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Rapid Bus

A Low-Cost, High-Capacity Transit System for Major Urban Areas

By Randal O'Toole

EXECUTIVE SUMMARY

Prompted by federal funding, more than 30 American cities have built or are building new rail transit lines. These expensive lines have debatable value as they put transit agencies in debt and impose high maintenance costs, yet they carry few riders more than the buses they replace and produce minimal, if any, environmental benefits.

As an alternative to rail transit, this paper proposes a "rapid bus" system that would offer fast, frequent, and comfortable transportation to most people in an urban area. This paper will estimate the annualized costs of such a system and compare it with the costs of a traditional system of rail supplemented by feeder buses. Based on these estimates, this paper finds that

- While rail lines serve a limited number of corridors, for less money a rapid bus system can reach nearly everyone in an urban area.
- A rapid bus system can offer more frequent service at faster average speeds and fewer transfers between transit vehicles, all at a lower cost than rail.
- Rapid buses also offer more comfortable rides because two-thirds to three-fourths of bus riders can be seated, whereas more than half of rail riders must stand when the rail system is operating at capacity.
- Rapid bus systems are scalable, with low incremental costs, as downtown employment centers grow from 40,000 to 500,000 jobs. In contrast, rail systems require huge expenditures to start up and expand.
- While a four-line light-rail system can bring only about 36,000 people per hour into a downtown area, the rapid bus system described in this paper can bring as many as 140,000 people per hour into downtown.
- While rapid buses cannot cost-effectively replace the long-established subways and commuter trains serving New York City, they could save taxpayers' money by replacing aging rail transit systems in Boston, Chicago, Philadelphia, San Francisco, and Washington.
- Urban areas with 40,000–200,000 downtown jobs should expand their transit systems using rapid buses rather than light rail or other rail systems.
- Urban areas with fewer than 40,000 downtown jobs probably do not need any form of high-capacity rapid transit.

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"Railcars may have higher capacities than individual buses, but because most rail lines can safely move only about 20 trains per hour, their actual capacities are often lower."

INTRODUCTION

Outside of New York City and a handful of other large cities, transit carries at best a minor and in most places an insignificant amount of passenger travel. While transit carries about a third of commuters to work in the New York urban area, it carries less than 20 percent in San Francisco and Washington, D.C.; less than 15 percent in Boston, Chicago, and Philadelphia; and less than 10 percent almost everywhere else. In such major urban areas as Atlanta, Cleveland, Dallas-Fort Worth, Denver, Miami, San Diego, and San José, transit carries less than 5 percent of commuters to work.[1]

Except in cities built in the 19th century that still have large concentrations of jobs downtown, transit is unsuccessful because jobs and housing are so spread out that there are few times when large numbers of people want to go from a few specific origin points to a few specific destinations. For this reason, a few urban planners have suggested that transit should rely on smaller vehicles capable of going from more origins to more destinations. The late Melvin Webber, a planning professor at the University of California, Berkeley, suggested that for transit to become "popular again," it should evolve into a system of ride-sharing and small jitney-like buses.[2]

However, in nearly all of the nation's urban areas with populations of a million or more people, transit agencies are moving in the opposite direction, putting most of their capital funds into what they call "high-capacity" transit lines capable of moving large numbers of people from specific origin points to specific destinations. The supposed higher capacities of rail transit over buses are used to justify the expenditure of tens to hundreds of millions of dollars per mile on construction of new rail lines. Even the few major cities contemplating bus improvements rather than rail transit often want to build expensive busways dedicated to transit's small share of travel.

Ranging from streetcars to subways, rail transit lines use vehicles that have higher capacities than individual buses. However, as I pointed out in a previous paper, for safety reasons many of these lines can only move about 20 vehicles or trains per hour, and so their actual capacities are often lower than those of buses.[3] This means that, with rare exceptions, the extra expense of building rail lines is entirely unnecessary.

