DEVELOPING A REGIONAL BUS RAPID TRANSIT NETWORK IN THE NEW YORK METROPOLITAN AREA

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for the New York University Rudin Center for Transportation symposium

CATCHING THE NEXT RIDE: THE POTENTIAL FOR REGIONAL BUS RAPID TRANSIT SYSTEMS

February 24, 2010

ABSTRACT

Bus Rapid Transit (BRT) is an enhanced bus system designed to "combine the flexibility of buses with the efficiency of rail." While applications are diverse, most BRT systems achieve higher speeds and greater reliability than conventional buses by providing priority treatments that include dedicated lanes, queue jumpers, signal priority, and by locating stops farther apart than is normal on local routes. Many systems also use real-time monitoring and management systems to maintain on-time performance. Vehicle and station designs, fare media and collection systems, and information systems can further improve operating efficiencies and customer experience. Construction costs for BRT can be lower than those for comparable rail services, although the closer to rail design, the smaller the cost difference (FTA, 2010; TCRP, 2009).

This paper examines the opportunities and challenges presented in implementing a regional BRT network. A review of key elements of BRT and a sample of applications shows the variety of options that can be utilized in BRT systems, as well as the many ways that planners have approached BRT design. Drawing from the lessons learned to date as well as from empirical evidence on travel behavior, the paper discusses policy considerations, planning approaches, and implementation strategies for integrating BRT into effective multimodal urban transit systems. Attention is also given to strategies for better integrating BRT with urban land use and development.

Possibilities for further application of BRT in the New York metropolitan area are numerous. BRT could improve transit in built-up urban corridors by allowing bus riders to bypass congestion, greatly improving speed and reliability. Applications in suburban corridors could provide direct links to major destinations or fast links to rail service, and could be designed as long-term improvements to existing bus services or as a strategy to grow ridership for eventual light rail implementation. A companion paper (Levinson, 2010) identifies specific opportunities.

A critical planning endeavor would be to identify BRT investments that could enhance connectivity and mobility at a regional scale. Regional analyses and forecasts could be used to identify areas with limited transit access to major trip destinations such as jobs, education, shopping, and healthcare services, as well as to identify major trip origin-destination linkages where transit travel times need improvement. Corridors then could be evaluated on a case-by-case basis to diagnose specific problems and identify opportunities for establishing better connections to major destinations. Future potential for growth and development could also be incorporated into the analysis and the resulting service needs and opportunities built into the plan. Funding priority then can be given to corridors where investments in BRT would have the greatest impact across the region.

Any BRT project requires high levels of interagency and intergovernmental cooperation to be successful. A system plan integrating BRT into a comprehensive regional transit network will require ongoing cooperation and coordinated actions of many stakeholders. State and regional agencies, transit operators, and local governments all have key roles to play in making sure that regional integration of transit systems will take place and be effective.

Introduction: The Promise of Bus Rapid Transit

Bus Rapid Transit (BRT) is an enhanced bus system designed to "combine the flexibility of buses with the efficiency of rail" (FTA, 2008). BRT systems use a variety of physical and operational design features and technologies to provide faster speeds and greater service reliability. By speeding up service, bus operators can increase productivity (provide more runs per hour, more seat miles per day, etc.), and riders can gain faster and more predictable travel times on the bus. Many BRT systems further enhance the user's experience by providing improved stops or stations, information systems, and other services and amenities (FTA, 2009; TCRP, 2009).

Because BRT refers to a family of services that can be used to respond to a variety of objectives, BRT comes in a variety of forms. Listed below are elements that have been included in BRT projects in the US and other countries.

Elements of BRT

- Relatively wide stop spacing
- Priority treatment at intersections
- Exclusive bus lanes or HOV lanes
- BRT route map and schedule
- Shelter
- Seating
- High-design BRT vehicles
- Level boarding and alighting
- Multi-door boarding and alighting
- Active monitoring and management systems to maintain schedule adherence and otherwise improve performance, safety and security
- Special vehicles and station designs, colors, signage, etc. to create a BRT "brand"
- Lighting – in shelter, outside
- Trash container / recycling
- Station area map
- Connecting services maps and schedules
- Real time information systems
- Fare prepayment machines, other payment techniques that reduce bus delay
- Security monitoring/CCTV
- Temperature control (heating, cooling)
- Emergency telephone
- Public telephone
- Restroom
- Station attendant
- Police presence
- Public address
- Vending (food, beverages, print media, flowers)
- Public art
- Street design and streetscape improvements to make access to BRT safer and more convenient for pedestrians and bicycles

All BRT lines use some sort of priority treatment for buses and provide fewer bus stops than are offered on local or feeder lines. The specific treatments and stop spacings vary, however. In addition, BRT lines differ on the types of vehicles used, whether and to what extent stations are upgraded in comparison to regular bus stops, whether fare payment systems are altered, and whether other amenities such as real time information, improvements to the surrounding area, are provided (Diaz (ed.), 2009, Kittleson & Associates, 2007). The wide variation in BRT design reflects the broad range of objectives that have motivated transit operators to undertake BRT, as well as the tendency to plan BRT at the individual corridor level. Different operators and diverse corridor types face different challenges, opportunities and constraints, and matching BRT design to the local context can be both pragmatic and cost-effective from the perspective of line performance. However, it is also important to examine BRT from a broader regional perspective, considering current and future conditions, because a line-by-line approach may fail to address latent demand, overlook cumulative impacts, and miss opportunities for synergies. For example, by coordinating fares, providing timed transfers, reducing transfer distances, and sharing information systems across lines and operators, transit providers may open up new markets for transit and are likely to provide better longer-term service to a growing and changing region.

