Reason Foundation
Policy Study No. 452
October 2016

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A Win-Win Combination

by Robert W. Poole, Jr.

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Executive Summary

Enhanced transit, such as Express Bus and Bus Rapid Transit (BRT), is gradually gaining acceptance among urban transit agencies and transportation planners, generally because the capital and operating costs are lower than those of light rail and commuter rail systems. Many agencies' preferred model for implementing BRT is on bus-only lanes. With only a few exceptions, transit agency and Metropolitan Planning Organization (MPO) planners have not fully taken advantage of the synergy that exists between priced "managed" lanes on expressways and higher-speed, higher-quality bus transit. Moreover, since the majority of proposed enhanced bus systems are planned for arterials, planners have seen no way to adapt the principle of priced lanes from their current use on expressways to use on arterials.

The synergy between enhanced bus and priced highway facilities makes it feasible to mix high-performance bus service with tolled automobiles. By using a priced, shared facility, the transit system obtains use of the virtual equivalent of exclusive bus lanes—but *without having to fund this new guideway* capacity out of limited transit capital budgets. And because large metro areas are moving toward building networks of priced managed lanes on their freeway systems, the potential now exists for region-wide Express Bus service using those networks.

Because conventional wisdom has been unable to figure out how to use pricing on congested arterials, current planning for BRT Heavy on arterials assumes the use of bus-only lanes. In most suburban cases, none of the proposed ways of implementing bus-only lanes on congested arterials is viable, from either a person-throughput or a traffic-flow perspective. To avoid reducing the person throughput of such arterials, buses in bus-only lanes would have to attract unprecedented numbers of bus users, which seems unrealistic in metro areas where peak-period transit mode share is in the vicinity of 3% to 5%.

By contrast, the Managed Arterial concept would address the most important capacity limitation of arterials: the signalized intersection. Converting an arterial into a Managed Arterial (MA) involves adding electronically tolled grade separations at those intersections, enabling paying motorists as well as Express Bus and BRT Heavy buses to bypass the intersections. A six-lane arterial reconfigured in this manner would have 69% more capacity than before, and 31% more capacity than if it were widened to eight lanes. Preliminary indications are that the toll revenues would cover a large fraction of the cost of adding the grade separations.

In addition to major arterials for which BRT Heavy service is planned, another candidate for MA treatment is the small number of exclusive busways in the United States. The first such busway conversion to something similar to the MA model appears to be feasible in the Miami area, as shown in a feasibility study commissioned by the Miami-Dade Expressway Authority (MDX). A similar busway conversion in Los Angeles might also be feasible and is worth further study.

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Part 1

Introduction

During the last four decades, dozens of U.S. metro areas have sought to improve their transit systems, aiming to reduce the long-term downtrend in ridership that occurred following World War II. While a handful of very large metro areas built heavy rail systems during the 1960s and 1970s (e.g., Atlanta, Baltimore, Miami, San Francisco, Washington, D.C.), most of the new rail transit added since then has been either light rail or commuter rail. The latter systems had lower capital costs than heavy rail (if they were implemented on existing railroad tracks), making federal, state, and local transit capital funding dollars go further. Transit agencies generally intended to boost "choice" ridership by investing in rail transit, moving beyond the de-facto mission of their bus systems as the provider of transportation for generally lower-income, transit-dependent riders.

Unfortunately, in many cases the addition of rail transit has failed to increase a metro area's overall transit usage. Commuting data from the 2013 American Community Survey show that work-trip mode shares for transit and driving alone in 23 metro areas that opened new rail transit service since 1970 have changed very little. As shown in Table A-1 in the Appendix, transit's market share decreased in 12 and increased in only 10 of these metro areas. The average of those with reduced transit share was a 1.2% decrease, while the average increase of the other 10 was 0.6%. Moreover, the drive-alone percentage increased in 18 of the 23, while decreasing in only four. Thus, the rail transit investments to date have generally failed to "get people out of their cars," as planners had hoped.

One possible reason for rail's modest impact is that the cost of building and operating the rail lines reduced the funding available for operating and maintaining the bus system (or led to bus fare increases, as occurred in Los Angeles). Many transit agencies understandably reconfigured a number of their bus routes to feed the mostly radially oriented rail lines, which reduced the grid-like configuration of the bus system and hence its utility for some of its transit-dependent riders.

Conventional bus transit systems can be divided into two different models: radial (focused on serving the central business district) and multi-destination. Florida State University researchers Jeffrey Brown and Gregory Thompson assembled a database on transit systems from 45 metro areas with between one million and five million people. They found that the radial model was significantly less productive than the multi-destination model. Their follow-up case study compared the multi-destination grid model of Broward County, FL (Fort Lauderdale) with the radial system of Tarrant County, TX (Fort Worth). They found that

Broward County Transit's grid system delivered four times as much service, with higher productivity for each mile of service.[1]

Another factor in the decline of transit's mode share in many metro areas has been the continued suburbanization of both housing and jobs. For several decades now, the largest fraction of commuting trips has been suburb-to-suburb, rather than the traditional suburb-to-CBD (central business district) pattern.[2] Yet most rail lines that have been implemented have served radial corridors, and many bus routes are reconfigured, as noted above, to feed those radial rail lines. This makes the transit system less conducive to serving a large fraction of work trips effectively.

In 2012 the Brookings Institution analyzed data from 371 transit providers in America's 100 largest metro areas.[3] It found that only 27% of jobs could be reached via transit (one-way) within 90 minutes. For reference, the average nationwide (one-way) commuting time, mostly via car, is 26 minutes. Economist David Levinson did a comparable study of access to jobs via auto commuting in the largest 51 metro areas. As of 2010, in 61% of those metro areas, people could reach 100% of the jobs by car (one-way) within 30 minutes or less.[4] Within 40 minutes, 100% of jobs could be reached in 76% of those metro areas, and within 60 minutes 100% of jobs could be reached in all 51 metro areas. The roadway system is ubiquitous, connecting every origin with every destination. By its nature, the transit system cannot be ubiquitous in this way. But a radial transit system is a poorer fit than a grid-type system.

The question before us is this: Can we figure out ways to increase transit use cost-effectively via enhanced bus service and uncongested guideways?