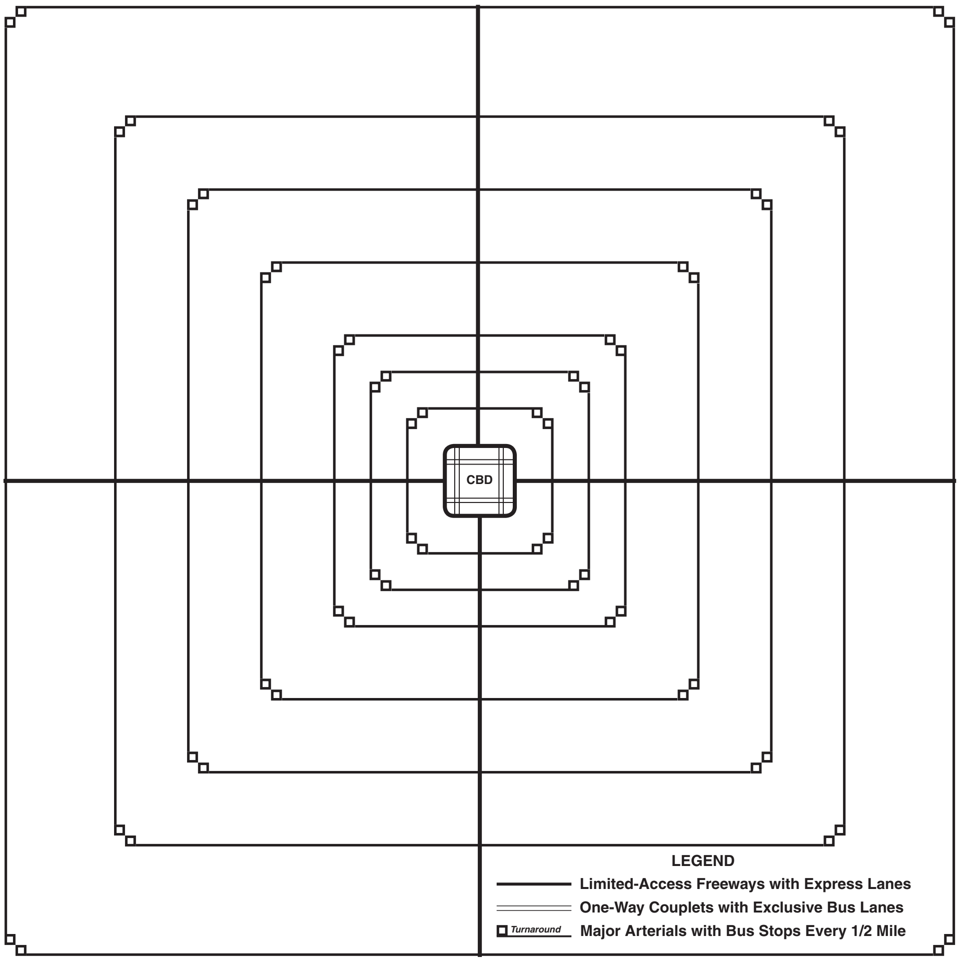
Ignoring Webber's case for low-capacity transit for the moment, this paper will propose a high-capacity rapid transit system that relies on buses rather than rails and shared infrastructure rather than dedicated transit ways. The paper compares the costs of this system with a rail-transit system. The paper will then assess which American urban areas could benefit from such a system, which areas might require the higher capacities that can only be provided by high-capacity rail transit, and which do not need any kind of a high-capacity transit system.

DEFINING A GENERIC URBAN AREA

Each large urban area consists of a central city surrounded by its suburbs. The central city typically has a central business district (CBD) that probably has the highest concentration of jobs in the urban area. Though the downtown itself might occupy about four square miles, the greatest concentration of jobs is likely to occupy only a small portion of that area. Downtown streets are typically one-way couplets, allowing easy coordination of traffic signals for smoother traffic flows.

Most major urban areas are served by at least two major freeways, one going north–south and one going east–west. These often meet in or near the downtown, and they or other freeways often form a belt around the downtown area. Urban freeways typically have exit and entrance ramps spaced about a mile apart. The ramps access other job centers and arterial and collector roads that reach neighborhoods and suburbs throughout the urban area. If the downtown is two miles square, the freeway belt around downtown is likely to have around eight exits into downtown, two from each of the four sides.

Figure 1
Rapid Bus Plan for an Urban Area of Two Million People



Note: This figure shows the downtown (central business district, or CBD), beltline freeway around downtown, radial freeways, downtown couplets with dedicated bus lanes, and major arterials served by rapid bus routes for a generic urban area of about 2 million people. Buses would leave downtown, take the freeways to one of the arterials, follow the arterials until they meet a perpendicular arterial, then turn around and return downtown.

Outside the central business district, most urban areas have a grid of major arterials crossing the north-south and east-west freeways spaced about a mile apart. Most of the arterials, especially in the inner city, have their own entrances and exits to the freeways. As the freeways move away from downtown the spacing of on- and off-ramps may increase to every two miles and, in the distant suburbs, every three miles. All of these features are shown in Figure 1.

The urban area in this generic plan is assumed to have about 2 million people living at an average density of about 3,000 people per square mile. At that density, the urban area will occupy about 667 square miles, or very close to 26 miles square.

Obviously, no urban area is exactly like this, but some in the Midwest are close. This generic plan can easily be scaled up or down for larger or smaller urban areas and modified to fit urban areas with different roadway configurations. The plan is for urban areas with a single central business district. More significant modifications might be needed for regions with twin business districts, such as Minneapolis–St. Paul, but still the basic concept will work.

> "Dedicating downtown lanes to buses might reduce the total lane-miles of streets open to general traffic, but it would also get nearly all transit buses off of general traffic lanes."

> "Express lanes will work best if major freeways have high-occupancy toll (HOT) lanes that buses can use for free with tolls varying so the lanes never become congested."

Downtown Bus Routes on One-Way Couplets

The first part of the low-cost, high-capacity transit plan is to connect pairs of freeway exits with one-way couplets. Each street in these one-way couplets should be at least three lanes wide, including any parking lanes. Two of these lanes would be dedicated to buses, one at a curbside for loading and unloading passengers and one next to the curbside lane to allow other buses to pass through. The other lane or lanes in the streets would remain open to general traffic.

For the urban area of two million people modeled here, two north-south one-way couplets and two east-west one-way couplets—for a total of about 16 lane-miles of street space—would be dedicated to buses. For areas of a million people, just one north-south and one east-west couplet might be needed, while additional couplets might be needed for areas with three million people or more.

While dedicating lanes of one-way couplets to buses might reduce the total lane-miles of streets open to general traffic, it would also get nearly all transit buses off of general traffic lanes, thus smoothing traffic flows because auto and truck drivers would no longer have to deal with buses pulling into traffic lanes after picking up or dropping off passengers.

