicated to some riders, will encourage more ridership and result in more revenue.

Depending on riders' income, transit operators may need to provide transit vouchers to some riders. Lower income riders will be one of the biggest beneficiaries of time-of-day and distance-based pricing since service will increase for these transit-dependent commuters. While this is currently administratively challenging, new technologies are expected to make this much easier.

While distance and time-of-day pricing are not feasible in all situations, these new technologies can help transit agencies provide better overall service.

2) Contracting and Competitive Bidding

Transit agencies should consider using competitive bidding to determine whether the transit agency offers the best overall transit service value by directly operating service or by contracting with an outside vendor.

Sometimes it will be cheaper for the transit agency to provide the services. But in most cases it will be cheaper for an outside entity to provide service.³⁴ In all situations the transit entity should receive at least three outside bids plus an internal bid when applicable. The transit entity should insist on the best value, not simply the cheapest cost. For example, as shown in the table below, Awesome transit service may operate a BRT line for \$5,000,000 with a rush hour headway of 30 minutes. Best transit service may operate the same BRT line for a cost \$7,500,000 with a rush hour headway of 15 minutes. The local transit agency, County Bus, can operate the same BRT line for a cost of \$9,000,000 with a rush hour headway of 10 minutes. Another bidder, Dream, can offer transit service every 15 minutes for \$7,000,000 but with 20-seat buses instead of the traditional 40–60 seat buses. Since Dream's buses are too small, Dream is ruled out. There is not sufficient ridership to operate the line every 10 minutes but every 15 minutes would be preferable to every 30 minutes. So Best has a better bid than Awesome or the local transit agency. But considering purely a low-cost strategy, Awesome transit would be the winner. And without competitive bidding the transit agency may have wasted money on service that they operated more frequently than needed.

Agencies should also bundle their services to ensure that profitable routes are combined with money-losing routes. Sometimes a transit entity will use different contractors, and bundling routes can ensure the best deal for the transit agency.

3) Coordinating Agency and Mobility Management Center

Metropolitan transit services are composed of many different transit agencies (i.e. city, suburban, exurban, university, business-operated) and different technologies (HRT, LRT, BRT, Express Bus, Limited Stop Bus, Local Bus). In the absence of a functioning free market in metropolitan transit, some entity needs to be organizing agencies and coordinating service so that different systems and technologies can work well together. Geography often determines the best coordinating agency structure. For metro areas in one state the State Department of Transportation, transit agency or Metropolitan Planning Organization (MPO) is often the best option to coordinate service. For metro areas that span regions or states, an MPO or other multi-governmental agency may be the best option.

Table 5: Transit Service Options

Transit Agency	Service Frequency	Price	Contract Length	Seats
Awesome	15 minutes	\$8 M	2 years	48
	30 minutes	\$5 M	2 years	48
	60 minutes	\$3 M	2 years	48
Best	15 minutes	\$7.5 M	2 years	48
	30 minutes	\$5.5 M	2 years	48
	60 minutes	\$3.5 M	2 years	48
County	10 minutes	\$9 M	2 years	48
	20 minutes	\$7.5 M	2 years	48
	30 minutes	\$6 M	2 years	48
	60 minutes	\$4.5 M	2 years	48
Dream	15 minutes	\$7 M	2 years	20
	30 minutes	\$5 M	2 years	20
	60 minutes	\$2.5 M	2 years	20

A mobility management center operated by the coordinating agency can help manage the different transit services. While primarily run by the coordinating agency, this center could be supported by state and regional highway and transit entities. This center would encourage route coordination between different transit agencies, enable vanpool and carpool partnerships, and link business organizations and residential associations to transit providers. The center would work with county and city governments to ensure that local areas have the most effective type of transit service for their community needs. The current mobility management center in Denver, which coordinates carpools, vanpools, taxi voucher and hourly car rental, is one example of this mobility management center.³⁵

Part 4

Managed Lanes and Managed Arterials

Today, bus service in the United States tends to operate in road space shared with cars and other vehicles, on both freeways and arterials. But the highest quality bus services operate in “managed lanes”—lanes in which the highway operator restricts use or applies pricing, capacity requirements or other vehicle requirements to proactively manage demand and capacity. The most common types of managed lanes are high occupancy vehicle (HOV) lanes and high occupancy toll (HOT) lanes. Managed lanes make transit more effective and reliable—and therefore more popular—by ensuring faster and more consistent journey times.

The same is true of another new concept in transportation, managed arterials, which allow buses and other paying drivers to bypass traffic lights on arterial intersections by using optional under- or overpasses. These lane management strategies provide an opportunity to ensure the transit service performance is insulated from the impacts of growing congestion over time. By pricing or otherwise controlling the overall demand for a given lane, the operator can ensure this high level of performance, making the service attractive for choice riders.

Of course, the benefits of managed lanes and managed arterials are not confined to transit users—indeed, their attractiveness is partly rooted in the fact that they can give fee-paying (or carpooling) drivers faster, more reliable journey times, while also generating revenue to support the cost of their construction and ongoing management. Accordingly, this study recommends building managed lanes and managed arterials, both to reduce traffic congestion and increase mobility and to provide shared high-quality guideways on which improved bus service can operate.

A. Managed Lanes

The Federal Highway Administration (FHWA) defines “managed lanes” as a highway facility or set of lanes in which operational strategies are implemented and managed (in real time) in response to changing conditions.³⁶ Traditionally, agencies have used various lane management strategies on freeway facilities—including reversible flow lanes, express lanes, HOV lanes, truck lanes and toll facilities—without using any active management or variation in traffic control in response to changing conditions. By comparison, there are several different types of managed lanes, including: HOT lanes with tolls that vary based on demand, exclusive bus- and truck-only lanes, HOV and clean air and/or energy-efficient vehicle lanes and HOV lanes that could be converted into HOT lanes in response to changing traffic and roadway conditions.