This paper examines key issues that arise when viewing BRT from a broader perspective, examining the opportunities and challenges presented in implementing a regional BRT network. A review of key elements of BRT and a sample of applications shows the variety of options that can be utilized in BRT projects, as well as the many ways that planners have approached BRT design. Drawing from the lessons learned to-date as well as from empirical evidence on travel behavior, the paper discusses policy considerations, planning approaches, and implementation strategies for integrating BRT into effective multimodal urban transit systems. Attention is also given to strategies for better integrating BRT with urban land use and development.

Varieties of BRT: Design Features and Policy Choices

A widely preferred configuration for a BRT line would include the following (see, e.g., FTA (2009):

- Stops spaced ¼ to ½ mile or more apart
- Signal preemption or other forms of bus priority treatment at intersections, entry ramps, and pullouts
- Bus-only dedicated (exclusive) lanes
- Elevated platforms or low floor buses to permit level boarding and alighting
- Active monitoring and management systems to maintain schedule adherence and otherwise improve performance, safety and security
- Fare prepayment or fare media to speed boarding
- Customer information services, shelter, and other amenities such as seating, lighting, and security at stations and stops
- Special BRT vehicle and station designs, colors, signage, etc. to create a BRT “brand”
- Street design and streetscape improvements to make access to BRT safer and more convenient for pedestrians and bicycles.

However, the term BRT has also been used in reference to improved buses that serve widely spaced stops and have intersection priority treatments but otherwise operate in mixed-flow lanes serving modestly upgraded stops. BRT has also come to be used for a variety of services using exclusive lanes along with at least some of the elements listed previously.

The variation in BRT design features in part reflects the widely varying objectives that different transit operators have brought to BRT, from bypassing congestion on established bus routes to creating a light rail-ready corridor serving a newly developing area, as well as the different problems and opportunities presented in different corridors as listed below.

Objectives for BRT Systems:

- Improve productivity and cut operator costs by increasing speeds and reducing variability in run times
- Reduce the number of bus stops to lower costs and speed operations
- Provide more service per unit of labor or per bus (extended areal coverage, more runs)
- Provide high capacity, high frequency services at modest cost (capital, operation, maintenance)
- Bypass congestion
- Reduce congestion
- Reduce stops and delays for buses
  Improve speed and reduce variability in travel times for current riders
- Accommodate growing ridership
- Attract auto drivers to transit
- Provide service better matched to markets – differentiate longer distance and local services
- Reduce fuel use and emissions
- Improve the comfort, convenience and safety of bus stops
- Improve the image of transit and its community acceptance
- Support land development and revitalization efforts
- Render a corridor “rail ready” and provide a service to build up demand for rail

For example, an operator that has stops every 400-500 ft. with few passenger boardings at many of them may conclude that stop delay is excessive. Consolidating stops to achieve 1200-1500 ft. spacing is a key element of its BRT plan. Conversely an operator with heavy demand at all its stops may determine that boarding and alighting delays are the key issue. This problem can be addressed by using off-board payment and vehicles configured to allow level boarding through multiple wide doors. An operator whose buses are frequently delayed by congestion will likely see exclusive lanes, signal priority, and station location as key factors in improving service. An operator whose passengers on a line that are mostly transferring to a rail system may see timed transfer as critical.

A regional BRT plan would look at these corridor-specific issues, but also would look at regional travel patterns since that examination may reveal additional information. For example, on a line with closely spaced stops, there may in fact be two markets – travelers who are going only a few stops and travelers whose trips are 6 to 15 miles long. This was the case, for example, along San Pablo Avenue in the dense East Bay suburbs of the San Francisco Bay Area. The planning solution for such a system was to retain some local service and add BRT “rapid” services as an overlay.

Because the importance of the various elements of BRT is a function of the implementation context and policy objectives, it is useful to briefly review key features and then discuss how these may apply to a major metropolitan region.

Stop spacing and location

Reducing the number of stops compared to local service is important not only to speed up bus operations but to allow for sufficient activity at BRT stops to justify a higher investment in stop or station improvements. In many US cities bus stops are spaced quite close together – 400 to 800 ft. apart – and buses often have to stop for only one or two passengers at some of these stops. Reducing stops can save time which over the length of a passenger’s trip (or from the bus operator’s perspective, the length of the route), can be substantial. For example, San Francisco Muni found that extending bus stop spacing on priority routes to 1000-1200 ft. saved about 10 seconds per eliminated stop and reduced the time to travel the route by 20%-30%. While passengers also had to walk farther, Muni retained the stops that regularly attracted the highest level of patronage, and ridership losses from the reduced number of stops were minimal (personal communication with Muni staff, 2009).