In its downtown area, Portland, Oregon, has staggered bus stops so that there are four bus stops every two blocks, and buses passing through downtown are scheduled to stop at every fourth stop. Both stops and buses are clearly marked to show transit riders which buses stop at which stops. Not everyone works downtown, but riders can transfer from one bus to another by walking no more than a single block, and in most cases a half-block or less.

Observations by Portland State University professor Robert Bertini found that a single loading area can handle 42 buses per hour, which means the downtown streets with staggered stops can move 168 buses per hour. In fact, Bertini found that Portland's transit agency, TriMet, schedules as many as 160 buses per hour on those streets, which confirms that his capacity calculations are reasonable.[4]

Portland has short blocks: only 200 feet on a side. Blocks in most cities are 300 feet on a side, and a few are 400 feet. In such cities, three different bus stops could be included in each block. Rather than use the extra space for more commuting buses, that space could be dedicated to downtown circulators as described below.

Express Lanes

Outside the central business district, this plan will work best if the major freeways have high-occupancy vehicle (HOV), high-occupancy toll (HOT), or express lanes that buses can use for free and that autos can use by paying an electronic toll that varies with the level of traffic so that the lanes never become congested.

If the freeways have HOV lanes that sometimes become congested, they should be converted to HOT or express lanes. If the freeways have no HOV, HOT, or express lanes, construction of such lanes typically costs about $10 million per lane mile. While the construction cost near the city center is likely to be higher, the cost in the suburbs is likely to be lower. The Fort Bend County (Texas) Toll Road Authority, for example, has built toll freeways at a cost of less than $2.5 million per lane mile.[5] The Central Texas Regional Mobility Authority has built or is building express lanes adjacent to several freeways for an average cost of $10 million per lane mile.[6]

Because of right-of-way issues, construction of new lanes will be more expensive near the city center. One way to minimize these issues is to elevate the lanes so they don't need additional right of way. The Tampa-Hillsborough (Florida) Expressway Authority has built elevated lanes supported by six-foot pillars in the median strip of the existing highway. The lanes cost under $10 million per lane-mile.[7]

As our hypothetical urban area has about 56 miles of freeway, at $10 million per lane mile the addition of express lanes in each direction would cost about $1.12 billion. Only a small fraction of that cost should be assigned to the transit system, as it is likely that the vast majority of users would be auto drivers and passengers. Studies of existing express lanes have shown that they not only offer large numbers of people a congestion-free transportation alternative, but they also significantly reduce congestion on the non-toll lanes for people who don't pay the tolls.[8]

Neighborhood Circulation

Once buses leave the downtown area, they can get on the north, east, west, or south freeways, then take one of the freeway exits and circulate in the neighborhoods accessed by those exits. Reflecting declining population densities as freeways move away from the city center, this study presumes that exits are located 1, 2, 3, 5, 7, 9, and 12 miles away from the downtown beltline on each of the four freeways.

To reach the maximum number of people, two bus routes can take each exit, one heading north or east and one heading south or west on the major arterial accessed by that exit. In a roughly square urban area, these arterials would extend about as many miles east-west or north-south as the freeways extended north-south or east-west from the central business district. In other words, a bus that got off at Mile 3 on the north freeway would go three miles west before it encountered the route of the bus that got off at Mile 3 of the west freeway and headed three miles north. At these meeting points, buses would turn around and return to the CBD.

Traditional bus routes have as many as eight stops per mile. Many light-rail and rapid bus systems stop only about once per mile. In order to reach as many people as possible, this plan will presume one stop every half mile on these arterials. That requires just under 400 stops outside the CBD and about 128 stops in the CBD.

Downtown Circulator

One problem with the system of using one-way couplets downtown is that many downtown workers are not going to have jobs located right next to the couplet that their bus line uses. To reach more downtown destinations, circulator buses could continuously loop around the one-way couplets. These circulators would be free to anyone riding the rapid buses, if not anyone at all, thus providing rapid bus riders access to the entire CBD.

As previously noted, in downtowns with 300-foot blocks, the circulators can use bus stops in the middle of each block, thus being easily accessible to people getting off any rapid bus. In Portland, which has only 200-foot blocks, the circulators would compete for space with rapid buses, thus somewhat reducing the capacity of the rapid bus system.

Assuming the circulators do a four-mile loop around the downtown at an average speed of 8 miles per hour, 12 buses could provide service every five minutes in both directions. The frequency could be cut to every two minutes by increasing the number to 30 buses.

No Signal Priority

Many bus-rapid transit systems give the buses priority over other traffic at signals. The buses may carry an electronic transponder; when they approach a signal, the signal changes to green for the buses. In fact, current federal law requires that bus-rapid transit systems get signal priority to be eligible for federal funding.[9]

However, this plan does not include signal priority for rapid buses. Studies show that signal priority offers only minor to modest improvements in bus speeds.[10] Those improvement come at a significant social cost: by disrupting the signal priority systems for other traffic, systems that give buses priority slow down all other travelers.[11] Since transit carries such a small proportion of urban travel in most regions, the costs to the nontransit riders are much greater than the benefits to transit riders.

Instead of giving buses priority at traffic signals, this rapid bus system relies on express lanes for roughly half the distance of all rapid bus routes. As shown below, the express lanes significantly improve average transit speeds to speeds well above those of ordinary bus transit.

“Giving transit priority at traffic signals provides only modest improvements in transit speeds but can significantly disrupt signal systems for other traffic.”

"At 40 to 45 feet, double-decker buses can hold twice as many people as standard buses, making them less expensive per seat than other buses."