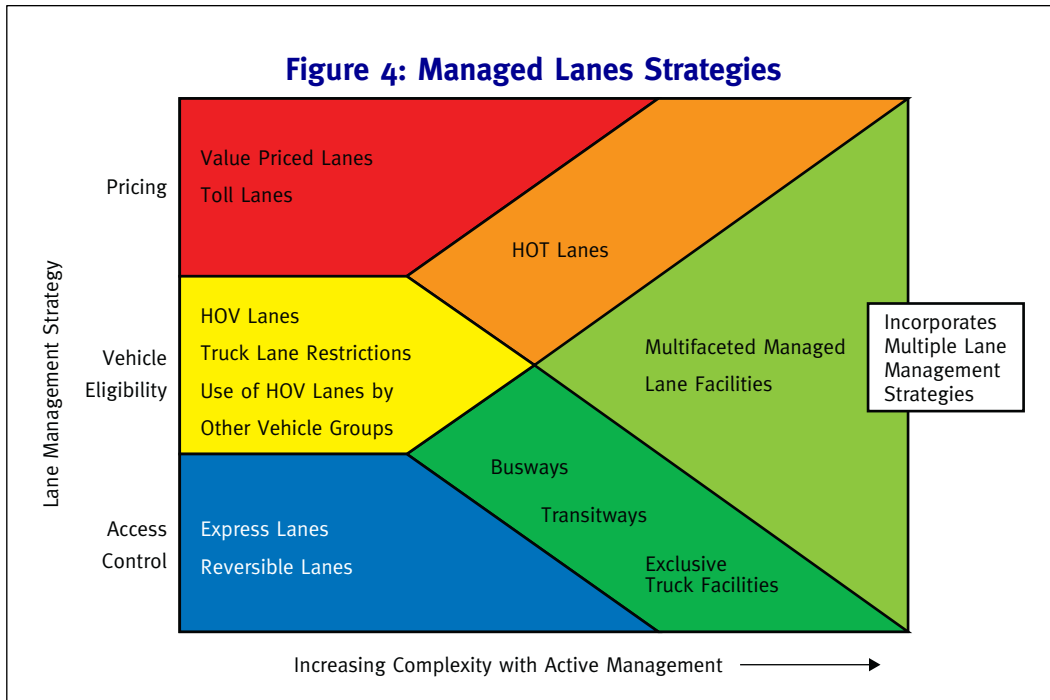
Managed lanes are strongly supported by research. Ginger Goodin, past chair of the TRB Managed Lanes Committee and a managed lane researcher with the Texas A&M Transportation Institute, explains why adding managed lanes better manages congestion than adding general lane capacity:

If you subscribe to the notion that you cannot build your way out of congestion in developed urban freeway corridors, then managed lanes offer an opportunity to preserve a portion of the freeway capacity for a higher level of service. That capacity does not necessarily have to be used exclusively for personal automobile mobility but can be operated flexibly to incorporate transit and ridesharing options according to the needs and goals of the community.³⁷

Existing managed lane projects demonstrate that managed lanes not only help control demand, but also improve the safety, mobility and performance of freeways and transit systems, and offer travel options that save time and enhance the reliability of travel times. Revenue may be generated when one of the operational strategies involves pricing.

Managed lanes can increase the benefits of freeway management. According to FHWA's *Freeway Management and Operations Handbook* (FHWA-OP-04-003), traditional freeway management strategies have the potential to reduce travel times up to 48%, increase travel speeds up to 62%, increase vehicle throughput on roadways up to 25%, decrease crashes by up to 50% and reduce delay caused by crashes that block traffic by up to 50%.³⁸ A 2001 survey of I-15 users in San Diego found that 92% of respondents agreed that managed lanes on I-15 are an effective time-saving option.³⁹

The following chart details the different types of managed lanes.



1. Dynamic Priced HOT Lanes

HOT Lanes are a specific type of managed lane. HOT lanes are limited-access lanes reserved for buses and vanpools but open to single occupant vehicles upon payment of a toll.⁴⁰ However the occupancy requirement varies based on the specific project. All managed lane operators charge single-occupant drivers. Some charge a fee for 2-person carpools, others 3-person carpools and some 4-person carpools.

A key feature of HOT lanes is the fact that pricing can more precisely control the demand for the facility and hence its level of service. HOT lanes use variable pricing that motorists pay if they do not meet the minimum occupancy requirement for free passage.⁴¹ Electronic toll prices are varied to keep traffic moving at speeds of 45–50 miles per hour to maximize throughput. Pricing is more effective than vehicle occupancy criteria, which relies on drivers choosing to pick-up additional passengers in their vehicle. Such lanes provide an option to gridlocked freeways for occasions when people must arrive on time, such as arriving at work or picking children up from daycare.

Tolls vary based on lane demand. During rush-hour when the lanes are more popular tolls can reach \$1.00 per mile, while on nights and weekends tolls can be as low as \$.01 per mile. The concept is to manage demand through tolling and induce drivers who can make their trip outside of rush hour to do so.

The variable tolls charged on managed HOT lanes can provide a large portion of the funds needed to build and maintain the lanes. Tolling on managed lanes on congested highways, such as the I-495 Capital Beltway in Northern Virginia and the North Tarrant Express Managed Lanes project in Fort Worth, has funded 73–79% of the costs.⁴² Tolling on less congested highways can fund 40–60% of the costs. Several metro areas, including Atlanta and Miami, have plans for a comprehensive managed lanes network. These plans include lanes on almost all of the freeways, since a comprehensive managed lane network delivers the best congestion-reduction results. Since these regions contain a mix of very congested highways and less congested highways, engineers and planners estimate that managed lanes can cover between 50% and 75% of the costs of a managed lane network depending on the metro area.

One major consideration for HOT lane operators is deciding if carpools can use the express lane for free. For new managed lanes, most operators are allowing free passage only to buses and vanpools, and requiring all other vehicles to pay to use the lane. The justification is that since highways with HOT Lanes have general purpose lanes that are extremely congested, there is a great demand from single-occupant vehicles to pay to use the managed lanes, and operators should provide these vehicles a choice. Additional tolled vehicles will also reduce construction, maintenance and operations costs resulting in lower tolls, less gas tax revenue needed for the project, or both. For example, the Georgia DOT has decided the reversible I-75 Northwest Managed Lanes and I-75 South Managed Lanes will be free to buses and vanpools but require a toll payment from all cars regardless of occupancy.

2. Converting HOV Lanes to HOT Lanes

Because of HOV lane limitations, many HOV lanes are now being converted to high occupancy toll lanes. Most newly built managed lanes are either HOT lanes or express lanes opened as express toll roads in which all vehicles except buses and vanpools pay.

HOV lanes have been converted to HOT lanes in California, Georgia, Minnesota, Virginia and Texas. Some states have preserved or increased the minimum vehicle occupancy requirement of existing HOV lanes from two or more to three or more, while tolling vehicles that do not meet this threshold and allowing them to use the lane. For example, I-85 in Atlanta raised the minimum occupancy requirement of cars using the lane from two passengers to three. This helped reduce congestion and return the lane to free-flow speeds. Other states have restricted access, at least through congested bottlenecks, in order to better manage flow, sustain travel benefits and more efficiently collect electronic tolls.

While HOT lanes are better than HOV lanes, they are not perfect. Many managed lane operators are still fine-tuning pricing. HOT lanes typically require a ramp-up period of about one year before traffic throughput is maximized. And some brownfield conversions of HOV lanes to HOT lanes have reduced both number of travelers and vehicle throughput.