Many transit operators plan for their BRT stops to be about half a mile apart so that the maximum walk distance along the route to a stop would be a quarter mile, or about five minutes. The stop spacing need not be treated as a fixed distance but can be adjusted to account for block lengths, provide direct service to major trip generators, facilitate transfers to other routes or modes, and avoid impediments such as important driveways. However, some systems have stops spaced closer together (e.g., quarter mile spacing), especially in areas with high demand or with a concentration of population groups for whom longer walks could be burdensome (e.g., around senior centers). When stops are relatively close together, vehicle designs, fare policies that reduce boarding, and alighting time are important (i.e., if more time is required for stopping, some of it can be offset by faster boarding and alighting). Alternatively, a dual service strategy may be an option – offering BRT service from a limited number of enhanced stations while retaining at least some local service to accommodate those with shorter trips and access concerns.

Lane configurations

Exclusive rights-of-way (ROW) are dedicated lanes and in some cases dedicated streets that can be provided for BRT in surface, elevated, and tunnel configurations. A few systems operate on modified former rail or other off-road ROWs, while most operate on local streets, arterials, and limited access highways or freeways.

Exclusive ROWs are important when buses are getting caught in congestion along the route or face significant delays at intersections. They can also be useful if buses are having difficulty entering and exiting from stops due to fast moving traffic or parked vehicles. Lanes protected from intrusion by other vehicles using physical barriers are especially valuable when traffic congestion is a major cause of low speeds and unpredictable travel times. The lanes can be installed the entire length of the route, or may be provided only at critical intersections. The choice usually depends on the design of the street in which BRT will be added as well as on the travel time savings to be gained from an exclusive lane – primarily a function of traffic levels in mixed-flow operations.

In suburban locations and along some urban arterials, there may be a center turn lane or a median that can be redesigned for exclusive bus use, or very wide lanes that can be restriped with no change in traffic capacity. However, the more common situation requires making hard choices about the allocation of street space to buses versus moving and parked cars.

In built-up areas, providing a bus lane will often require at the very least, a narrowing of existing lanes to fit the new bus lane. In many cases it will require taking lanes from general traffic, or removing on-street parking, or both. For example, suppose the ROW from curb to curb is 60-ft. and is striped for four 11-ft. mixed-flow lanes and two 8-ft. parking lanes. To accommodate BRT, the ROW can be reconfigured to two 12-ft. bus lanes and two 10-ft. mixed-use travel lanes (one in each direction, instead of two) with the parking retained. Alternatively, buses could be equipped with mechanical or electronic lane guidance devices, allowing them to operate on lanes not much wider than the bus itself (a common bus width is 8'6" for the body, 10' 4" with mirrors). A narrow bus lane strategy may, however, make it infeasible to replace BRT with rail at a later date if required dimensions for rail are not met.

On arterials, many designers prefer center lane BRT lines and stations because the buses are less prone to being blocked by double parked cars and trucks, delayed by parking vehicles, or right turning vehicles waiting for crossing pedestrians to clear. Center lane treatments are commonly and successfully used on light rail systems and there is considerable experience in how to design access and manage traffic flows. Center lanes may require left turn restrictions and detailed attention to pedestrian and bike access to and from the stations. Transfers to local bus services and to rail stations also will require special attention if center lane BRT stations are used. These latter functions may be more easily handled by curb lane designs, or for high volume transfer points, multilevel, multimodal stations where bike parking facilities and pedestrian aids to walking such as escalators and elevators, overpasses and underpasses, and moving sidewalks may have a place.

When funds allow, boulevard designs may be an attractive alternative. In these designs, streets are reconfigured to provide slow moving curb lanes and faster moving center lanes separated from the curb lanes by medians. The curb lanes serve local traffic and driveways, and if width allows, accommodate on-street parking. Buses run in the fast lanes, usually from exclusive lanes and stations along the outer edge of the median separating the through and local lanes.

One-way streets present a special design problem. Dividing the BRT line into two directional routes is one option and in most cases simply replicates the unidirectional service of bus operations already on the streets. Putting both directions of BRT on a designated street that remains one-way for mixed traffic is another option, and converting the one-way street to two-way for all traffic is a third. The latter two options may create more legible BRT service but will require far more extensive changes to intersection traffic controls and signage.

Regardless of the specifics of the design, exclusive lanes will usually require installation of medians, other physical barriers, or regulatory signs to require traffic on minor streets to turn right, in order to reduce potential conflicts with bus movements.

While many bus operators believe that exclusive, continuous, protected bus lanes are the ideal, a number of lower-level lane treatments and configurations are in use. Sometimes, lower-level lane treatments were found to suffice, and sometimes because an exclusive bus lanes were deemed physically or politically infeasible. Other lane treatments include operation in designated but unprotected bus lanes where vigorous enforcement is likely to be needed to preserve bus-only use; lanes shared with other high-occupancy vehicles (HOV) such as carpools, vanpools, and sometimes taxis, where speeds may deteriorate if too many other vehicles also qualify for the lane or enforcement is lax; or operation in mixed-flow lanes with priority lanes only at key intersections, typically in the form of queue jumpers. The latter system may provide adequate priority for buses much of the time, but can tangle buses up in traffic on those days when the queue is longer than the queue jumper.