Enhanced Bus Basics

Factors such as these have led to a growing interest in enhanced bus alternatives. Three types of bus transit offer service that goes beyond basic municipal bus service in various performance and service features, potentially offering benefits similar to those of rail transit in lower-cost and more-flexible ways. They are as follows:

- **Express Bus** refers to a service that links residential areas to an employment or commercial area by making various stops in the residential area, traversing a non-stop line-haul route on an exclusive or virtually exclusive guideway, and then making a number of stops in the employment or commercial area.[5] (Example: Miami's 95 Express)
- **BRT Heavy** refers to a Bus Rapid Transit service that has an exclusive guideway, unique station design, larger vehicles, SMART cards, off-board fare collection, transit signal priority, and more-frequent service.[6] (Example: Los Angeles Orange Line)
- **BRT Lite** refers to BRT service that shares a lane but has some priority compared with other vehicles such as transit signal priority and/or queue jumps, uniquely identified stops, larger vehicles, SMART cards, off-board fare collection, and more-frequent service.[7] (Example: Los Angeles Metro Rapid)

The principal focus of this paper is Express Bus and BRT Heavy. Some definitions of these services specify exclusive guideways, but in this paper that is amended to include *virtually* exclusive, meaning corridors in which traffic flow is managed by variable pricing to ensure uncongested conditions, typically at Level of Service C. From a bus operations perspective, what matters is not whether there are non-bus vehicles in the lane but whether that lane is reliably uncongested. Variably priced managed lanes have demonstrated such performance over their more than two decades of existence.

One of the first federal government assessments of BRT was conducted by the Government Accountability Office (then called the General Accounting Office) in 2001.[8] GAO analysts reviewed 20 BRT systems (both Heavy and Lite) and 18 light rail projects. They found that "The Bus Rapid Transit systems generally had lower capital costs per mile than the Light Rail systems," with the former ranging from a low of $200,000 per mile (for a BRT Lite system) to $55 million per mile (for a BRT Heavy system using an exclusive busway). The light rail systems ranged in capital costs from $12.4 million to $118.8 million per mile. These numbers are all in 2000 dollars, so are considerably lower than those for more recent light rail projects in Table A-2 in the Appendix.

Since that time, the Federal Transit Administration (FTA) has gradually embraced BRT, creating a Small Starts program that includes grants for BRT systems. In 2011, FTA Administrator Peter Rogoff made widely quoted comments urging more transit agencies in medium-sized metro areas that were seeking New Starts rail funding to reconsider the merits of BRT, both Lite and Heavy.[9]

Enhanced Bus's Operational Advantages

Although much of the discussion about enhanced bus in recent years has focused on its lower capital costs, that is probably not its most important advantage compared with rail transit. One of the most detailed studies of the potential of BRT in the United States, published in 2011 by the Institute for Transportation & Development Policy (ITDP), cited three main advantages (which also apply to Express Bus):

- **Speed of Implementation:** The time from planning to opening tends to be far shorter for enhanced bus than for rail-based alternatives. (For BRT Lite, there is seldom any environmental clearance requirement.)
- **Cost:** Capital costs tend to be considerably lower than those for rail-based mass transit alternatives; operating costs are also lower in some contexts.
- **Network Connectivity:** Since portions of the service can operate on normal streets, it is much cheaper and faster to establish a full network using bus-based mass transit. In this way, modern BRT can offer more one-seat rides than the typical trunk-and-feeder systems offered by most light rail, heavy rail, or commuter rail systems.[10] The same applies to Express Bus.

The latter point is sometimes referred to as greater flexibility, but that seriously understates its importance. First, there is considerable empirical evidence showing that significantly more people will opt for transit to get from point A to point B if they do not have to transfer from one vehicle to another.[11] (This is referred to as a "one-seat ride.") Also, data show that people perceive time spent waiting for a transit vehicle to arrive as subjectively longer than time spent in the vehicle, in motion. Thus, a transit mode that can offer a significantly higher fraction of one-seat rides will, all else equal, attract higher ridership.

The ITDP report contrasts two different BRT modes of operation. The "trunk mode" envisions BRT Heavy (exclusive guideway) serving a corridor from a transfer terminal at one end to another such terminal at the other end. By contrast, in the "direct service mode," multiple bus routes use the corridor, each of them picking up passengers from several different local areas at one end of the corridor, making a line-haul trip in the dedicated lane the length of the corridor, and then serving various destinations at the other end. (This is essentially an Express Bus model.) This second model provides significantly more one-seat rides to people making use of the corridor for the higher-speed (express) portion of the trip.

Elsewhere, that report shows how an alternatives analysis that considers a BRT alternative to a rail project can "cook the books" against bus by modeling the BRT as operating in the trunk mode, rather than in the far more attractive (to riders) direct service mode. It cites examples of this occurring in the comparison of BRT and rail in both the Detroit Woodward Avenue case and the 2002 Silver Line route in northern Virginia, both of which ended up selecting rail over BRT, at least in part because of modeling only the inferior BRT alternative.

Another difference between rail and enhanced bus relates to the benefit of rail being permanently located in the specific corridor. The intended benefit is an increase in land values near stations, due to the access provided (on a long-term basis) by the rail line and its stations. There are certainly examples of this occurring, but the phenomenon is far from universal. Robert Cervero, for example, examined the extent to which higher-value land uses developed adjacent to BART stations in the East Bay region of the San Francisco metro area. He found no consistent pattern, which he hypothesized was due to local opposition to higher-density zoning around most station locations—a very real phenomenon.[12]

The flip side of rail's permanence is the problem of sunk costs. If an expensive rail line is built in a particular corridor, and ridership turns out to be far below projections, the major capital costs (the rail infrastructure and stations) are sunk and cannot readily be recovered and put to better use elsewhere. By contrast, if a BRT service implemented in the same corridor turns out to be a dud, the buses could be shifted to a more promising corridor, and the right of way could be repurposed to operate as express toll lanes or general purpose lanes in most cases.

Expressway Managed Lanes and Enhanced Bus

Priced managed lanes as of early 2016 are in operation on the freeway systems of 16 large metro areas across the country, including Atlanta, Baltimore, Dallas, Denver, Houston, Los Angeles, Miami, Minneapolis/St. Paul, Salt Lake City, San Diego, San Francisco, Seattle and Washington, D.C. Most of these projects are conversions of HOV lanes to high-occupancy/toll (HOT) lanes, but others represent new lanes funded largely or entirely by the toll revenues generated from vehicles using the lanes. Managed lanes use variable toll rates to limit the number of vehicles to the maximum number compatible with maintaining free-flow conditions. Since adjacent general-purpose lanes in major metro areas often operate under stop-and-go conditions during peak hours, the actual vehicle throughput per lane on the managed lanes is typically much higher than in the general lanes.