3. Managed Lane Designs and Configurations

There are several different managed lane designs. Some feature one to three lanes in each direction while others feature one to four lanes that are directional (they operate in different directions based on time-of-day traffic flow). Some managed lanes are separated from the general purpose lane by a concrete barrier, and others feature pylons that can, if necessary, be crossed in emergency situations without damaging automobiles. Still others are separated by pavement striping. Managed lanes separated by a physical barrier offer dedicated exits for traffic in the managed lane. Managed lanes not separated by a physical barrier typically offer a mix of dedicated exits and exits shared with the general purpose lanes. Shared exits are typically on the right and can require vehicles to cross several lanes of traffic. Where freeways intersect, there should be direct entrance and exit ramps between managed lanes on one freeway and managed lanes on the other freeway. Dedicated ramps reduce congestion and weaving and improve safety.

The ideal managed lanes design offers a minimum of two lanes in each direction with a pylon-separated barrier. Two lanes allow faster-moving traffic to pass slower-moving traffic. The pylon-separated barrier offers the safety of a permanent barrier that can be crossed in emergencies. Available right-of-way and budget dictate the managed lanes system. While the 2 X 2 lane system is the most optimal, any type of managed lane is an improvement over no lane.

Dual Managed Lanes System on SR 91 in California with Pylon Buffers



Proposed Elevated Managed Lane System on I-820 and SH 183 in Texas with Concrete Barriers



Note: ETL = express toll lane. Express toll lanes differ from HOT lanes in that they do not allow toll-free access for high occupancy vehicles.

I-15 Directional Managed Lanes in California with Concrete Barrier



I-405 Managed Lanes and Transit Direct Access Ramp in Washington



4. *The Transit Components of Managed Lanes*

For a comprehensive BRT and express bus system to operate optimally in a managed lanes environment, the following components are needed.

Pylons or Concrete Barriers

Managed lanes are separated from general purpose lanes by a concrete barrier, pylons or pavement striping. There are several different types of concrete barriers, including jersey, F-shaped, 9.1 degree single-sloped barriers, constant slope, vertical barriers and barriers specifically designed for trucks.⁴³ State DOTs choose different barriers based on highway traffic and design. Pylons, as discussed above, are the optimal solution. Several different types of pylons and manufacturers are available.

Dedicated Ramps

Managed lanes separated by concrete barriers or pylons need dedicated entrance and exit ramps. These ramps are in addition to ramps for the general purpose lanes. Dedicated ramps eliminate the need to cross multiple general purpose lanes of traffic in order to exit. Crossing multiple lanes can lead to weaving and accidents.

B. Managed Arterials

Managed lanes on limited access freeways and Interstates work well because such roads have limited entry and exit points. Such lanes can have capacity requirements or can be easily tolled because limited access decreases tolling infrastructure needs and allows for practical lane enforcement. But most of the road mileage in major metro areas is on arterials, which are very different. Arterials are high-capacity roads that primarily connect freeways and collector roads at the highest level of service.⁴⁴ They feature multiple intersections with side roads, shopping centers and businesses. Because of this, managing arterial lane capacity and tolling is much more challenging.

A “managed arterial” is an arterial that has been upgraded with a series of grade separations at major intersections. The managed arterial offers drivers the choice of using an overpass or underpass to bypass the intersection and traffic light.⁴⁵ These overpasses or underpasses allow an arterial to provide the same type of dependable travel time as managed lanes. Managed arterials are one of the best solutions to relieving traffic congestion and offering quality transit service on busy arterials. Since the largest chokepoints on arterials are traffic signals at

major cross streets, creating grade separations at these intersections is the optimal way to relieve back-ups and congestion.

Limited resources make funding overpasses or underpasses very challenging, but managed arterials can be financed similarly to managed lanes. Managed arterials are functionally similar to managed lanes as they offer drivers a choice of paying a small fee to use optional lanes to bypass traffic. Because of a high degree of congestion, these overpasses or underpasses can be partially paid for by charging a small toll, generally \$0.15 to \$0.25 per crossing, depending on the size of the intersection and the congestion. For proper operation, the tolling must be done via all electronic tolling (AET). AET uses transponders or sensors to determine the number of axles per vehicle and the corresponding toll rate. Then, toll readers automatically deduct the correct toll amount from the customer's account. Drivers can also choose to continue on the main road and proceed through the signalized intersection for free.

Figure 5: Arterial Overpass



Figure 6: Arterial Underpass



The biggest congestion factor for all arterials is intersection capacity, which defines arterial capacity.⁴⁶ Traffic signals that are used to control vehicular movements at the intersection of two roadways must, by design, reduce the capacity of both roadways by reducing the number of vehicles that can travel through an intersection during a particular time period. “Green time” is the time allotted to a certain movement and is usually expressed as a percentage. For example, if an arterial road has a capacity of 1,800 vehicles per hour per lane with no traffic signals, that same arterial would have a capacity of 1,080 vehicles per hour per lane with that movement receiving green time for only 60% of the hour (0.60 X 1,800). Sixty percent is a relatively large amount of green time for any one movement to have. Taking into account the cross-street-through movements, protected-turning movements, and lost time for clearance intervals, the amount of green time for major movements can easily fall below 50%. In other words, it is common for an arterial lane to have less than 50% of the capacity of its uninterrupted flow counterpart.

Through using underpasses and overpasses, managed arterials provide uninterrupted traffic flow across the intersection. As well, managed arterials will lead to reduced congestion in the untolled lanes since many previous lane occupants will choose to use the overpasses or underpasses. In this way the managed arterial provides not only more lanes, but a different option, which does not further constrain the intersection, as the mere adding of lanes would do.

While converting a six-lane arterial into a managed arterial is slightly more expensive than widening the six-lane arterial to an eight-lane arterial, managed arterials can be paid for through tolls. Even in situations where tolls support only 60–80% of managed arterials costs, substantially less gas tax revenue is needed to upgrade the highway. Managed arterials will lead to reduced congestion in the untolled lanes since many previous lane occupants will choose to use the overpasses or underpasses. Therefore, non-tolled users will benefit providing a strong justification for using gas tax revenue. Traditional arterial widenings, which cost \$10–\$20 million a mile and sometimes more, are paid for by all motorists or all taxpayers regardless of whether they use the road or not.⁴⁷

All of these factors make managed arterials an attractive option for policymakers trying to improve transit and reduce traffic congestion. However, the managed arterial concept is still evolving. Managed arterials were first studied in Lee County, FL (Fort Myers) under the Federal Highway Administration’s Value Pricing Pilot Program, in 2002. The study examined the possibility of using grade-separated overpasses at congested intersections to allow drivers who were willing to pay a toll to bypass the traffic signal and its queue.⁴⁸ It also examined operational issues, public acceptance and cost feasibility, finding that from an

operations standpoint such grade separations are feasible. There are no technical or operational issues that would prohibit their use. With some (non-tolled) grade-separated intersections already in existence in Lee County, this was not a surprising finding. In addition, an overview of managed arterials was presented in 2012 at the National Academy of Sciences Transportation Research Board (TRB) Annual Meeting, and a paper on the subject has been published in TRB's journal, *Transportation Research Record* No. 2297.