Bus systems operated largely in mixed traffic are sometimes called “rapids” (or “BRT-lite”) to distinguish them from the more advanced BRT systems (“BRT-heavy”) (McDonnell, 2008). Rapids are usually easier to accommodate on urban streets but may not be able to provide the same speeds or reliability as exclusive ROW systems. BRT systems also can be hybrids, using exclusive ROWs on some sections and in mixed-flow with queue jumpers on others. They may travel on a combination of urban arterials, limited access highways, and local streets. ROW designations vary by time of day in some applications (e.g., transit-only street during daytime hours, open to other vehicles at night). BRT or express segments may be exclusive to a particular line or may be shared by multiple lines whose routes diverge on other segments.

In some corridors, BRT operates on limited access highways (e.g., freeways) for some or most of the route. Such services are often referred to as express buses or freeway flyers. The bus services typically operate in a bus-only or HOV lane on the freeway built by using the shoulder, the median, or air rights. The bus services stop at a limited number of park-and-ride facilities, rail stations, and multimodal terminals. Most often, the park and ride facilities and terminals are offline, although some systems use terminals constructed in the freeway ROW. Bus-only lanes or ramps may be provided for freeway entrance and exit. These ramps are linked directly to the busway in the shoulder and air rights designs. However, these designs may only give priority access to the freeway itself. Center-lane designs require the bus to cross several lanes of mixed-flow traffic to reach a center HOV lane.

Priority treatments on the offline portion of the route can be critical elements in the design of freeway BRT systems, because delay in the off-freeway operation can offset much of the benefit of the freeway priority lanes. In one San Francisco Bay Area example, freeway HOV lanes allowed buses to save 3 to 6 minutes compared to travel time in mixed-flow lanes, but delays at signals off the freeway were losing up to three minutes of that time. Queue jumpers and priority left turn signals were recommended as a way to avoid those losses (Deakin, et al., 2006).

The management of the freeway priority lane may also be a consideration: US freeway applications occasionally provide exclusive lanes for buses, but more often buses share HOV lanes with carpools and vanpools (and in some cases, with tolled cars and trucks). In the latter instances, enforcement can be more difficult and congestion in the lanes can become a problem, as has happened on several California HOV lanes.

Priority treatments at intersections and highway interchanges

In addition to exclusive lanes, which themselves are a form of priority treatment for transit, BRT can be provided a variety of preferential treatments at intersections along urban arterials and at on and off ramps along limited access highways.

Priority treatment at intersections most often includes bus detection and signal priority such as holding the signal green a few seconds longer or turning it green a few seconds early, to allow the bus to proceed without delay. Protected left and right turn signal phasing for buses also can be an important priority treatment, allowing buses to make the turn before pedestrians begin to cross.

Investment in signal equipment that can handle bus priority is a prerequisite to using these strategies, but even older signal systems can be timed to give transit some priority through the use of transit-weighted plans by treating each bus as the equivalent of 50 to 100 motor vehicles. For example, as part of a fuel-efficient traffic signal timing program, the City of Berkeley, CA timed its downtown signals to give more green time to buses on Shattuck Avenue through the downtown and around the downtown BART (metro rail) station.

In addition, physical treatments and traffic regulations can provide priority to buses. Such treatments include exclusive bus through and turn lanes, installation of medians, other physical barriers, or regulatory signs to require traffic on minor streets to turn right, and restriction of parking and loading during congested periods to reduce potential conflicts with bus movements.

In some cases, parking can be relocated to side streets, where it may be possible to install diagonal parking to reduce the net parking loss, or moved to parking structures where mechanical lifts and stacked parking may be options for increasing capacity. Loading zones also can be moved to side streets or to off street locations in some cases. Alternatively, regulatory restrictions, such as bans on auto turning movements that might block or delay the bus, can be applied. Likewise, tighter regulation and enforcement of double-parking by delivery vehicles, which in many cities block travel lanes even when a loading zone or parking spot is available, also can help speed buses. Unless enforcement is ongoing through substantial fines and towing, some drivers will choose to take their chances and will disrupt services. Physical barriers preventing intrusion into the bus lanes and protecting bus turning movements may be the only practical solution in such cases.

When bus stops/stations are located in curbside pullouts, it can be useful to establish and enforce a yield-to-bus traffic statute or ordinance to allow the bus to move back into traffic or cross traffic to reach the exclusive lane. Here too, vigorous enforcement may be needed for this strategy to work. Bus bulb-outs are an alternative and in many cases preferable way to treat this issue, giving buses priority and passengers better waiting and loading areas.

Priority treatment also can be provided to buses at the interchanges to and from limited access highways. On-ramps can be metered for most traffic and ramp meter bypass lanes can be provided for buses. In some applications downstream metering rates could be adjusted in accordance with bus arrivals at the ramp to make it easier for the bus to cross the mixed-travel lanes to enter a HOV lane. Signals around freeway exits could include bus detection to allow priority treatment. Occasionally, highway operators use mainline flow metering, and this can be another location where transit can be given priority passage.

Pricing can also be a form of priority treatment. In general terms, if a bus uses twice the street capacity of a car, but carries 25 times the passengers, the price for it should be twice that of a car, resulting in a per-passenger charge of only 4% that of autos. In most applications buses and other HOV are simply exempted from congestion charges and given priority lanes to bypass toll queues. For example, at the San Francisco-Oakland Bay Bridge, buses save about 20 minutes during peak periods by bypassing both toll booths and flow metering lights.