Bus Models

Transit agencies can select from at least three models of buses for high-capacity rapid service. First is a standard 40-foot bus, which has about 40 seats and room for at least 20 people standing. Fueled by low-sulfur diesel fuel, these buses cost about $300,000 to $400,000. Add about $30,000 per bus to use compressed natural gas or a similar fuel.[12] The circulator buses would probably all be some variation of a standard bus, while the rapid buses might be a standard bus or one of the other two models, described below.

The second most-popular bus for this kind of service is the articulated bus, popularly known as a "bendy bus" because the bus pulls a trailer that makes the vehicle appear to bend around corners. These 60-foot buses have about 60 seats and room for about 30 people standing. This extra capacity comes at a cost of around $700,000 to $900,000, which makes them more expensive per seat than a standard bus.[13] Because they are longer, they are less maneuverable than a standard bus and could require a little more time to pull in and out of bus stops.

The latest offering from bus manufacturers is the double-decker bus. At 40 to 45 feet, these buses aren't significantly longer than a standard bus and should be just as easy to maneuver. However, even with two wide doorways for easy loading and unloading, they have about 80 seats and room for at least 25 people standing. Their disadvantage is that people in the upstairs level will take longer to unload than those on a single-level bus. At a cost of about $700,000 per bus, they are less expensive per seat than either the standard or articulated bus.[14]

Fare Collection and Platforms

Fare collection is a major cause of delay for bus transit. Light-rail lines avoid this problem by requiring riders to pay before they board the trains. However, sporadic fare inspections encourage people to avoid payment and anecdotal evidence suggests that many do. Heavy-rail trains use turnstiles requiring people to pay using coins or, more recently, electronic tickets or passes as they enter (and, in systems that have variable fares, leave) the stations.

Rapid bus systems in Curitiba, Brazil; Bogota, Columbia; and other Latin American cities have adopted the heavy-rail model, installing turnstiles at every rapid bus stop. Before boarding the bus, people step up to a raised platform and pay to enter the turnstiles. When buses arrive, people are already at the level of the bus floor and simply enter through two or (in the case of articulated buses) more wide doors on each bus. This also makes buses more easily accessible to disabled passengers.

Most American rapid bus systems use the light-rail model, relying on an honor system with occasional random fare inspections. This saves the cost of building platforms and turnstiles at every bus stop. However, many transit agencies build fancy platforms for their rapid bus systems anyway, and those that do should use the turnstile system. For example, a proposal for a bus-rapid transit system in Grand Rapids, Michigan, projects a cost of $30,000 to $40,000 per platform. Adding turnstile payment systems would increase that cost by only a small amount.[15]

Frequencies and Speeds

Buses in the CBD would travel an average of about 8 mph. On the freeway express lanes, they could average 60 mph. Circulating on the arterials, with one stop every half mile, they would average 14 mph. The average speed for the average passenger of a bus that exits one mile from the CBD would be about 17 mph; the average for a bus that exits 12 miles from the CBD would be about 25 mph. The average for the entire system is 22 mph. While those speeds may sound low, the average bus speed in most American cities today is only about 10 mph, and the average for light-rail lines is not much more than 20 mph.

Two bus routes serving each of seven exits on each of the north, east, west, and south freeways results in a total of 56 different bus routes. With the one-way couplets sending as many as 336 buses per hour on each of the free-

Table 1
Rapid Bus System Capacity in People per Hour

	Buses per Hour on Each Route		
	6	10	24
Standard 40-foot buses	20,160	33,600	80,640
Articulated buses	30,240	50,400	120,960
Double-decker buses	35,280	58,800	141,120

Note: Calculations based on 56 different rapid bus routes of varying length at frequencies of 6, 10, and 24 buses per hour on each route, multiplied by 60 people per bus for standard buses, 90 people for articulated buses, and 105 people for double-decker buses.

ways, each of the routes could have as many as 24 buses per hour or one every 2.5 minutes.

Based on the above average speeds, providing service every 10 minutes on the route that takes an exit one mile from downtown would require four buses; the route that exits 12 miles from downtown would require 17 buses. A total of 531 buses would be needed to serve the entire region. Increasing frequencies to every six minutes would require 885 buses. At the maximum frequency of 24 buses per hour on each route, a total of 2,125 buses would be needed. Of course, a few additional buses should be available in case of breakdowns and for maintenance rotation.

Buses would only operate at the highest possible frequencies during peak periods. At other times of the day, frequencies would be about half of the highest frequencies; for example, every 20 minutes if the peak frequency is every 10 minutes. At other hours of the day, such as late at night, they wouldn't operate at all or only at very low frequencies. This paper assumes that the average bus operates 12 hours a day.

System Capacity and Use

A system running standard 40-foot buses on 56 routes every 10 minutes could bring more than 20,000 people per hour into a central business district (see Table 1). Using double-decker buses and increasing frequencies to the maximum of 24 per hour would bring more than 140,000 people per hour into the downtown.

These numbers assume every seat and much of the standing room is occupied. In practice, buses average less than half full, as they are nearly empty at the beginnings of their runs and will not be full when they are running in the opposite direction of most commuters. According to the 2012 National Transit Database, the average bus-rapid transit line attracted 5.7 passengers per vehicle revenue mile. With this system, that is equal to about 663,000 trips per day when peak-period buses operate six times per hour, 1.1 million trips per day at 10 times per hour, and 2.7 million trips per day at 24 times per hour.