While the managed arterial concept is gaining acceptance as a way to address arterial traffic congestion, there is little experience in the physical design, operation and customer acceptance aspects of this new facility. Further, there are impacts to adjacent properties with building grade-separated intersection treatments. As a result of their cost and uncertain operating characteristics, managed arterials are not appropriate for all intersections. They should be considered only in locations where traffic would back up at intersections without grade separations.

1. Transit Components of Managed Arterials

Like express buses, which benefit from operating in managed lanes, bus rapid transit can benefit from operating on managed arterials. While managed arterials will feature grade separation at major intersections, some minor intersections will be at-grade. The following components will help BRT vehicles operate optimally.

Traffic Signal Priority

According to the Federal Highway Administration, traffic/transit signal priority (TSP) is an operational strategy that reduces the delay transit vehicles experience at traffic signals.⁴⁹ TSP features communications between buses and traffic signals, allowing a priority green for the transit vehicle. In this way, TSP can improve transit reliability, efficiency and mobility.

TSP is different from signal preemption, which interrupts the normal signal to accommodate a special event such as a fire truck or an ambulance. For example, an emergency vehicle may send a preemption request that instantly alters the traffic signal timing. Preemption skips or replaces certain signals altogether often causing long back-ups at the intersection. While this is acceptable for emergencies, it is not appropriate for regular use and would likely cause a backlash from drivers. In TSP a change of light is always optional; the computer or a traffic engineer in a control center can override the request.

There are many different types of TSP, including extending greens on the existing phase, altering phase sequences and adding new phases that do not interrupt the overall traffic signal synchronization loop. Transit signal priority has a limited effect on signal timing because it adjusts to normal timing to serve a specific vehicle type. Also, the light cycle will include all phases for all movements. Some of these phases may be shortened, but none will be eliminated.

As traffic signals are updated and become more computerized, TSP is expected to improve substantially. To achieve greater uniformity, a “family” of communication standards was developed known as The National Transportation Communications for Intelligent Transportation Systems (ITS) Protocol (NTCIP) (6).⁵⁰ It provides a set of communication standards for exchanging information among signal control and prioritization systems such as TSP.

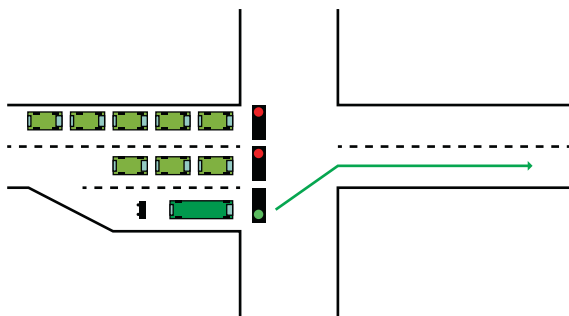
Queue Jumps

Most TSP systems use queue jumps. A queue jump is a roadway feature that provides a preference to certain vehicles, enabling transit vehicles to bypass long queues (or lines) at signalized intersections. Queue jumps are often paired with signal priority treatments, which give buses an early green light or extend a green light. An intersection with a queue jump provides an additional travel lane, which can be transit-only or shared on the approach to a signal. Specifically, queue jumps:

- 6) Help buses to re-enter the traffic stream when a bus lane is ending;
- 7) Allow buses to jump to the front of a queue at a traffic signal after they have picked up passengers at a bus stop, and
- 8) Assist buses in crossing lanes ahead of other traffic to reach a left-turn lane without obstructions.

The diagram below shows a basic queue jump with the bus in the right turn lane receiving a priority signal to move across the intersection. The picture below shows a Seattle area queue jump.

Queue Jump Sketch



Metro Seattle Queue Jump



How, specifically, does a queue jump work? When a bus reaches a red light in a right-turn lane with a queue jump and decides to use it, the bus receives a special signal to continue through the intersection. Sometimes the signal is instantaneous; other times the bus may have to stop completely and wait for a short period of time. The signal typically precedes the signal for other traffic moving in the same direction. Sometimes it will interrupt a signal for cross-traffic or traffic turning left.

It may take several months to a year for roadway users (motorists, bicyclists, walkers) to become familiar with a queue jump. Since a queue jump provides a special green to the right-turn lane, drivers may become confused. Some of them will start moving into the intersection as soon as the bus does. Others may illegally go straight in the right-turn lane to try to get a jump on other traffic. The pedestrian crosswalk signals may need to be modified for the bus priority signals. Enforcement and education will be vital.

Intersections may require minor modifications. Bus stops, at intersections with queue jumps, should be placed upstream of (before) the intersection. If the bus stop is downstream of (after) the intersection, the bus will have difficulty merging into traffic. Advanced stop bars may need to be installed where the right-turn lane ends before the intersection. These bars (painted white lines) stop traffic approximately 50 feet before the intersection to allow buses to merge into the standard lanes before the intersection. Stop bars are not needed at traditional intersections. The picture below illustrates a stop bar.

Stopbar



Examples

Transit signal priority and queue jumps are being used across the United States. King County (Seattle), Washington and Portland, Oregon offer two different examples.

For the TSP system with the King County Metro, the transit vehicle does not have to generate a request for signal priority.⁵¹ Instead, the vehicle communicates its presence to the traffic signal system, which in turn has the ability to generate a signal priority request for the approaching bus.

TSP has improved transit performance in King County. For example, the combination of TSP and signal optimization is responsible for a 40% reduction in traffic signal delay for transit along two transit corridors.⁵² Another one of the observed benefits from TSP in King County was a 35–40% reduction in bus travel time variability.

In contrast with the TSP system in King County, transit vehicles in Portland, Oregon have the ability to decide whether or not to request priority through the automatic vehicle identification integration process.⁵³ The vehicle is equipped with detection equipment similar to that used to provide an emergency vehicle with a preemption request. Unlike preemption, the transit vehicle using intelligent transportation systems only transmits input to the signal control system when it needs priority, such as when it is behind schedule.