The fact that high speeds and high flow can be combined and sustained makes managed lanes an excellent "guideway" for Express Bus and some forms of BRT Heavy service. This synergy between priced lanes and Express/BRT has been pointed out by a number of transportation researchers, including Poole and Balaker, who dubbed such lanes "virtual exclusive busways" in a 2005 policy study.[13]

Express buses have a long history of operating on Houston's radial HOV lanes, which were recently converted to HOT lanes, and also on the recently expanded Katy Freeway (I-10), where a single, reversible HOT lane was replaced with two managed lanes in each direction. Los Angeles in 2013 converted the HOV lanes on I-10 (El Monte Busway) and I-110 (Harbor Transitway) to HOT lanes, with expanded express bus service. Conversion was also recently completed on the HOV lanes on I-95 south of Washington, D.C.

One of the country's most successful managed lanes projects is on I-95 in Miami. Formerly a single HOV lane in each direction, the corridor now hosts two managed lanes in each direction, using dynamic pricing. Express bus service connecting nearby Broward County with downtown Miami has been significantly improved since the opening of the I-95 Express Lanes. What had previously been only a single bus route, linking Fort Lauderdale with Miami via the often-congested HOV lanes on I-95, has grown to six Express Bus routes between various park & ride lots in Broward County and Miami. Even though the initial Phase 1 of the Express Lanes covered less than eight of the 21 miles between Ft. Lauderdale and Miami, the reduction in congestion on those eight miles has led to bus schedule time reductions of 22% in the AM peak and 31% in the PM peak. Monthly (weekday) boardings on the express bus routes increased from an average of 18,400 in February 2010 to 75,276 by December 2015.[14] These numbers are likely to grow further once Phase 2 of the Express Lanes project is completed in 2016, bringing the managed lanes corridor to 21 miles.

Transportation agencies in Southeast Florida won federal funding to implement the 95 Express Lanes via the U.S. DOT's Urban Partnership Agreement competition. Part of their winning proposal was the intention to develop a network of such managed lanes, encompassing a significant portion of the region's expressway system, with Express Bus service intended to be an integral part of the concept.[15] A second managed lane corridor opened to traffic in 2014: three reversible express toll lanes on I-595 in Broward County. And construction is under way in 2016 on express toll lanes on I-75 in Broward County and on the SR 826 Palmetto Expressway in Miami. When built, these and other new managed lanes will create a seamless network of managed lanes, which will facilitate region-wide Express Bus service.

Bus-Only Lanes on Arterials

Nearly all the literature on BRT Heavy stresses the importance of keeping BRT vehicles from getting stuck in peak-period congestion. The standard definition of BRT Heavy includes the provision of an exclusive guideway, with the only exception being HOV lanes (and more recently, the Federal Transit Administration's acceptance of HOV lanes converted to HOT lanes as the functional equivalent). But those definitions apply to expressways, which are the only corridors where HOV and HOT lanes are used. So when it comes to arterials, both FTA and metro area transportation planners increasingly advocate bus-only lanes on major arterials as a key factor in the success of arterial BRT Heavy projects.

From a congestion management standpoint, however, arterial bus-only lanes could be counter-productive, depending on how congested the arterial already is and on the probable bus ridership if the bus-only lane is implemented. There are three principal ways to implement such lanes:

1. Convert the median to a single-lane reversible bus-only lane, if necessary narrowing the other traffic lanes from 12 feet to 11 (or sometimes 10) feet.
2. Convert an existing lane in each direction to bus-only use.
3. Widen the arterial by one lane in each direction, with the new lanes operated as bus-only lanes.

The first alternative poses safety and operational problems, in that buses traveling in the peak direction would be moving in the opposite direction from vehicles traveling in the opposing lanes, without the protection of a median. This approach would also be constrained in providing safe locations for passenger boarding and unloading.

The second alternative would result in a large reduction in the traffic capacity of the arterial due to the loss of two traffic lanes to non-bus vehicles. In a recent analysis as part of a mobility study for Southeast Florida (the three-county Miami urbanized area), traffic engineer Chris Swenson carried out a quantitative analysis of this alternative for a six-lane arterial.[16] Since BRT is generally proposed for high-traffic arterials, the analysis assumed that, prior to conversion, the arterial was operating at its maximum throughput during peak periods (defined as Level of Service E—LOS E). Swenson found that the corridor's pre-conversion *person throughput* could only be maintained if the BRT service attracted 34% of all the people using the arterial in the peak direction during the peak period. (With 40-passenger buses, that would require 28 buses per hour, nearly one every two minutes). In many largely suburban metro areas, where peak-period transit mode share is between 3% and 5%, that level of ridership seems unlikely. Any transit capture rate significantly less than that would result in worse congestion (often LOS F) in the arterial's four remaining lanes, with likely spillovers of congestion to parallel arterials.

The third alternative—adding a new lane each way—may be do-able, but in many cases will face political resistance from opponents of growth, from those concerned about the high cost, and from those opposed to the property takes that would usually be required. Assuming those obstacles can be overcome, devoting all the capacity of the new lanes to buses would have less near-term impact on person throughput than the above lane-conversion, but could represent a loss of *future* vehicle capacity. Swenson's analysis of this case found that to achieve a person-throughput capacity equivalent to an eight-lane arterial during peak periods, the bus-only lanes would have to attract enough riders to fill 42 buses per hour. That also seems problematic in suburbanized metro areas.