Vehicle choices

Just as BRT lane designs and priority treatments can be matched to corridor characteristics, vehicle choices can be matched to demand, to station requirements, and to marketing strategies. For example, BRT systems that operate on corridors with heavy demand often use specialized buses (double and triple articulated vehicles, extra wide doors to speed boarding and alighting). Systems that operate in a center lane use vehicles with doors on the left side, and some systems use vehicles with both left and right doors to allow them to serve either center lane or curbside stations. Many BRT systems utilize “green” vehicles, powered by low carbon liquid fuels, batteries, etc., improving their environmental performance. Some use high design vehicles to create a modern look and feel. A few systems incorporate guidance devices (mechanical or electronic) that permit operation on narrow lanes and assist in “docking” at stops. Some of these are very close to rail in look, operation and cost. Many other BRT systems, however, use conventional diesel buses.

Station designs, fare payments, access plans

Station designs for BRT systems vary widely. Many are rather simple, with high quality shelters offering protection from the elements along with lighting, route and schedule information, and in some cases, seating. Such BRTs most often use on-board payment, prepaid fare media, or proof of purchase strategies.

In more elaborate system designs, BRT stations include features that aim to reduce boarding and alighting time. For example, stations can incorporate ticketing machines for off-board payment, along with turnstiles, fare gates, or proof of payment systems. In addition, station designs can help reduce boarding and alighting time by incorporating level entry and exit from the vehicles, precision docking to eliminate gaps between vehicles and platforms, and if space allows, extended platforms to allow multi-bus use. A few very high capacity systems (e.g., Bogota) have platforms designed to accommodate multiple bi-articulated buses simultaneously. Some system designs also provide passing lanes at the stations or elsewhere along the line to allow overtaking and express services on BRT lines. These latter features can be very useful if both express and multi-stop services are desired or if bus bunching is a problem, but few US cities or even suburbs can accommodate such massive station designs except, perhaps, on freeways, parkways, and expressways.

Some station designs also include pedestrian overpasses or underpasses to reach center lane stations, bike parking facilities, taxis, auto drop-off zones, and transfer facilities for connections to local buses, rail systems, etc. These design features reduce passenger access time and increase accessibility and convenience, although they can be costly and may not fit into the space available.

Monitoring and management systems

Many bus systems now include GPS or other monitoring systems along with operation centers. These driver communication systems allow operators to manage the system closely and make on-the-fly operations adjustments. Such systems can be extremely important in BRT operations to keep buses running on time. Advanced monitoring and management systems can detect problems early, dispatch police or emergency vehicles if needed, communicate with traffic signal managers, or direct drivers to hold or bypass particular stations, allowing fast response should incidents require it. Management information systems also can be tied to real time consumer information systems, providing accurate information on bus arrival times and warnings if problems should arise.

In addition, many operators have found it important to add driver training to the list of system management tasks. For BRT systems, driver training can help assure a smooth ride at higher speeds, more effective docking at stations, and better customer relations.

Other measures

As indicated previously, user services and amenities that may be incorporated into BRT system designs range from simple interventions such as lighting and heating at stations, to large-scale transit oriented development (TOD) along the line. Many cities are using BRT as an opportunity to implement context sensitive designs that include improved sidewalks, bikeways and bike parking, landscaping as well as bus priority and traffic and parking management elements. In addition, some cities are using BRT as the basis for revitalizing commercial districts, citing affordable and mixed income housing, accommodating infill office development, and reusing warehouses and industrial buildings for higher-intensity activities.

Some of the interventions included in BRT designs can help to mitigate potentially adverse effects of BRT, especially if they are broadly conceived. For example, improved signal timing on a network-wide basis can help make up for reduction in road space for mixed traffic on BRT street, parking management can help offset the effects of parking removal, and improved sidewalks and landscaping can compensate for the loss of a landscaped median to BRT**.**

Examples of BRT

BRT has been implemented in cities in around the world. The various systems use different mixes of BRT elements, though all incorporate some form of priority treatment and station improvements. The systems have utilized a variety of lane and station designs. They place differing emphasis on such matters as station amenities, vehicle design, "branding", etc. To some degree the differing designs are a result of differing policy intentions as previously listed, which range from cutting bus operating costs to building demand in anticipation of eventual rail construction. The differing designs also reflect the widely different urban environments in which BRT has been introduced.

Latin America

Some of the earliest and best known applications are in South America and Canada, but BRT examples also can be drawn from number of cities in the EU, Asia, and the US. Many of these examples have been documented by the Federal Transit Administration and by BRT research centers and advocacy groups.

Applications in Curitiba, Brazil (regional population 3.5 million) and Bogota, Colombia (regional population 7 million) have received widespread attention because of their low cost and effective services. They also deserve attention because they are regional systems, designed to offer area-wide transit coverage and provide customer-friendly transportation across the region. In the Curitiba example, which has been developing for more than forty years, BRT has been integrated with regional socioeconomic policies and with regional land use planning that concentrates urban activities along BRT corridors (Figure 1). The result has been very high levels of use, with an estimated 75% of commuters in the city using BRT to go to work. Riders include some who are also auto owners.