Similar to King County, transit vehicles in Portland have experienced some measurable benefits with the TSP implementation. These benefits have included a 10% improvement in travel time and a 19% reduction in travel time variability. With the increased reliability, less schedule recovery time is needed to keep the buses on schedule. Moreover, the benefits of TSP have enabled the Portland transit agency, TRIMET, to avoid having to purchase an additional bus.

C. How Well Do Managed Arterials Work?

In an effort to answer this question, Reason Foundation's 2012 policy study *Increasing Mobility in Southeast Florida: A New Approach Based on Pricing and Bus Rapid Transit* modeled the effect of various different lane configurations on auto, transit and total throughput on arterial roads. To better examine costs and benefits, adding managed lanes to arterials is compared to converting two general purpose lanes to bus lanes and to adding two new bus lanes.

The option of converting one general purpose lane to a bus-only lane in each direction of a six-lane arterial would likely increase congestion. Almost 34% of those people using the corridor would have to shift to transit just to maintain the existing throughput and level of service.⁵⁴ At any lower percentage shift to transit, severe congestion would increase. Since 34% transit use is seven times higher than average U.S. transit usage and higher than the metro transit share for the New York City metro area, a dedicated lane is not the best solution for most arterials.

Another way to examine bus only lanes' effectiveness is per person throughput. The maximum one-way vehicle capacity of the two general purpose lanes is 1,870 vehicles per hour. If drivers switch to transit, the cars that they were using would no longer be in the general purpose lanes. With induced demand (when a highway is widened more vehicles will use the lane), other vehicles would choose to use the lane, keeping the general purpose lane throughput at 1,870 vehicles per hour. But, for every transit percentage less than 34%, total person throughput in the corridor remains below the level of demand (3,250 persons per hour). Unless transit usage in the corridor rises to 34%, converting general purpose lanes to bus-only lanes creates degraded service or a reduced capacity.

The option of adding one bus-only lane in each direction to a six-lane arterial would likely increase total costs. The actual managed arterials roadway conversion would be somewhat more expensive than widening a six-lane arterial to an eight-lane arterial (underpasses would cost slightly more than overpasses, but may be a better fit in many areas). However, managed arterial conversions would require taking less land, affect property values less and be more effective at relieving congestion than widening the road by two lanes. Adding bus only lanes would reduce congestion. A six-lane managed arterial fits in the same right-of-way as an eight-lane arterial. (The eight-lane arterial needs more land to accommodate turning motions at intersections.

An additional major benefit is the ability for managed arterials to complement transit service. The greater the transit usage, the more total throughput of the corridor. For all percentages of transit use, the managed arterial has a significantly higher person throughput than a six-lane arterial with four general purpose lanes and two bus-only lanes. At 4% transit use, the six-lane managed arterial is able to move 3,857 persons per hour compared to 2,240 persons on the 4 GP/2 bus-only arterial. Therefore, the managed arterial has a 72% greater person capacity than the 4 GP/2 bus-only arterial and maintains a significantly higher LOS. At a transit usage of 34% the managed arterial would provide almost 70% greater person throughput, and at a higher level of service.

Table 6: Alternatives for Arterial Improvements

	Restriping*	Convert General Purpose Lanes to Bus-Only Lanes	Add New Bus-Only Lanes	Managed Arterial
Right of way cost	None	None	High	Low
Construction cost	Low	Low	High	Very high
Reduced left turns	Yes	Yes	Yes	Yes
Impact on auto throughput	Minor, negative	Major, negative	Minor, positive	Major, positive
Under-utilized bus lane	Yes	Yes	Yes	No
Impact on congestion	Minor, negative	Major, negative	Minor, positive	Major, positive
Impact on safety	Significant, negative	Some, negative	Minor, positive	Minor, positive
Revenue generation	No	No	No	Yes, significant

* Restriping adds a bus lane and eliminates a general purpose lane

Source: *Increasing Mobility in Southeast Florida*

Part 5

Future Technological Advances

Combining managed lanes, managed arterials, BRT and express bus could revolutionize both highway and transit travel. The following new technologies could make these services even better.

A. New Tolling Technology

Both managed lanes and managed arterials include tolling for certain vehicles. While tolling has long been a preferred revenue source, freeway toll booths and toll plazas have created congested bottlenecks and led to rear-end collisions. But managed lanes and managed arterials will use a different type of tolling—21st century tolling. Around the year 2000, toll road systems began offering customers a way to bypass the tollbooths in separate lanes, without having to slow down or queue up. This open road tolling (ORT) spread rapidly since it reduced toll plaza congestion and accidents, in addition to reducing toll collection costs. It also eliminated the need for drivers to carry large amounts of cash. Since 2010, toll road operators have used the new all-electronic tolling (AET) to dispense with tollbooths and toll collectors.

Using AET for managed lanes and managed arterials has other advantages. It allows toll lanes to be built on constrained freeways and allows drivers on arterials to bypass intersections. Metro areas across the U.S., including Atlanta, Los Angeles, Miami, Minneapolis and Seattle, use AET tolling in their managed lanes.

Most tolling entities are moving toward interoperability, or the ability to use any toll transponder on any tollroad throughout the U.S.⁵⁵ Interoperability will make it easier for travellers to use managed lane and managed arterial systems away from home. E-Z Pass is currently the leading toll technology with 14 north-eastern and midwestern states. But California, Florida and Texas each have their own systems. The recently passed surface transportation bill, MAP-21, mandates interoperability by 2016.

Emerging technologies will make using managed lanes and managed arterials easier. New smart phone applications that display real time traffic help consumers decide whether or not they want to use the managed lanes. Many managed lane operators have special applications customized for their roads. Future connected vehicle technologies that permit less spacing between vehicles could lead to new managed lanes on constrained facilities.

B. Real-Time Transit Information

According to recent research from Carrel, Halvorsen and Walker of the University of California, Berkeley, one of the reasons commuters do not take transit is the wait time.⁵⁶ Another reason is that commuters do not know when the next bus will arrive. New computer and mobile applications can provide up-to-the-minute updates. These applications track bus locations and provide real time updates. Not only do passengers know when the bus will arrive, they can actually monitor the bus's location as they wait. There are many variations of this technology. The only requirement is for the transit operator to open source its data to application developers.

Highway drivers can also benefit from this technology. Many new cars have built-in GPS systems, which can suggest routes and warn drivers of upcoming congestion. This information can help drivers choose whether to use the managed lanes and/or managed arterial crossings.