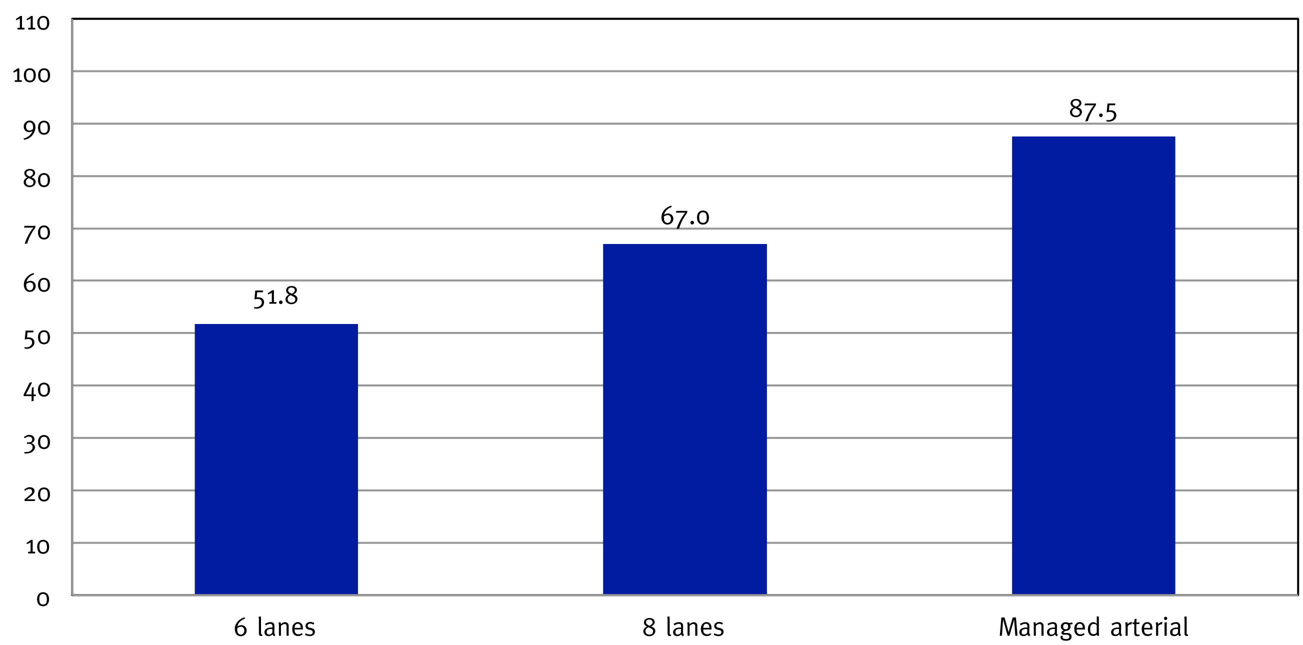
The Managed Arterial Alternative

An alternate way to facilitate BRT Heavy and Express Bus on major arterials is to use a different approach to increasing the arterial's person and vehicle throughput. Developed by Swenson and Poole in a recent paper for the Transportation Research Board, the concept—which has been dubbed "Managed Arterial"[17]—adapts the variable pricing principle used in managed lanes to address congested arterials.

The key insight underlying the Managed Arterial concept is that the primary limiting factor for arterial throughput is not the number of lanes (as on expressways) but the signalized intersections. Arterial throughput is affected by both the number of such intersections and their total cycle time (which can be three minutes or more in some metro areas, including many in urban areas of California, Florida, Georgia and Virginia). Hence, an alternative to widening a six- (or more) lane arterial is to add grade separations (overpasses or underpasses) at signalized intersections. An arterial with tolled grade separations as an option for vehicles is defined as a Managed Arterial (MA).

Swenson used standard Florida DOT highway capacity tables to compare the throughput capacities of six-lane and eight-lane arterials with that of a six-lane arterial modified to MA configuration. The configuration assumed for the grade separations is that two lanes each way would use the underpass to bypass the signalized intersection. Drivers would still have access to all the current traffic movements at the intersection: right turn lane, through traffic (two lanes each way), left turn lane, and U-turns. Thus, the capacity of the MA can be estimated as the sum of the capacities of (a) a four-lane uninterrupted-flow highway plus (b) one-half the capacity of a four-lane divided arterial. That total is 87,450 vehicles per day (vpd).[18] By comparison, the same FDOT tables show the capacity of a standard six-lane arterial as 51,800 vpd and the capacity of a standard eight-lane arterial as 67,000 vpd, as depicted in Figure 1.

Figure 1: Daily Arterial Vehicle Throughput Comparison (in thousands)



Source: Robert W. Poole, Jr., Thomas A. Rubin and Chris Swenson, *Increasing Mobility in Southeast Florida*, Policy Study No. 400, (Los Angeles: Reason Foundation, March 2012), Figure 5.

To be sure, adding a number of overpasses or underpasses to a six-lane arterial would be costly, and in some cases would cost more than widening it to eight lanes. Conversion to MA might also require widening the six-lane arterial in the vicinity of the intersection, to provide enough room for the at-grade through lanes, left-turn, and right-turn lanes in addition to the underpass. But the MA concept would address the cost problem by charging an electronic toll (ranging from 15¢ to 35¢ per crossing, depending on time of day) for each use of a grade separation. Preliminary feasibility calculations estimate that the toll revenues from those opting to pay to bypass congested intersections would cover a large fraction of the capital costs of implementing MA treatment on a congested arterial (see Text Box).[19]

An arterial corridor given MA treatment would provide an uncongested guideway for Express Bus and BRT Heavy service, offering shorter travel times than would be possible on any of the arterial exclusive bus lane alternatives (even with traffic signal priority). It would also avoid the negative impact on person and vehicle throughput of the bus-only lane-conversion alternative and the limitations on future throughput in the lane-addition alternative. Table 2 provides a summary (qualitative) comparison of the four alternate ways of providing improved service for Express Bus and BRT Heavy on arterials.

Summary of Traffic and Revenue Estimation for Managed Arterials

This estimate was developed as part of Reason Foundation's Southeast Florida mobility study in 2012.[20] That study proposed a set of Managed Arterials in the Miami urbanized area totaling 107 route-miles that would require the construction of 78 underpasses on the arterials in question. The toll rates and usage assumptions were taken from the federally funded study of tolled grade separations in Lee County, Florida.[21] Those assumptions were derived from stated preference surveys of drivers using congested arterial intersections in Lee County.

The calculations assumed that the unmodified arterial would be operating at LOS F during peak periods as of 2035, while the underpasses would operate at LOS C. Table 1 summarizes the assumptions made and the estimated revenue derived. Further details are provided on pp. 49–51 of the 2012 Reason study.

Table 1: Managed Arterial Network Weekday and Weekend Revenue Estimation

	Daily Traffic	Fraction Using	Rate per Underpass	Number Used	Daily Revenue
Peak	43,800	60%	$0.35	78	$717,444
Shoulder	21.500	45%	$0.25	78	$188,662
Off-Peak	21,500	30%	$0.15	78	$75,465
Weekday Total					$981,571
Weekend & Holiday	52,560	40%	$0.20	78	$327,974

Source: Robert W. Poole, Jr., Thomas A Rubin and Chris Swenson, *Increasing Mobility in Southeast Florida*, Policy Study No. 400, (Los Angeles: Reason Foundation, March 2012), pp. 49–51.