Figure 1: Curitiba, Brazil BRT with Adjoining High-Rise Development

The newer Bogota system, Transmilenio, adapted the lessons of Curitiba to a much larger metropolitan area. Transmilenio, which first opened in 2000, now has nine lines totaling 54 km in length, with more underway. Operating on four reserved lanes in the center of large urban arterials (Figure 2), the initial 42 km system was designed and built in a few years at a fraction of the estimated cost of a proposed rail system that had been under consideration for the metropolitan area. Transmilenio was an instant hit and the bus system currently is carrying crush loads. The system design uses tri-articulated vehicles, multi-bus stations and passing lanes, with pedestrian overpasses to reach most stations, and feeder buses to reach destinations not served by BRT lines. Transmilenio also has been linked to redevelopment projects in the downtown as well as to region-wide bike access improvements. Reported 2009 daily ridership was 1.4 million on BRT portion only, and hourly volumes of 40,000 – 45,000 passengers per hour per direction have been reported. The system is currently being expanded with new lines, transfer stations, and coordinated multimodal feeder services.

Figure 2: Bogota, Colombia Transmilenio Station on Major Arterial

While many of the design features of these Latin American applications can be used nearly anywhere, lessons on operations and ridership from Curitiba and Bogota are not as easily transferable to most US cities. The Latin American systems operate on massive arterials, so that it was possible to take multiple lanes for buses and still leave multiple lanes for other traffic. The arterials traverse long blocks with few intersections, characteristics that allow for the design of passing lanes, multi-bus stations, etc. The routes pass through high density development, conditions that produce high ridership levels. Such urban contexts are rare in the US. In addition, while the popularity of the Curitiba and Bogota systems reflect their speed and reliability of service, they also reflect the relatively modest incomes and low auto ownership levels among the population of the two cities, along with a tolerance for crowding (up to 170 passengers per bus compartment or 6+ persons per square meter) that is of dubious acceptability in the US.

Projects in Countries with Advanced Economies

From a demand and operations perspective, BRT applications in Canada, Australia, the EU, and the US are more likely to be useful in planning proposed US applications than examples from developing countries. Currently there are at least 28 operators in the US with functioning BRT lines, some with multiple routes, and at least two dozen in the EU. The count varies because of different definitions of what to include in a count of BRT.

These systems operate on a wide range of facilities, from off-street ROW (e.g., Pittsburgh), limited access highways or freeways (e.g., Houston, Washington, and San Diego), and local streets and arterials (e.g., Los Angeles, Orlando, and Oakland). The systems use a variety of operating policies, bus technologies and station designs. Few have passing lanes, but they nevertheless operate at speeds of 20-30+ km/hr (12-20 mph) on arterials and at considerably higher speeds for freeway and separate guideway operations. Several websites report on these systems extensively and only brief examples will be presented here. (See *References*).

Vehicles. Figures 3-7 illustrate the types of vehicles in use in BRT applications. Los Angeles uses the standard polished conventional buses, Las Vegas' MAX features high design vehicles and Nancy, France utilizes high-tech rail guidance systems with rubber-tired vehicles. Many other variations can be found in use, reflecting the different emphasis different cities and operators have placed on image in promoting the service versus more traditional operating time and cost considerations.

Figure 7: Rubber Tires and Rail Guide: Nancy, France

Figure 9: Leeds Guided Busway

Lanes. The lanes on which BRT vehicles operate also differ considerably, as shown in Figures 8-11. Several systems use separate guideways, taking advantage of available ROWs along rail corridors, freeway medians, and even through alleys. A number of these systems, such as the one in Leeds, UK, operate on excusive lanes in urban streets part of the time, and on separated guideways on limited access highways part of the time. Many other systems operate entirely on urban and suburban arterials and city streets where room for the buses is created by medians, removing parking lanes, narrowing travel lanes, or a combination of these interventions. Still, other systems including the Los Angeles' extensive Rapid service, operate mostly in mixed-flow lanes but do have transit signal timing and transit priority treatments at key intersections.

On a few of BRT systems, guidance technologies have been used to fit BRT into narrow lanes while allowing high speed operations. These guidance technologies can be rather simple mechanical devices such as the wheel shown in Figure 10, but systems also can use optical technologies or sensors for guidance. Adelaide, Essen, and Caen are among the cities making use of guidance technologies for their BRT systems.

Figure 10: Leeds- Guidance Device

Stops and Stations. BRT stops and stations show large variations based on the opportunities presented by the urban and suburban street systems and adjacent land uses. They include urban bus stops similar to the ordinary bus stop in the city (Leeds, Figure 12) and park and ride stops with limited amenity in the outer suburbs (Pittsburg, Figure 18). They also include designs that are intended to create a "brand recognition" for BRT, e.g., the standard Rapid stop design used by Los Angeles both in the city center and in the suburbs (Figures 16 and 17), though the surroundings are hardly alike. Other areas have used more context-specific BRT design. For example, in Orlando, Florida, whose BRT system links express service connecting the suburbs to the central city with a limited stop circulator service downtown, has used a variety of station locations and designs that reflect the varying opportunities (street widths and configurations, pedestrian spaces, etc.) (Figures 13-15).