Part 6

Applications of the Comprehensive Network

This study suggests how the following different components added to existing local bus service, and in some cities limited-stop bus service, can help build a new type of 21st century transit system:

- 9) **Bus Rapid Transit (BRT):** BRT is an enhanced bus service that operates with characteristics of a dedicated guideway including signal prioritization, dedicated lanes at intersections and expedited fare collection systems. As BRT mainly operates on arterials, has frequent stops along the transit line every ¼ to ½ mile, and serves multiple origin and destination pairs, its service characteristics are similar to heavy or light rail.
- 10) **Express Bus:** A bus service that provides point-to-point service from one of many park-and-ride lots in the suburbs to business districts throughout the city. Many metro areas such as Atlanta and Houston have several different bus routes serving a park-and-ride area or have intermediate stops where commuters can transfer from one bus to another. Express bus mainly operates on freeways or expressways, making its service characteristics similar to commuter rail.
- 11) **Managed Lanes:** A highway facility or set of lanes in which operational strategies are implemented and managed (in real time) in response to changing conditions. Express buses can travel for free in the managed lanes, offering a consistent, reliable trip for commuters.
- 12) **Managed Arterials:** An arterial facility or set of lanes in which pricing strategies are implemented and managed (in real time) in response to changing conditions. Bus rapid transit vehicles can travel for free on managed arterials, offering a consistent, reliable trip for commuters.

Let's examine how three commuters might use this 21st century transit system:

Sue lives in Super Suburbia. But her job is downtown. Before the new managed lanes, she tried the direct bus service but the bus became stuck in the same highway traffic congestion as cars. Since it cost her \$20 per day to park

downtown and \$150 per month in gas and wear and tear costs on her vehicle, she saved money by taking the bus instead of driving her car. However, the trip was substantially longer. Local bus service did not serve her residential area and driving to the express bus parking lot, parking, waiting for the express bus to arrive and traveling to downtown in congested traffic took substantially longer than driving. After using the direct bus for three months, she returned to driving alone.

With the new managed lanes, Sue has again started to use the express bus service. The bus trip on the freeway has decreased from 60 minutes to 45 minutes. The total trip from Sue's house to the transit station to her workplace has decreased from 75 minutes to 60 minutes. The transit agency has seen ridership on this route increase by 30%. The agency has added additional buses so that instead of operating every 30 minutes, the express buses can operate every 15 minutes. Ridership from Sue's area has increased so much that the transit agency is considering adding local bus service from Sue's neighborhood to the transit station. And Sue is now much more relaxed when she gets to work.

Charlie is not the traditional suburban to downtown commuter. He lives and works in the suburbs. But his commute distance from Carrot Cave to Pumpkin Peak is 20 miles. He rides in a vanpool with other Carrot Cave residents who work in Pumpkin Peak. The arterial that the vanpool uses has significant congestion. The vanpool frequently must wait three light cycles at many of the cross streets. The 20-mile route takes 60 minutes most days. Pete is considering dropping out of the vanpool and driving himself because the trip takes so long.

With the new managed arterials, Charlie's vanpool ride is 25 minutes shorter. Instead of sitting through multiple light cycles at each major cross street, the vanpool uses the new managed arterial. As a registered vanpool, the passengers do not have to pay to use the queue jump tunnels. And since the vanpool does not have to sit in congestion at traffic lights, it is in almost continuous motion. Pete is happy with the quicker ride and has no plans to leave the vanpool. The vanpool has added another rider, Allan. Since vanpool users each pay a portion of the vanpool expenses, with an additional rider everybody's expenses decrease.

Tom reverse commutes from his center city residence to his suburban job every day. Tom lives within walking distance of the express bus line but getting to his job requires transferring to a local bus in the suburbs. His express bus trip was fairly quick, generally 20 minutes. But some days, even though most traffic traveled in the opposite direction, the route could become slow and congested. The bigger problem was the local bus ride from Alligator Alley to Zebra Zenith.

It took 40 minutes to travel seven miles on the arterial. Occasionally, Tom has a meeting after work so he has to drive. Driving takes about the same amount of time as taking transit but Tom prefers transit when it fits into his schedule. Tom liked living in the city but he was considering either moving to the suburbs or switching jobs because the commute was becoming intolerable.

With the combination of the managed lanes and managed arterials, Tom's trip has dropped from 60 minutes to 35 minutes. His bus commute in the freeway managed lanes is now five minutes quicker. He did not think the HOT lanes could improve his trip that much, but the difference is significant. More importantly, due to the demand and corridor improvements, the transit agency is now operating a BRT on the arterial that uses the new underpasses. The combination of fewer stops on the BRT service and the underpasses on the arterial reduce his arterial commute from 40 minutes to 20 minutes. And the underpasses are free for bus riders. Tom still needs to drive some days and he sometimes takes advantage of the managed lanes and managed arterial to reduce his driving time. Tom can now sleep later. He can continue his lifestyle of living in the city and working in the suburbs.

While local bus, express bus/BRT, managed lanes and managed arterials are four different concepts, to create a comprehensive transit network all four need to work together. All metro areas should study how they can implement such a transportation system that will benefit drivers and transit users at a low price.

Part 7

Current Managed Lanes and Arterials in U.S. Cities

While no region has all aspects of this 21st century transit system, three metro areas have limited systems:

- South Florida (consisting of Miami-Fort Lauderdale-West Palm Beach metro area), which has BRT on managed lanes and is examining managed arterials;
- Minneapolis, which has an extensive managed lane network, and
- Los Angeles, which is converting its HOV lanes to HOT lanes

A. South Florida

Under an Urban Partnership Agreement (UPA) grant, Florida's Department of Transportation, the MPOs of Miami-Dade and Broward Counties, the two county transit agencies and Florida's Turnpike Enterprise are working together to widen I-95 from 10 lanes (four general purpose lanes in each direction and one HOV lane) to 12 lanes (four general purpose lanes in each direction and two managed lanes in each direction).⁵⁷ The project stretches from I-195 (exit 4) in Miami to Broward Blvd. in Fort Lauderdale. Phase one has been completed (from I-195 to SR 826); phase two is under way for a completion date in 2014. Further plans call for a managed lanes network encompassing most of the tri-county region's freeway system.

The managed lanes feature electronically collected, variably priced tolling via "SunPass" transponders.⁵⁸ ("Sunpass" transponder technology is inter-operable statewide in Florida.) These tolls vary based upon network demand. Prices are set to ensure the managed lanes flow freely at 50 miles per hour or more. Changeable message signs notify motorists of the current toll rate, which may change as often as every three minutes. Registered vanpools, carpools with 3+ occupants and hybrid vehicles can use the lanes for free after registration. Transit, school and intercity buses along with motorcycles can travel in the managed lanes for free without registration.