With 250 weekdays per year, the annual revenue from weekday use is $245,392,750, and 115 weekend and holiday days yield another $37,717,010. The result is total annual revenue of $283,109,760. This revenue stream should permit financing, using a 10X factor, of a $2.8 billion capital expenditure. The cost estimate for the 78 grade separations was $3.74 billion. Thus, if the assumptions made about pricing and usage are in the right ballpark, the MA system could cover about 75% of its construction costs from toll revenues.

Table 2: Alternatives for Enhanced Bus on Six-Lane Arterial

	Restriping	Convert 2 GP Lanes to Bus-Only	Add 2 Lanes as Bus-Only	Managed Arterial
Right of way cost	None	None	High	Low
Construction cost	Low	Low	High	High
Reduced left turns	Yes	Yes	Yes	No
Impact on person and vehicle throughput	Minor, negative	Major, negative	Minor, positive	Major, positive
Under-utilized bus lane(s)	Yes	Yes	Yes	No
Impact on congestion	Minor, negative	Major, negative	Minor, positive	Major, positive
Safety impact	Some, negative	Some, negative	Minor, positive	Major, positive
Revenue generation	No	No	No	Yes, significant
Nonstop bus service	No	No	No	Yes
Increased transit use	Low	Some	Some	Moderate

Source: Robert W. Poole, Jr., Thomas A. Rubin and Chris Swenson, Increasing Mobility in Southeast Florida, Policy Study No. 400, (Los Angeles: Reason Foundation, March 2012), adapted from Table 9.

Each of the four alternatives involves trade-offs. All but the Managed Arterial would restrict left turns across the median to avoid holding up buses in the bus-only lanes alternatives. All except the MA would use only a small fraction of the bus lanes' capacity in most cases. The restriping alternative would introduce safety problems. Only the MA approach brings with it potentially significant new funding, in the form of toll revenues. And because it offers faster bus service than the bus-only lanes alternatives, it should generate larger ridership increases than the others.

Figure 2 illustrates a typical underpass concept of the grade separations proposed for use in MA treatment of arterials. In their recent Southeast Florida study, Poole and Swenson used recent Florida project cost data to estimate that the capital cost of the underpass would be $41.8 million, only slightly higher than an overpass that would cost $39.5 million in the same location (both in 2010 dollars). Those numbers would be higher in states with significantly higher construction costs than Florida.

Figure 2: Typical Arterial Underpass

Some have expressed concern about extending the variable pricing idea to arterials, arguing that this would represent tolling of existing capacity, which is still considered off-limits by most elected officials. But, in fact, the MA concept was developed *in accord with* this principle. By employing all-electronic toll collection only for cars using the grade separations, this approach would be charging only those who opt to use the *new capacity* added to the arterial. Those not choosing to use the tolled underpasses would still have all the choices available to them at the signalized intersections as before. (The provision of four non-tolled through lanes, rather than the previous six, assumes significant diversion of traffic from the non-tolled lanes to the tolled underpass, leaving ample non-tolled capacity for the remaining traffic.)

Another concern is the visual impact of the grade separations. This is especially the case for arterial intersections in the more-densely developed portions of metro areas. The underpass alternative is intended to address those concerns, providing a far less visually intrusive form of grade separation than an overpass, at only a modest increase in cost. The underpass approach is feasible even in geographical regions such as southern Florida where the water table is high. Two such underpasses already exist within the Miami urbanized area, one in downtown Fort Lauderdale (allowing US 1 to go beneath a downtown river) and the other on US 27 in Hialeah (allowing highway users to go beneath a railroad, alongside a canal). Both have stand-by pumping systems to deal with heavy rainfall.

Enhanced Bus Service on Managed Arterials

As noted previously, the focus of this paper is on Express Bus and BRT Heavy, the services that rely on exclusive (or virtually exclusive) lanes to avoid congestion. BRT Lite by definition operates in regular traffic lanes. Express Bus is inherently for longer-distance trips, analogous to commuter rail. BRT Heavy that is deployed in what the ITDP report termed the "direct service" mode (which offers single-seat rides from various suburban locations to various destinations and uses a virtually exclusive guideway for the line-haul portion) can offer service comparable to or better than some light rail or heavy rail systems, thanks to its one-seat ride advantage.

In the previously mentioned study of the potential of managed lanes and Managed Arterials in Southeast Florida, the authors estimated the extent of Express Bus service on a three-county network consisting of 301 route-miles of expressway managed lanes plus 107 route-miles of Managed Arterials. Based on inputs from the transit agencies of the three counties, the researchers estimated 150,000 daily riders using this new service, based on routes suggested by transit agency planners.[22]

For BRT Heavy (as opposed to Express Bus) service, a key question is how many intermediate stops to include on the line-haul portion of the trip. The positive aspect of adding such stops, presumably at intersections with major perpendicular arterials with significant bus service, is to permit transfers between the bus service on the perpendicular arterial and the BRT Heavy service using the MA. The negative aspect is that the more such stops, the greater the travel time for those boarding the BRT Heavy bus at its suburban origin. Such trade-offs will require locally specific analysis. The point to remember is that the virtually exclusive guideway provided by the Managed Arterial facilitates both nonstop Express Bus and several-stop BRT Heavy service with carefully selected station locations.

Where there are such stops for BRT Heavy buses, they would be located at grade, just before the signalized intersection. To ease the bus's rejoining traffic that uses the underpasses, the system should provide for a queue jump (a traffic signal modification allowing the bus to pass through the intersection before the through lanes get a green light).

A Special Case: Converting Exclusive Busways

A possible near-term implementation of the concept is re-purposing low-performing exclusive busways that are traversed by numerous cross streets with signalized intersections. Grade separations (generally underpasses) would replace signalized intersections and the lanes would be opened to a managed number of toll-paying personal vehicles. In this special case, Express Bus and BRT Heavy would use all or most of the underpasses, while BRT Lite would use at-grade stations with queue jumps at most or all of the intersections.