System Costs

Table 2 shows the cost of buying enough buses to provide rapid service at a peak of 6, 10, and 24 times per hour, plus downtown circulators, plus some spare buses. Estimated figures are shown for each type of bus: single-decker, articulated, and double-decker.

The Federal Transit Administration (FTA) estimates that buses have a useful lifespan of 12 years, while platforms and most other infrastructure have 30-year lifespans. The FTA also requires transit agencies to use a 2 percent interest rate when amortizing capital costs. Based on this, Table 3 shows the annualized capital costs of the buses shown in Table 2.

Other capital costs include bus platforms and express lanes. Turnstile-equipped platforms are estimated to cost about $50,000 each. With about 525 platforms in the system,

"Double-decker buses at maximum frequencies could bring more than 140,000 people per hour into a downtown area."

“Substituting rail transit for buses results in a trade-off between higher capital costs for rail versus higher operating costs for buses.”

Table 2
Rapid Bus Capital Costs in Millions of Dollars

	Buses per Hour on Each Route		
	6	10	24
Standard 40-foot buses	$240	$380	$880
Articulated buses	540	855	1,980
Double-decker buses	420	665	1,540

Note: Includes the cost of 45 standard buses plus 5 spares to use as circulators, plus about 20 extra buses as spares for the rapid bus service.

Table 3
Annualized Capital Costs of Buses in Millions of Dollars

	Buses per Hour on Each Route		
	6	10	24
Standard 40-foot buses	$22.50	$35.70	$82.60
Articulated buses	50.70	80.20	185.80
Double-decker buses	39.40	62.40	144.50

Note: Based on calculated number of buses needed to serve the system times $400,000 for standard buses, $900,000 for articulated buses, and $700,000 for double-decker buses.

this adds up to $26.3 million. Amortized over 30 years, this represents a $1.2 million annualized cost. The $1.12 billion worth of express lanes that would be needed if no HOV/HOT/express lanes are already available works out to an annualized cost of $50 million per year. This paper attributes 10 percent of this cost to transit.

The 2012 National Transit Database says that ordinary bus operations cost about $127 per vehicle revenue hour, while rapid bus operations cost $157 per hour. Since most rapid bus systems use articulated buses, Table 4 applies the $157 cost to articulated and double-decker buses, and the $127 cost to standard buses. The numbers shown in Table 4 also presume that frequencies on weekends and holidays would be half of those on weekdays. The numbers also include the cost of operating the downtown circulator buses on two-minute frequencies.

Table 5 shows the total annual cost of a rapid bus system, including the annualized capital costs of buses and platforms. While this may look like a lot of money, the transit systems of all but one of the nation’s urban areas with more than 2 million people spent more than $272 on operations and capital in 2012, and all but five spent more than $500 million.

COMPARISON WITH RAIL

Substituting rail transit with buses results in a trade-off between higher capital costs for rail and higher operating costs for buses. Rail operating costs are not necessarily significantly less per passenger than for buses, but since rails are so expensive to build they tend to serve only a small fraction of the routes served by buses. Transit agencies usually supplement the rail lines with feeder buses, and the cost of these buses really should be included in rail costs.

Applied to the generic urban area defined in this paper, a rail transit system would have rail

Table 4
Rapid Bus Annual Operating Costs in Millions of Dollars

	Buses per Hour on Each Route		
	6	10	24
Standard 40-foot buses	$243	$391	$909
Articulated buses	295	478	1,118
Double-decker buses	295	478	1,118

Note: Based on calculated hours of service multiplied by $127 per hour for standard buses and $157 per hour for articulated and double-decker buses.

Table 5
Rapid Bus Total Annual Costs in Millions of Dollars

	Buses per Hour on Each Route		
	6	10	24
Standard 40-foot buses	$272	$433	$999
Articulated buses	352	564	1,310
Double-decker buses	340	548	1,269

Note: Sum of Tables 3 and 4 plus $1 million for annualized cost of bus platforms and $5 million for annualized cost of transit's 10 percent share of the cost of express lanes.

lines paralleling each of the major freeways, for a total of 52 miles of rail radiating from downtown in four lines. The average light-rail line being built today costs about $100 million per mile (including the cost of stations, park-and-ride lots, and other infrastructure but not railcars), for a total of $5.2 billion. Amortized over 30 years at 2 percent interest, this comes to an annual cost of $231 million.

Light-rail trains that stop about every mile average about 22 mph. Though this is the same speed as the rapid bus system, riders who transfer from buses to trains will have a longer commute time because of time spent on the 14-mph feeder buses and waiting for connections at the bus-rail stations.

At an average speed of 22 mph, a light-rail train would take just under 1.2 hours to make a trip from the north or east end of each line to the south or west end. For safety reasons, most light-rail lines can operate no more than 20 trains per hour, but lines more typically operate 8 trains per hour. At 20 trains per hour, 95 trains are needed to serve the entire 56-mile system; at 8 trains per hour, only 38 trains are needed.

Light-rail cars are just under 100 feet long, so cities with 300-foot blocks can run three-car trains. This means 285 cars are needed for the high-frequency system and 114 for the low-frequency system. The cars cost about $4.5 million and have an expected service life of 25 years. Adding a few cars for spares, the total capital cost is $1,332 million for the high-frequency system and $504 million for the low. Amortizing at 2 percent results in an annualized cost of $68 million for the high-frequency system and $26 million for the low.

Using the same assumptions regarding peak/off-peak and weekday/weekend and holiday service as for the rapid bus lines, operating 20 peak-hour three-car trains per hour would

> "American transit agencies are guilty of deferring maintenance, so we have no good way to estimate maintenance costs."