South Florida also has several express bus routes that have benefited from the managed lanes. Both Miami-Dade Transit and Broward Transit have added new service in coordination with the managed lanes project. Service in the peak direction during rush hour operates between the following locations:

1. Downtown Miami and Fort Lauderdale every 7.5 minutes⁵⁹
2. Downtown Miami and University Dr. and Pines Blvd in the Broward County suburbs every 13.5 minutes
3. Downtown Miami and the Miramar Town Center route A every 15 minutes
4. Downtown Miami and Miramar Town Center route B every 20 minutes

Transit ridership on these express bus routes increased 22% over a year despite a 12% decrease in overall transit ridership.⁶⁰ Fifty-three percent of new riders on the 95 Express Bus service indicated that the express lanes influenced their decision to use transit and 38% of new rides said that they used to drive.

While managed lanes and expanded express bus service have been implemented in many regions, South Florida is unique because it is also considering managed arterials. While no decision has been made, research indicates managed arterials could reduce congestion on arterials just as managed lanes have decreased congestion on I-95. (Some regions such as DeKalb County, Georgia have implemented BRT service on arterials with priority signaling and queue jumps.⁶¹ However, no region has implemented this BRT service with managed arterials.)

South Florida is unique in that the transit system (express bus and BRT) and the managed lane and managed arterial network are being developed together. Several studies have examined extending these concepts throughout South Florida. The engineering firm, HNTB, will be releasing a study in June 2014. A Reason Foundation study includes four key components:⁶²

- A region-wide network of expressway managed lanes (MLs) like those on I-95, encompassing 302 route-miles and 1,117 lane-miles;
- Upgrades for 14 key arterials (107 route-miles) with underpasses at major signalized intersections, converting them into managed arterials;
- Premium bus rapid transit (BRT) as in the current long-range plan, but operating mostly on the “virtually exclusive busways” made possible by the network of MLs and MAs, rather than using bus-only lanes;
- A series of system operational improvements, including extensive expressway ramp metering and further expansion of traffic signal coordination.

When the Florida Department of Transportation (FDOT) modeled the proposed network, the results showed that Vehicle Hours of Delay (VHD) would be 13%

less with the proposed ML/MA network than without the network.⁶³ And South Florida's gross regional product was estimated to be \$3.5 billion per year greater thanks to the increased mobility.

A potential express bus and BRT network was developed as part of the Reason Foundation March 2012 study *Increasing Mobility in Southeast Florida*. The study proposed adding variably priced managed lanes to all of the region's freeways, including toll roads.⁶⁴ This would add 1,117 lane-miles to 24 different limited access freeways. The study also proposed adding 14 managed arterial corridors, ranging in length from two to 25 miles. Managed arterials were proposed on corridors that were expected to have extreme congestion (LOS F) by 2030. These changes would be augmented by non-recurrent congestion reduction techniques such as ramp metering and emergency response patrols. Modeling in South Florida suggested that a complete managed lanes and managed arterial system would save 66,049,500 annual hours of delay or 47% of the current total delay. These savings total \$1.004 billion for cars and \$350 million for trucks. Net farebox revenue for the BRT system is estimated at \$31.3 million per year in today's dollars.

B. Minneapolis

Under a separate Urban Partnership Agreement between the U.S. Department of Transportation, Minnesota DOT and the Twin Cities Metropolitan Council, the agencies are working together to convert sections of HOV lanes on I-35W and I-394 to HOT lanes.⁶⁵ The agencies are also operating dynamically priced shoulder lanes on sections of I-35W, increasing park-and-ride and transit capacity along the corridors by adding new BRT services, park-and-ride lots, BRT stations and ITS technology.⁶⁶

The managed lanes, which stretch for 25.5 miles on I-35W and 11 miles on I-394, feature electronically controlled tolls using MnPASS transponders. Prices are set to ensure the managed lanes flow freely at 50 miles per hour or more. Changeable message signs notify motorists of the current toll rate, which may change as often as every three minutes. Registered vanpools, carpools with 3+ occupants and hybrid vehicles can use the lanes for free after registration. Transit, school and intercity buses along with motorcycles can travel in the managed lanes for free without registration.

Minneapolis has added 26 new express buses on eight new routes connecting suburban destinations such as Lakeville with downtown Minneapolis. MinDOT and the Twin City Council built six new or expanded park-and-ride lots. A new BRT station with a transit bypass lane was built above I-35W.

Table 7: New Express Bus Service in Minneapolis

Route No.	Weekday Ridership Increase	AM Rush Headway	PM Rush Headway
250	0.2%	5	30
252	20.3%	60	60
264*	209.9%	30	30
288	35.5%	15	15
597	23.9%	15-30	15-30
467	29.4%	10	10
477	6.3%	5-10	5-10
579	168.1%	60	60

* This route operates continually from 5:45 AM to 7:00 PM with midday headways of 60 minutes

C. Los Angeles

Under a Congestion Reduction Demonstration Agreement among the U.S. Department of Transportation, the California Department of Transportation and the Los Angeles County Metropolitan Transportation Authority, the California agencies agreed to convert the HOV lanes on I-10 and I-110 into HOT lanes.⁶⁷ This is part of a larger plan to implement a network of congestion-priced lanes throughout the metro area.

The first phase includes 28 lane-miles on I-10 from I-605 to Alameda Street and the 33 miles from 182nd Street to Adams Blvd. The lanes feature electronically controlled FAStack transponders. Prices are set to ensure the managed lanes flow freely at 45 miles per hour or more. Registered vanpools, carpools with 2+ or 3+ occupants (depending on corridor and time of day) and hybrid vehicles can use the lanes for free after registration. Transit, motorcycles, school and intercity buses can travel in the managed lanes for free without registration.

Los Angeles has also added 59 new buses mostly for the Metro Silver Line BRT.⁶⁸ Bus boardings for existing buses are up between 45% and 103% depending on location.⁶⁹ The line now operates on a 10-minute headway. To improve existing Metro Rapid service the city added transit signal priority for 15 downtown intersections on Figueroa and Flower Streets. The city added 30 bus bays to the El Monte Transit Center and added 143 parking spaces at the Pomona Metrolink Station. Los Angeles has made other improvements such as expanding its vanpool program, improving local bus access, adding ticket vending machines and supplementing signage.

There are several reasons why South Florida's, Minneapolis's and Los Angeles's experiences are transferrable to other large metro areas. Such regions are relatively large travel markets with high volumes of commuters, constrained existing facilities and long transit trips. Such conditions are necessary to make some of the capital investments and win the public's acceptance of pricing.

Part 8

Conclusion

Metro areas face two significant transportation challenges: traffic congestion continues to worsen and transit service remains inadequate. Policy makers typically choose either to reduce congestion or increase transit service. Budget challenges make addressing both problems challenging.