Two such busways are the Orange Line in the San Fernando Valley of Los Angeles and the South Miami-Dade Busway in Florida. Both facilities took advantage of no-longer-used railroad rights of way through suburban areas—in both cases former freight lines. Although the Orange Line is considered a BRT Heavy service, its long travel time due to a mandated 10 mph speed limit through each of the more than 40 signalized intersections along its 18.2-mile route results in far from optimal performance—an average speed of just 21 mph. Most of the bus service on the Miami-Dade Busway is local bus, though several routes are designated as express. But all of these services are seriously constrained by 53 signalized intersections along the 19.8-mile length of that busway.

In the Los Angeles case, only some portions appear to have enough right of way to provide two priced lanes each way, and adding underpasses would be difficult without acquiring land in many cases. Discussions are under way in Los Angeles about potentially adding grade separations to the Orange Line corridor, but the capital costs of doing so are not in any current long-range plan. Many local officials would like to replace the buses with a light rail line, but that would be even more costly than just adding the grade separations—current estimates are between $1.2 billion and $1.7 billion.[23] A current project is testing an increased 25 mph bus speed limit through the signalized intersections.[24]

In Miami-Dade County, two feasibility studies of managed lane conversion alternatives have been carried out, but more detailed work has not been completed. The Busway runs parallel to US 1, the most congested arterial in the fast-growing southern portion of Miami-Dade County. Because the Busway is not living up to what many consider to be its potential, and also because of the severe congestion on parallel US 1 during peak periods, the Miami-Dade MPO commissioned a feasibility study of possible improvements, including grade separations. The initial study, released in 2008, suggested some kind of managed lanes approach, in which the Busway would be widened from two lanes to four, and the whole facility would operate much like a managed lanes facility on an expressway, with variable tolls charged to non-bus users.[25]

Since the revamped approach to the Busway would require electronic tolling, a more detailed feasibility study was commissioned by the Miami-Dade Expressway Authority and Miami-Dade Transit. This project development and environmental (PD&E) study, including extensive public outreach, evaluated alternate configurations with the aim of producing final environmental and engineering documents.[26]

Only the Tier 1 report of the planned two-tier PD&E study has been released, despite relatively favorable feasibility results.[27] There was considerable local opposition from officials of several of the communities through which the Busway passes, focusing primarily on the "visual eyesores" expected to result from a series of Busway overpasses at every location where there is now a signalized intersection. Although the Tier 1 report noted that underpasses were an alternative, that point did not appear to be communicated very effectively. Also of concern was the potential of the revamped Busway Express Lanes being configured as a "roller coaster," which might be the case if overpasses or underpasses were put in place at all 53 intersecting streets along its 19.8 miles. Media coverage of the ongoing Tier 2 study continued into 2014, with various assumptions and results discussed in an article as late as June of that year.[28] But no Tier 2 study report has been released, though the project still appears on the Miami-Dade Expressway (MDX) website.

That is unfortunate, because the Tier 1 results were actually quite promising. Traffic analysis found that the US 1 congestion, and hence demand for an express lanes alternative to US 1, was greatest north of SW 232nd Street. Likewise, 60% of bus service on the Busway occurs north of SW 232nd Street. So the later iterations in Tier 1 focused on the northerly 12 miles. Iteration 8 assumed two lanes each way with grade separations at all 22 intersections along those 12 miles, along with five access points to the revamped facility. Its 20-year projected revenue (in 2011 dollars) exceeded the cost of construction, but was not sufficient to also cover the facility's operating and maintenance (O&M) costs. Very restrictive assumptions about transit assumed only the same mostly all-stop bus service, which ignores the greatly improved transit performance that being able to offer Express Bus and BRT Heavy service on this nonstop facility would offer. The report's authors also seemed to not quite understand that priced lanes inherently function as virtually exclusive busways, since they frequently mentioned the possibility of bus-only lanes (which would significantly reduce toll revenue and under-utilize the bus-only lanes if implemented).

A more realistic approach would be to revamp the Iteration 8 version in several ways. First, use *underpasses* rather than overpasses, to take the "visual eyesore" issue off the table. Second, have *both* lanes in each direction serve cars and buses, to maximize toll revenue without interfering with the flow of express buses. Third, instead of comparing capital and operating costs with revenue over a mere 20 years, use the far more common *30-year* life of toll revenue bonds. Table 3 compares the Iteration 8 numbers from the Tier 1 report with revised numbers based on these changes. As can be seen, the projected toll revenue would come close to covering both capital and operating costs of the Busway.

Most new-capacity managed lane projects are not expected to be fully self-supporting from toll revenue alone. State DOTs typically partner with private-sector developer/operators by providing 20% to 30% of the capital costs. If that practice were applied in the case of this Busway conversion, it would be quite feasible in terms of current managed lanes practice.

Table 3: Busway Express Lanes Comparison

	Iteration 8 Costs at 20 Years	Underpass Version Costs at 30 Years
Revenue		
Toll revenue	$485.5M	$728.2M
Costs		
Construction	$427.3M	$470.0M*
O&M	$223.8M	$335.7M
Total Cost	$651.1M	$805.7M
Net	**-$165.6M**	**-$ 77.5M**

* Note: Creating underpasses adds 10% to construction costs.
Source: Author calculations of data from Gannett Fleming, "US 1 Express Lanes Project Development and Environment Study, Tier 1 Concept Development & Analysis Technical Memorandum," Miami-Dade Expressway Authority, December 2012.

Figures 3, 4 and 5 offer conceptual design illustrations for this facility. A 3% grade was assumed on either side of each underpass to ensure no degradation in bus performance. A maximum clearance height of 12 feet (which would require a design exception from FDOT standards) is sufficient to accommodate transit buses, and would hold down the costs of excavation and structure for the underpasses. If underpasses were provided at only one-mile intervals, any "roller-coaster" feel would be minimal—but that would require closing off about half of the 22 intersections in the 12-mile corridor. Since that is not likely to be acceptable, an alternate way to minimize the roller-coaster effect would be to semi-depress the entire corridor (e.g., six feet below grade in between the 12-foot depressions needed for underpass clearances).