Figure 17: LA-Rapid Suburban Stop

Multimodal integration. Planned systems such as those in San Francisco (Figures 19 and 20) aim to integrate BRT lines into an already built up area and in so doing, to significantly improve street design, including sidewalks, street crossings, landscaping, and pedestrian access to transit. Bus rapid transit also links to rail systems, and transfer points often are designed as multimodal, multilevel stations. These terminal projects can be modest, but some, such as the Transbay Terminal project in San Francisco (Figure 21) and the Union Station redevelopment project in Denver, are major undertakings in their own right. In San Francisco, where groundbreaking for the terminal recently took place, the facility is anticipated to serve local and express buses, BRT, light rail, and BART, as well as high speed rail in the longer term future, and will be paid for in part by value capture from development at and around the station. In Denver, where the Union Station redevelopment project is just getting underway, elements will include an underground bus terminal for BRT and local lines, a new commuter rail terminal and tracks, and reconfiguration of several streets.

Figure 19: SF Geary BRT (Rendering)

Figure 21: Cross-Section of Transbay Terminal Design, San Francisco

BRT's Role in Regional Transit Strategies and Systems Integration

While most BRT projects have made significant service improvements for travelers in the corridors where the projects have been implemented, the projects mostly focus on a single line or a single operator's lines, with relatively little attention to trips that cross operator service boundaries. However, in most large metropolitan areas in the US (New York, Los Angeles, Chicago, Washington, the San Francisco Bay Area, for example), the region crosses county and sometimes state lines where more than one transit agency serves the region, and many travelers not only transfer but do so across jurisdictional / agency boundaries. Travelers who use more than one service may not be well served by a process that looks only at individual lines or operators.

Many BRT systems also pay relatively little attention to those who do not currently use transit. The emphasis has been on reducing operating costs and providing improved service to existing transit users. The resulting BRT projects do in fact improve service for many existing transit riders by offering them faster and more comfortable service, but may also miss opportunities to serve markets that have not yet been well served by transit.

The next challenge will be to consider how BRT can be integrated with other transport services to improve access and mobility at a regional scale. Regional analyses and forecasts can be used to identify areas with limited transit access to major trip destinations such as jobs, education, shopping, and healthcare. They can also be used to identify major trip origin-destination linkages where transit travel times need improvement or multiple transfers are common. Corridors could then be evaluated on a case-by-case basis to diagnose specific problems and identify opportunities for establishing better connections to major destinations. These corridors would not necessarily be identical to existing transit routes.

Short trips are probably best served by local transit services and shuttles. Longer trips are often best served by BRT, rail or a combination. In selecting service types, changes anticipated as a result of growth and development should be considered, in addition to current needs.

The resulting improvement package would be evaluated from both a corridor and regional perspective. At the corridor level, evaluations would consider the cost effectiveness of the proposed service, as well as mitigations needed for changes in traffic and parking; evaluations also should include an assessment of what partnerships will be necessary to fully implement the plan, how they will be funded, and what long-term operations and maintenance commitments will be needed to keep the package of measures operating as intended.

From a broader regional perspective, some of the questions that should be addressed include:

- How will new investments in BRT corridors affect total ridership and transit mode share across the region, in the short term and over the longer term?

- How will land development patterns in the region be affected by the cumulative impacts of multiple BRT investments, well connected to existing rail and local bus networks? How can government help steer these changes?
- How will these transportation and urban development changes affect regional growth and economic performance?
- What types of ongoing planning and evaluation activities will be needed to check performance and make adjustments as needed, both to the BRT and to related networks and investments ?

Funding priority could then be given to corridors where investments in BRT would have the greatest positive impact across the region, and where local governments and community members are receptive to the investments and ready to make long-term commitments to transit and related urban development.

In short, while many BRT implementations have focused on single corridors, **BRT is likely to be far more effective if it is implemented as part of a larger regional strategy for transit.** As Bogota and Curitiba have shown, BRT can be the principal technology for the entire regional network. It also can be used to complement and supplement existing regional bus and rail networks as seen in Cleveland, Boston, and the San Francisco Bay Area. Tying BRT to local feeder services, to regional rail systems, and to intercity bus, rail and air terminals can produce a robust and sustainable regional transit system.

Potential ways to apply BRT as part of a regional transit strategy include the following:

1) Use BRT in corridors with moderate demand for transit services, i.e., where demand is not sufficient to justify costly rail investments. Possible markets would be suburb-to-suburb corridors or urban corridors in the city but outside the CBD.
2) Use BRT in a corridor that is planned for future light rail service. This could be a corridor with no current rail service or rail terminus, where BRT could be used to extend the corridor.
3) Use BRT to help build demand for transit in a corridor where growth is occurring or is planned. A decision on whether BRT is a permanent fixture or an interim service could be made at a later date, as development unfolds.
4) Link BRT via timed transfers with local routes and feeder buses that provide first and last mile services (collect /deliver riders) from/to lower density outlying areas. Local routes could be downtown circulators or could serve residential districts. The feeder services could connect passengers to business parks or other major employers such as universities or hospitals. Public-private partnerships could be forged to promote and financially underwrite the services.
5) Link BRT to rail lines via timed transfers such that BRT acts as a high capacity limited stop feeder to rail.
6) Use BRT as an express (limited stop) service to complement local services along the same corridors.

Strategies 1) through 3): Use BRT to expand the network of high quality truck line services. In the first alternative, BRT is likely to put forward as a permanent addition to the transit system, whereas in the second and third it may eventually be replaced by rail. In either case, the system could be designed to offer rail-like (or rail-ready) alignments and stations, providing a level of service that mimics rail.