This study proposes a solution that combines managed lanes, managed arterials, express bus, bus rapid transit (BRT) and local bus to reduce traffic congestion and create a 21st century transit system. For highway and road users, managed lanes and managed arterials provide an alternative to congested general purpose freeway lanes and standard arterials. For transit users, managed lanes provide a reliable, consistent corridor for express buses traveling from suburb to suburb, suburb to downtown and downtown to suburb. Such buses offer an alternative to commuter rail. Managed arterials provide a reliable, consistent corridor for bus-rapid transit traveling throughout the metro area by combining priority signaling, turn lanes at minor intersections and bypasses at major intersections. BRT is an alternative to heavy rail and light rail.

These new roadways and transit services are largely self-supporting with automobile users paying the roadway construction and maintenance costs for automobile and transit users. The costs to build, maintain and operate these facilities are substantially cheaper than rail alternatives. Most U.S. metro regions need to improve both their roadway and transit facilities. And 21st century transit provides a way for metro areas to do just that effectively and efficiently.

Appendix A

Appendix A: Metro Areas with Managed Facilities

**Table A1: Metro Areas with Bus, HOT and HOV Lanes
(In Alphabetical Order by State)**

Metro Area	Highways w Managed Lanes	Type	Metro Area	Highways with Managed Lanes	Type
Phoenix	I-10, I-17, US 60, SR 51, SR 103, SR 101, SR 143, SR 202, SR 303	HOV	Minneapolis	I-35E, I-35W, I-94, I-394, I-694, US 61, US 169, SR 5, SR 7, SR 36, SR 47, SR 51, SR 62, SR 65, SR 77, US SR 252, CR 1	HOT, Shlder
Los Angeles-Orange County –San Bernardino-Riverside	I-5, I-10, I-105, I-110, I-210, I-215, I-405, I-605, SR 14, SR 22, SR 55, SR 57, SR 60, SR 71, SR 73, SR 91, SR 118, SR 133, SR 134, SR 170, SR 241, SR 261	HOT, HOV	New York City-Northern New Jersey	New Jersey Turnpike, I-495	Buswy HOV
Sacramento	I-80, US 50, SR 99	HOV	Charlotte	I-77	HOV
San Diego	I-5, I-15, SR 125	HOT	Portland	I-5, I-84	HOV
San Francisco-Oakland-San Jose	I-80, SR 84, SR 92, I-580, I-680, I-880, US 101, SR 85, SR 87, SR 237	HOT, HOV	Memphis	I-40	HOT
Denver	I-25, US 36	HOT, HOV	Nashville	I-24, I-40	HOV
Hartford	I-84, I-91, I-384	HOV	Dallas-Fort Worth	I-35, I-635, US 67, US 75	HOT, HOV
Miami	I-95, I-595, FL Turnpike, US 1, SR 836	HOT, HOV	Houston	I-10, I-45, US 59, US 290	HOT, HOV
Atlanta	I-20, I-75, I-85	HOT, HOV	Salt Lake City	I-15	HOT
Chicago	I-90, I-94	HOV	Washington DC	I-66, I-95, I-270, I-495	HOT, HOV
Baltimore	I-95	HOT	Norfolk	I-64	HOV
Boston	I-90, I-93	HOV	Seattle	I-5, I-90, SR 14, SR 167, SR 520, SR 522,	HOT, HOV
Detroit	Michigan Ave	ARTL, HOV	Milwaukee	I-94	HOV

Source: CalTrans, California Managed Lanes, FHWA Converting HOV lanes to HOT lanes
Also Memphis: I-40 HOV

Table A2: Metro Areas with HOT Lanes (In Alphabetical Order by State)

Name	Location	Form of Priced Managed Lane
I-15 FasTrak	San Diego, CA	HOT lane
I-680 Express Lane	Alameda County, CA	HOT Lane
Metro Express Lanes (I-10, I-110)	Los Angeles, CA	HOT Lanes
SR 91 Express Lanes	Orange County, CA	HOT/ETL Hybrid
SR 237/880 Express Lanes	San Jose, CA	HOT Lanes
I-25 HOV Express Lanes	Denver, CO	HOT Lanes
95 Express	Miami, FL	HOT Lanes
I-595 Express	Fort Lauderdale, FL	HOT Lanes (under construction)
Express 85	Atlanta, GA	HOT Lanes
I-95 Express Toll Lanes	Baltimore, MD	ETL
MnPass Express Lanes	Minneapolis, MN	HOT Lanes
LBJ Express	Dallas, TX	HOT Lanes (under construction)
North Tarrant Express	Fort Worth, TX	HOT Lanes (under construction)
Katy Tollway	Houston, TX	HOT Lanes
Metro HOT Lanes (5 corridors)	Houston, TX	HOT Lanes
I-15 Express Lanes	Salt Lake City, UT	HOT Lanes
495 Express Lanes	Northern Virginia	HOT Lanes
SR 167 HOT Lanes	Auburn, WA	HOT Lanes

Source: Federal Highway Administration, Tolling and Pricing Opportunities

About the Author

Baruch Feigenbaum is a transportation policy analyst at Reason Foundation, researching and implementing transportation policy reforms. He wrote *Getting Georgia Going*, an in-depth transportation study detailing the Georgia 1% Special Purpose Local Option Sales Tax that was cited by leaders both for and against the tax. He has also written about public-private partnerships, the federal TIGER program, high-speed rail and bicycle commuting. He is a member of the Transportation Research Board Intelligent Transportation Systems Committee and is actively involved with the Revenue and Finance, Bus Transit Systems, and Metropolitan Planning and Processes Committees. He is a council member of the Transportation and Research Forum Washington Chapter, the American Planning Association, Institute of Transportation Engineers, and Young Professionals in Transportation. His work has been featured in the *Atlanta Journal-Constitution* and the *Washington Post*. Prior to joining Reason he handled transportation issues on Capitol Hill for Representative Lynn Westmoreland. He earned his Master's degree in City and Regional Planning from the Georgia Institute of Technology.

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- Light Rail Transit (LRT)*: A rail technology featuring trains powered by overhead electric wires. Light-rail can range from a streetcar that operates in a lane shared with automobiles to a two-to-three-car train that operates in its own right-of-way so it does not have to stop for cars. LRT may approach HRT capacity and operating characteristics if grade-separated. Because of the smaller number of people carried, LRT systems are also called low-capacity rail. Los Angeles, Dallas, Houston, San Diego, Denver, and Portland have light rail systems.
- Commuter Rail (CRT)*: A rail technology featuring trains powered by locomotives operating on train tracks often owned by freight railroads, the commuter rail agency or Amtrak. CRT typically transports people from suburban or exurban areas into the central city. New York, Los Angeles, Chicago, San Francisco, Philadelphia, Washington D.C. and Boston have extensive commuter rail systems.
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