"Light-rail trains would serve only a small portion of the urban area compared with the rapid bus system."

Table 6
Light-Rail and Feeder Bus System Costs in Millions of Dollars

	Frequency of Trains/Buses per Hour	
	20/10	8/4
Light-rail capital costs	$5,200	$5,200
Annualized	231	231
Railcar capital costs	1,332	504
Annualized	68	26
Light-rail operating costs	273	109
Bus capital costs	110	46
Annualized	10	4
Bus operating costs	123	49
Downtown circulator annualized cost	15	15
Total annual costs	$447	$325

Note: Calculations as described in the text. Capital costs are annualized by amortizing over 30 years for infrastructure, 25 years for railcars, and 12 years for buses at 2 percent interest, all as required by the FTA.

work out to 1.05 million vehicle revenue hours per year, while 8 peak-hour trains per hour works out to be 420,000 vehicle hours per year. The 2012 National Transit Database says that the average cost of operating light rail was $260 per vehicle revenue hour, for a total annual cost of $273 million at 20 trains per hour and $109 million at 8 trains per hour.

These light-rail trains would serve only a small portion of the urban area compared with the rapid bus system. To reach the rest of the urban area, feeder buses could circulate on the same major arterials used by the rapid bus system. Since transit agencies depend on many people driving to rail stations, they tend to operate feeder buses less frequently than the rail lines. This paper assumes feeder buses would operate at half the frequencies of the trains.

At average speeds of 14 mph, about 263 feeder buses would be needed to serve the 20-trains-per-hour system and 105 needed to serve the 8-trains-per-hour system. Assuming that a few extra buses would be purchased as spares, and assuming standard 40-foot buses, the capital cost of these buses would be $110 million for the higher-frequency system and $46 million for the lower-frequency system. Amortized over 12 years at 2 percent, those costs equate to $10.3 million per year for the higher frequencies and $4.3 million for the lower. At $127 per hour, operating these buses would cost $123 million per year for the higher frequencies and $49 million per year for the lower. Table 6 summarizes those costs and includes the annualized cost of a downtown circulator similar to the one designed for the rapid bus system.

One cost that this paper has not considered is maintenance. The main reason for this exclusion is because American transit agencies are guilty of deferring maintenance, so we have no good way to estimate those costs. Although generally accepted accounting principles state that maintenance is an operating cost, the FTA allows transit agencies to count it as a capital cost.[16] Rail maintenance, which requires maintenance of tracks, power facilities, stations, and railcars, is far more expensive than maintaining buses, so counting it as a capital cost allows agencies to pretend that rail

Table 7
Light-Rail and Feeder Bus System Capacities in People Per Hour

	Frequency of Trains/Buses per Hour	
	20/10	8/4
Light-rail capacities	36,000	14,400
Feeder bus capacities	33,600	13,440

Note: Calculated based on three-car trains, each car holding 150 passengers, on four routes at the frequencies shown in the table.

Table 8
Transit Frequency, Capacity, and Cost

Frequency Per Hour	Capacity People Per Hour	Annual Cost ($ millions)	Cost Per Unit of Capacity ($)
Standard Bus			
6	20,160	272	13,492
10	33,600	433	12,887
24	80,640	999	12,388
Articulated Bus			
6	30,240	352	11,640
10	50,400	564	11,190
24	120,960	1,310	10,830
Double-Decker Bus			
6	35,280	340	9,637
10	58,800	548	9,320
24	141,120	1,269	8,992
Light-Rail and Feeder Bus			
8	14,400	325	22,569
20	36,000	447	12,417

operating costs per passenger are competitive with bus operating costs.

The FTA says that American rail transit systems have about a $60 billion maintenance backlog and bus systems have about an $18 billion maintenance backlog, and these are growing because transit agencies are spending less than needed to keep transit in its current state of repair.[17] Clearly, if the full costs of maintenance were included in the figures shown in this paper, the results would become even more lopsided in favor of rapid buses over rail.

Table 7 shows the capacities of the rail and feeder bus systems. The rail capacity shown is the number of passengers the four light-rail lines can bring into the downtown area per hour. The bus capacity shown is the number of passengers the feeder buses can bring into light-rail stations per hour. As shown, they are fairly similar.

> "The lowest-cost rapid bus system costs 10 percent less per year than rail, but has a 40 percent greater capacity for moving people."

Table 9
Central Business District (CBD) and Metropolitan Statistical Area (MSA) Jobs and Transit's Share of Commuting for Metropolitan Areas of More than 1 Million People Plus Honolulu