Figure 3: Underpass Cross-Section

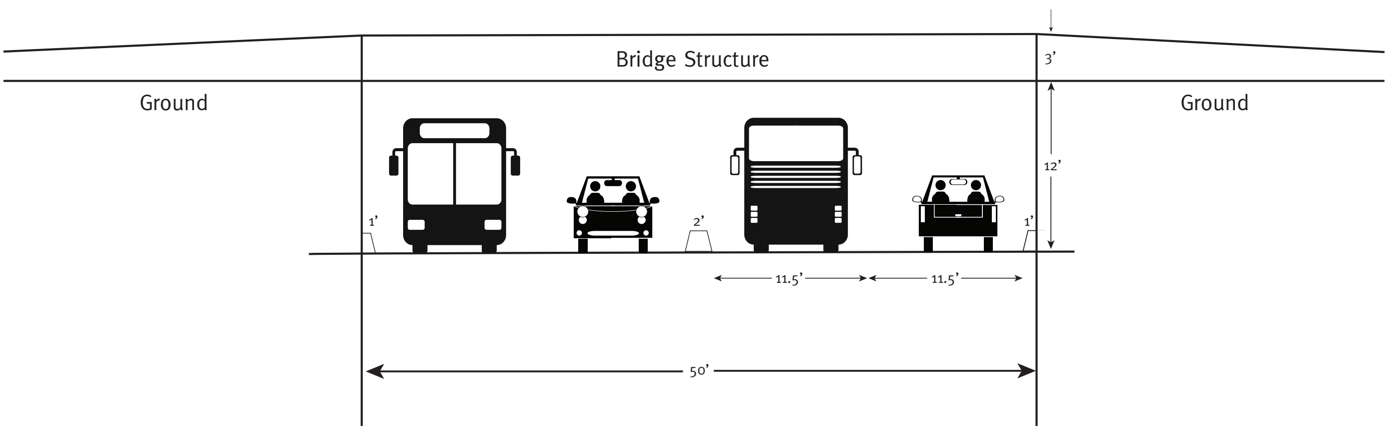
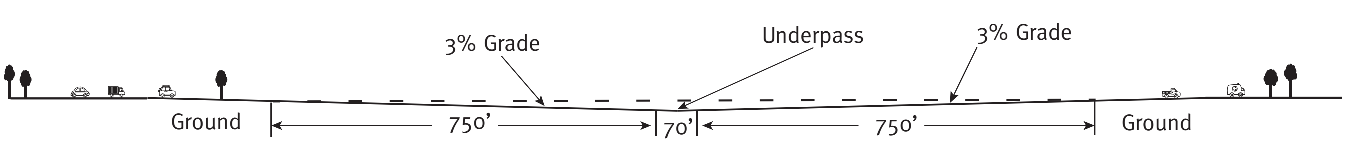
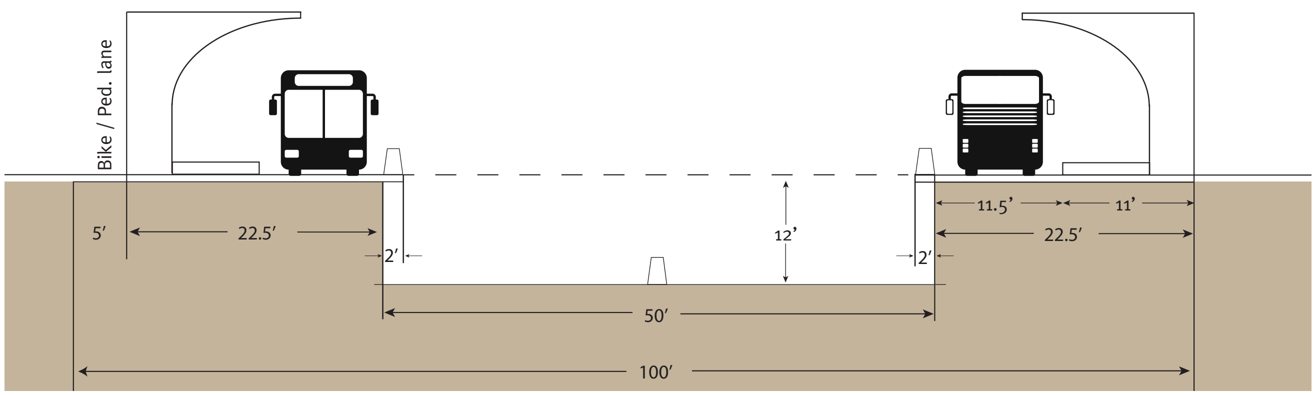


Figure 4: Underpass Side View



The 12-mile Express/Bus corridor would permit the operation of higher-speed, non-stop Express Bus and limited-stop BRT Heavy service. Multi-stop BRT Lite service would not use the underpasses, due to the need to stop at most or all of the intersections. Stations would be located strategically at key intersections along this corridor, based on transit agency preference. Figure 5 illustrates such a station located just before a cross street, at the same level as the cross street. Buses would reach the station by taking an exit lane from the Busway prior to the start of the main lanes' downgrade to the underpass. Buses would rejoin the Busway after crossing the signalized intersection (using traffic signal priority and/or a queue jump) via an entrance lane. Thus, buses would be decelerating as they ascend to the station at the surface level and would accelerate as they descend to rejoin the busway lanes. Note that all facilities could be accommodated within the existing 100-foot Busway right of way.

Figure 5: Cross-Section at Bus Station



Current discussions in South Miami-Dade focus on local desires to replace the current mediocre bus service with a light rail line using the corridor, which advocates admit would require grade separations at all signalized intersections. Even if built *at grade* along the entire 19.8 miles, at the average new light-rail system cost based on the FTA figures in Table A-2, the project would cost $2.1 billion. Adding grade separations at all 45 intersections would significantly increase that cost, as would building an entirely elevated line. No funding source for such a project has been identified.

By contrast, the Busway conversion to a Managed Arterial offers a number of advantages. Its cost could be covered largely by toll revenue from drivers who chose to divert from congested US 1, easing congestion on that LOS F arterial. It would increase the Busway's transit capacity dramatically, by adding true Express Bus, BRT Heavy, and BRT Lite services to the largely local bus services now using it. If the transformed Busway generated more transit ridership than projected for a light rail line, that would represent a very large savings for Miami-Dade County Transit's always-limited capital improvement budget, which could be devoted to other needed projects. And if transit ridership overwhelmed the capacity of all four kinds of bus service, that would generate a strong case for a future extension of the existing elevated Metrorail heavy rail service southward along the Busway right of way, while retaining the Express/Busway as a congestion reliever to US 1.

Conclusions

Enhanced bus is more flexible than fixed-rail transit, and can offer comparable service levels when operated either on exclusive rights of way or on virtually exclusive rights of way that are kept uncongested by variable pricing. Since expressways and major arterials typically serve all parts of suburbanized metro areas, taking advantage of these routes for faster and more-reliable enhanced bus service could address transit's static or declining mode share in such metro areas.