	CBD Jobs	MSA Jobs	CBD's Share (%)	Transit's Share of CBD Jobs (%)	Transit's Share of Other Jobs (%)
New York	1,971,305	8,983,981	21.9	76.6	16.3
Chicago	500,450	4,407,655	11.4	57.4	5.5
Boston	242,900	2,279,803	10.7	52.2	7.0
San Francisco-Oakland	297,420	2,069,673	14.4	50.7	8.5
Washington	379,215	2,892,018	13.1	47.1	8.8
Philadelphia	239,625	2,758,126	8.7	44.2	6.0
Seattle	163,830	1,690,490	9.7	37.0	5.1
Pittsburgh	92,010	1,096,780	8.4	32.5	3.3
Minneapolis-St. Paul	99,315	1,718,389	5.8	31.5	2.9
Portland	85,195	1,043,671	8.2	27.0	4.3
Los Angeles	136,585	5,810,839	2.4	22.5	5.7
Denver	119,565	1,252,889	9.5	19.8	1.2
Baltimore	91,600	1,320,217	6.9	17.7	5.4
Cleveland	85,235	958,330	8.9	15.1	2.8
Atlanta	172,975	2,434,641	7.1	14.2	2.5
Dallas-Ft. Worth	69,710	2,968,972	2.3	14.0	1.3
Cincinnati	64,660	991,623	6.5	13.3	1.7
Houston	169,495	2,645,276	6.4	13.1	1.8
Sacramento	75,970	929,984	8.2	13.0	1.8
Salt Lake	44,015	514,702	8.6	12.2	2.5
Phoenix	26,225	1,827,419	1.4	11.8	2.1
Buffalo	32,890	518,632	6.3	11.5	3.1
St. Louis	57,810	1,316,191	4.4	11.2	2.2
Milwaukee	54,010	749,094	7.2	11.1	3.1
Providence	23,305	764,373	3.0	10.5	2.4
San Diego	70,285	1,420,901	4.9	10.2	2.9
Miami-Ft. Lauderdale	96,760	2,504,316	3.9	9.4	3.5
Charlotte	61,915	1,006,814	6.1	8.8	1.2
San José	31,120	844,729	3.7	8.4	3.1
Hartford	62,520	589,357	10.6	8.1	2.1
Detroit	70,655	1,840,867	3.8	7.5	3.0

Table 9 *Continued*

	CBD Jobs	MSA Jobs	CBD's Share (%)	Transit's Share of CBD Jobs (%)	Transit's Share of Other Jobs (%)
Kansas City	39,090	970,244	4.0	7.0	1.0
New Orleans	49,250	510,454	9.6	6.7	2.1
Louisville	54,245	591,742	9.2	6.5	1.7
Richmond	56,815	498,175	11.4	6.5	1.4
San Antonio	57,015	928,004	6.1	6.4	2.0
Las Vegas	24,350	894,892	2.7	5.6	3.6
Austin	71,605	835,052	8.6	5.1	2.3
Columbus	78,875	897,380	8.8	4.9	1.3
Rochester	26,560	569,488	4.7	4.9	1.8
Nashville	50,490	776,796	6.5	3.6	0.8
Memphis	19,455	579,235	3.4	3.5	1.3
Virginia Beach-Norfolk	24,305	834,719	2.9	3.2	1.7
Tampa-St. Petersburg	30,450	1,231,174	2.5	3.1	1.3
Orlando	59,025	988,437	6.0	2.9	1.6
Indianapolis	73,140	877,076	8.3	2.6	0.9
Jacksonville	44,035	621,153	7.1	2.3	1.0
Raleigh	32,830	530,723	6.2	1.8	0.8
Riverside-San Bernardino	15,975	1,650,384	1.0	1.8	1.6
Grand Rapids	25,240	456,730	5.5	1.7	1.1
Birmingham	32,225	499,403	6.5	1.3	0.7
Oklahoma City	10,040	579,514	1.7	0.9	0.5
Honolulu	51,635	358,728	14.4	13.8	7.5

Source: Wendell Cox, "United States Central Business Districts (Downtowns)," 3rd ed., Demographia.com, March, 2014, Tables 2 and 5.

Table 8 summarizes the previous tables and reveals that the lowest-cost rapid bus system costs 10 percent less per year (and 40 percent less per unit of capacity) than the less-frequent rail system. Moreover, transit riders are sensitive to frequencies and speeds, and since the rapid buses operate faster and more frequently than the light-rail/bus system, the rapid buses are likely to attract more passengers. Buses are also more comfortable for many riders; when trains are full, more than half the passengers must stand, whereas two-thirds to three-fourths of bus passengers can be comfortably seated.

The high-frequency rail system has about the same capacity as the 10-bus-per-hour rapid bus system using standard buses or the 6-bus-per-hour rapid bus system using double-decker buses. Both of those bus systems cost less than the rail systems.

Perhaps most important of all, the rapid bus system is more easily scalable than the rail sys-

> “Buses can easily carry half of downtown commuters to work in every metropolitan area except New York City.”

tem, meaning the cost per passenger is about the same no matter what the level of ridership. The first few hundred passengers a day of a rapid bus system require only a few buses, costing a few million dollars, while the first few hundred passengers a day of a rail system requires an initial expenditure of close to a billion dollars. Adding capacity to the bus system simply means buying more buses, while with the rail system it means building more miles of rail, buying expensive rail cars, and lengthening platforms.

This example used light rail, whose capacity is limited almost by definition: the term *light rail* refers not to weight but to capacity. Light rail is low-capacity rail transit while heavy-rail (subways and elevateds) is high-capacity rail transit. Heavy-rail can run up to 30 times per hour and train lengths are limited only by platform lengths, generally between 8 and 11 cars. The highest-capacity heavy-rail lines in America are some New York City subway lines that run 11-car trains; these can move close to 50,000 people per hour. However, elevated train systems cost about three times as much per mile as light rail, and subways are more expensive still. New York City is currently building a subway at a cost of $2.1 billion per mile.

This shows that, in general, buses can provide better service than rail at a lower cost. However, buses may not work in every urban area, and many urban areas won't need a rapid bus system.

URBAN AREAS

The rapid bus system described here is designed to provide the best service to people going downtown. People going to other destinations will probably have to make a transfer downtown, and this can make transit noncompetitive if someone is trying to get from, say, a northwest suburb to a northeast or southwest suburb.

This is a disadvantage of any hub-and-spoke system, including nearly all rail transit systems. Nearly all American transit systems follow the hub-and-spoke formula, and commuters who work in a downtown of one of the nation's 50 largest metropolitan areas are five times more likely to take transit to work than commuters who work outside of downtowns in those metro areas.

This means hub-and-spoke systems work best in locations that have lots of downtown jobs. New York City has nearly 2 million jobs located in Midtown and Lower Manhattan, and these represent 22 percent of all the jobs in the New York metropolitan area. But in the 50 largest metropolitan areas outside of New York, an average of less than 7 percent of the jobs are located in downtowns.

Of the commuters who work in Midtown and Lower Manhattan, 77 percent take transit to work. Transit's share of commuters to the downtowns exceeds 50 percent in only three other metropolitan areas: Boston, Chicago, and San Francisco. The average for the next 46 largest urban areas is less than 20 percent.

Table 1 shows that a rapid bus system can bring 80,000 to 140,000 people into a downtown area in one hour, while Table 7 shows that a four-line light-rail system running three-car trains can bring in only 36,000 people per hour. A four-line heavy-rail system can bring close to 200,000 people per hour into a downtown.

Assuming that most people commute to and from work over a two-hour period, the rapid-bus system using double-decker buses can move 280,000 downtown commuters to work. Table 9 shows that buses can easily carry half of downtown commuters in every metropolitan area except New York City. The rapid bus system designed here might have a slight problem in Chicago, where 287,000 people currently commute by transit, but minor modifications could make it work there as well.

On the other hand, the lowest-capacity rapid bus system considered here can move 20,000 people into downtown in one hour. Such a system could move half the commuters into downtowns with 80,000 or more jobs over the two-hour commute period. As Table 9 shows, only 17 U.S. metropolitan areas have that many downtown jobs.

Based on Table 9, urban areas fall into several categories. First, New York appears to be the only urban area in America that absolutely requires rails to move the massive number of commuters who work in its downtown job center. Second are urban areas with 200,000 to 500,000 downtown jobs, including Boston, Chicago, Philadelphia, San Francisco, and Washington. A somewhat scaled-up rapid bus system based on the one described in this paper could easily meet the demand for downtown commuting in these regions. All of these regions already have fairly complete rail transit systems, but they are old and suffer from poor maintenance and inadequate budgets.[18] Rather than spend billions of dollars rebuilding rail lines that the regions can't afford to maintain, the most cost-effective policy is to phase out rail as it reaches the end of its useful service life and replace it with rapid buses.

Third are about 30 urban areas of a million people or more, ranging from Salt Lake City to Atlanta, that have between 40,000 and 200,000 downtown jobs. Honolulu, which is shown in Table 9 because it has a high rate of transit commuting even though it has fewer than a million residents, also has more than 40,000 downtown jobs. These regions are ideally suited for the kind of rapid bus system described in this paper. Most of these areas have a skeletal rail system and are seeking funding to expand their rail lines. Instead, they should plan rapid buses on routes not currently served by rail and transition rails to buses as the rail lines wear out. Columbus, Detroit, Hartford, Indianapolis, Jacksonville, Louisville, Milwaukee, Richmond, and San Antonio have not built any light- or heavy-rail lines and would be natural candidates for implementation of a rapid bus system.

Finally, there are the remaining urban areas with fewer than 40,000 downtown jobs, including a dozen in Table 9 as well as almost every urban area smaller than 1 million people other than Honolulu. Considering that these urban areas have very low rates of transit usage today, heavy expenditures on any form of high-capacity or rapid transit are not worthwhile. Instead, transit agencies serving these cities should concentrate on low-capacity transit systems, including shared rides and jitneys.

CONCLUSION

As an alternative to rail transit, this paper has described a rapid bus system for a generic urban area of about 2 million people. This rapid bus system would be accessible to almost everyone in an urban area, with most people located within a half-mile and almost half located within a quarter mile of rapid bus platforms.

The rapid buses would allow most people in the region to reach downtown in a single trip at faster average speeds than a bus-rail system that requires many people to transfer between buses and rail. The rapid buses could also operate more frequently than light-rail trains, and when systems operate at capacity, a greater share of bus riders can be comfortably seated. All of these factors make it likely that the rapid buses would attract more passengers than light rail.

This paper has also shown that a rapid bus system is capable of carrying more people than light-rail lines at a far lower cost. A light-rail system with four lines radiating from downtown can only move about 36,000 people into downtown per hour. About the same number of people can be moved with a rapid-bus system at a 22 percent lower cost.

Rapid bus systems are easily scalable for any size urban area that has more than about 40,000 downtown jobs. This means the capital and operating costs per rider are about the same for regions that have 40,000 jobs as for regions with 400,000 jobs. It also means that the bus system can easily grow as a region grows. By comparison, rail systems are costly to start up, expand, and maintain.

Rapid buses could not substitute for subways and commuter trains that serve New York City. But they could replace rail lines in Boston, Chicago, Philadelphia, San Francisco, and Washington as those lines wear out. Smaller regions with 40,000 to 200,000 downtown

“Urban areas with 200,000 to 500,000 downtown jobs should phase out aging rail systems and replace them with rapid buses.”

jobs should scrap plans for new rail transit lines and rely on rapid buses instead. Regions with fewer than 40,000 downtown jobs probably do not need any form of high-capacity rapid transit.

NOTES

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