This study recommends going beyond the emerging practice of operating express bus service on what amounts to the starter segments of region-wide networks of priced managed lanes. It has proposed adapting the same principle to selected major arterials, not via adding priced lanes but via adding priced grade separations. The combination of these Managed Arterials and the network of expressway managed lanes would provide transit agencies with the infrastructure needed for region-wide Express Bus and BRT Heavy service—without the transit agency having to fund this new infrastructure.

Another candidate for Managed Arterial treatment is the small number of exclusive busways whose performance is hampered by numerous signalized intersections with local streets. One promising example is the South Miami-Dade Busway examined in this study.

About the Author

Robert Poole is director of transportation policy and the Searle Freedom Trust transportation fellow at Reason Foundation, a national public policy think tank based in Los Angeles.

His 1988 policy paper proposing supplemental privately financed toll lanes as congestion relievers directly inspired California's landmark private tollway law (AB 680), leading to similar public-private partnership legislation in about two dozen other states. In 1993 Poole that introduced the term HOT (high-occupancy/toll) Lane, a concept which has become widely accepted since then.

Poole has advised the Federal Highway Administration, the Federal Transit Administration, the White House Office of Policy Development and National Economic Council, the Government Accountability Office (GAO), and the California, Florida, Georgia, Indiana, Texas, Utah, Virginia, and Washington State Departments of Transportation. He has served on various transportation committees throughout the U.S.

Poole is the author of dozens of policy studies and journal articles on transportation issues. His popular writings have appeared in national newspapers, including the *New York Times* and *The Wall Street Journal*; he has also been a guest on such network TV programs as "Crossfire," "Good Morning America," and "The O'Reilly Factor," as well as ABC and NBC News. He writes a monthly column on transportation policy issues for *Public Works Financing*, and produces the monthly e-newsletter, *Surface Transportation Innovations*. The *New York Times* has called him "the chief theorist for private solutions to gridlock."

Poole received his B.S. and M.S. in mechanical engineering at MIT and did graduate work in operations research at NYU.

Appendix: Data on Rail Transit Projects Since 1970

Table A-1: Changes in Work-Trip Share in New-Rail Metro Areas

Metro Area and Rail Type		Last Pre-Rail Census	Pre-Rail Transit Share	2013 Transit Share	Pre-Rail Drive-Alone Share	2013 Drive-Alone Share
Atlanta*	(H)	1970	7.3%	3.1%	68.3%	77.7%
Austin	(L)	2000	2.5%	2.4%	76.5%	77.1%
Baltimore	(L)	1990	7.7%	6.8%	70.9%	77.1%
Buffalo	(L)	1980	6.6%	2.9%	66.6%	82.4%
Charlotte	(L)	2000	1.2%	1.7%	80.9%	80.2%
Denver	(L)	1990	4.3%	4.4%	75.4%	75.4%
Dallas	(L)	1990	2.3%	1.4%	78.6%	80.5%
Houston	(L)	2000	3.2%	2.4%	77.0%	79.7%
Los Angeles	(H/L)	1990	5.6%	5.8%	71.7%	74.1%
Miami	(H)	1980	4.4%	4.1%	72.6%	77.8%
Minneapolis	(L)	2000	4.2%	4.6%	78.3%	78.4%
Nashville	(L)	2000	0.8%	1.0%	80.6%	82.8%
Phoenix	(L)	2000	1.9%	2.6%	74.6%	76.5%
Portland	(L)	1980	7.9%	6.4%	65.3%	70.7%
Riverside	(C)	1990	0.8%	1.5%	74.6%	76.8%
Sacramento	(L)	1980	3.4%	2.6%	75.3%	75.1%
San Diego	(L)	1980	3.3%	3.2%	63.8%	75.8%
Seattle	(L)	2000	7.0%	9.3%	71.6%	69.7%
San Francisco*	(H)	1970	15.9%	16.1%	57.9%	59.9%
San Jose	(L)	1980	3.1%	4.2%	72.4%	75.9%
Salt Lake City	(L)	1990	3.3%	3.2%	75.5%	75.0%
St. Louis	(L)	1990	2.9%	2.9%	79.4%	83.2%
Washington, D.C.*	(H)	1970	15.5%	14.2%	54.2%	66.1%
Average			**5.0%**	**4.6%**	**72.3%**	**76.0%**

Source: Census Bureau American Community Survey 2013 and previous Census data

*1970 drive-alone data not available; used 1980 for these metro areas

Note: C = commuter rail, H = heavy rail, L = light rail

Table A-2: Capital Cost of Recent Rail Transit Projects						
Metro Area	Project	Type	Capital Cost ($M)	Route Miles	Cost/Mile ($M)	250-Mile System Cost ($B)
New York*	2nd Ave. Subway	Heavy	$4,887*	2.3*	$2,125*	$531.2B*
Los Angeles	Westside	Heavy	$5,129	8.9	$576	$144.0B
Washington, D.C.	Silver	Heavy	$3,143	11.7	$269	$67.2B
San Jose	BART	Heavy	$2,218	10.2	$217	$54.2B
Total/Average*		**Heavy**	**$10,490**	**30.8**	**$354**	**$88.5B**
Phoenix	Central Mesa	Light	$190	3.1	$61	$15.2B
Sacramento	South	Light	$262	4.3	$61	$15.2B
San Diego	Mid-Coast	Light	$1,596	10.9	$146	$36.5B
Baltimore	Red	Light	$2,219	14.5	$153	$38.2B
Washington, D.C.	Purple	Light	$1,926	16.3	$118	$29.5B
Minneapolis	Southwest	Light	$1,221	15.8	$77	$19.2B
St. Paul	Central	Light	$957	9.8	$98	$24.5B
Charlotte	Blue	Light	$989	9.3	$106	$26.5B
Portland	Milwaukee	Light	$1,229	7.3	$168	$42.0B
Dallas	NW/SE	Light	$1,406	21.0	$67	$16.8B
Houston	North	Light	$756	5.3	$143	$35.8B
Houston	Southeast	Light	$823	6.7	$123	$30.8B
Salt Lake City	Draper	Light	$194	3.8	$51	$12.8B
Total/Average			**$13,768**	**128.1**	**$105.5**	**$26.4B**

*Totals/average excluding New York, which is an outlier

Source: Federal Transit Administration 2013 New Starts Report

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