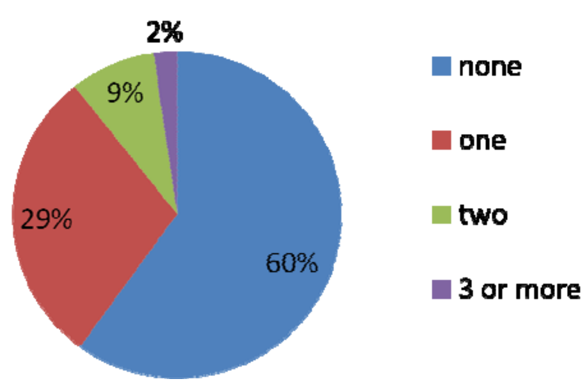
Figure 7: Rubber Tires and Rail Guide: Nancy, France

The choice of bus technology may strongly affect Strategies 2) and 3), where market building and possible technology substitution are considerations. To the extent that consumers find a rail-like image and rail-like customer amenities important, advanced bus technologies may attract more riders. Use of conventional buses may not have the same impact. Further, with advanced bus technologies such as those shown in Figures 4, 5, and 7, the distinction between bus and rail begins to fade, both in terms of capacity and in customer experience. Thus the use of advanced bus technologies may reduce the impetus to switch to rail.

However, for a variety of reasons (costs, a desire to maintain a uniform fleet, etc.) the operator may wish to use conventional buses in its BRT application. If it does so, future technology changes may remain attractive to customers.

Strategies 4) and 5) emphasize BRT's connections to other services. The success of these strategies depends to a considerable extent on being able to provide seamless services: quick, convenient, comfortable transfers from local services to BRT and/or from BRT to rail. Recent transit reporting data shows that 40% of US transit riders make at least one transfer on their transit trip; 11% make two or more (Figure 22). While transfers are thus quite common, travel demand studies indicate that riders find transfers far more onerous than in vehicle time. Therefore a successful system design must also keep in mind the distance and time between transfers and keep them short and comfortable. This means that considerable attention has to be given to schedule adherence (so that timed transfers work) as well as to the comfort of the transfer - minimizing distances and exposure to the elements, for example.

Figure 22. Number of Transfers to Make the Typical Transit Trip



Automatic vehicle location, advanced communications systems, and operations center-based real time management systems can be used to actively manage service delivery and quickly identify and rectify problems, and thus can help with schedule adherence. However, the job will be far easier if rigorous priority treatments (exclusive bus lanes, bus priority signalization) are part of the system's design and harder if less advanced BRT treatments are used. Station design and location can help make transfers quick and comfortable (or the opposite) and are particularly critical at major transfer locations.

Strategy 6 recognizes that markets along a line or corridor may not be homogeneous therefore matching services with markets can require potentially higher costs of service against rider comfort and convenience. The strategy requires analysis not only of transit line operations, but travel demand patterns.

Travel Demand Issues

The discussion of the impact of transfers and the need to manage transit systems to minimize their negative impacts points to an issue that has not always received the attention it deserves in planning BRT: the effects of BRT system design on travel demand.

BRT systems in the US have been reported to attract significant increases in ridership ranging from 10% to 30%. However, a closer look at the ridership numbers reveals that in many cases, operators are not accounting for shifts from parallel routes and services. For example, of the total ridership increases in Los Angeles' Rapid system, only one third of the additional riders were "new". Moreover, on any system, but especially in areas where transit service is implemented in a growth corridor, some new riders would be expected regardless whether BRT was implemented or more conventional services were provided. Few of the systems have done comprehensive before-after/with-without studies, so most ridership evidence is not highly reliable as evidence of BRT ridership impacts.

In general terms, faster and more reliable service should increase ridership, all else being equal, but the magnitude of the increase also depends on the extent and quality of service that existed before BRT services were introduced, the trip lengths and travel patterns on the corridors served, and the advantages over competing modes (auto, other transit services). Network effects are important: ridership will be higher if BRT corridors are well integrated with both feeder services and regional and metro rail systems (where the latter exist). In addition, coordination with urban development along BRT corridor can greatly affect ridership: if transit-oriented uses are located in the corridor, higher ridership can be expected.

It is important to understand how system changes affect conditions for riders and not just for operators. Many of the reports on BRT performance are from the operators' perspective: reported time savings of travel times of 20%-30% are based on bus times, not passenger door-to-door travel times. This distinction is important because we know from travel demand studies that travelers are more sensitive to out-of-vehicle times (access time, wait time, transfer time) than they are to in-vehicle time. Thus, system designs that speed up the bus by eliminating stops (requiring riders to walk farther, on average) must make up the "hit" that the longer access times will have on ridership.

How big is this hit? Table 1 shows mode choice model coefficients for such variable as in vehicle travel time, out of vehicle time, drive access time, and transfers, from a recent users' guide for BRT planning (Kittleson Associates, 2007). The coefficients indicate that out-of-vehicle time is at least twice as negative (onerous) as in-vehicle time.

With this information we can examine the effects that longer stop spacing could have on ridership. Consider a system that currently has local buses with stops every quarter mile that is proposing to replace the service with a BRT with stops every half-mile. Los Angeles MTA's Rapid along Wilshire Boulevard originally sited stations approximately 0.75 to 0.80 miles apart; the reduced stops were largely, though not exclusively responsible for reducing bus travel time along Wilshire by about 29 %. With this change, riders will have to walk farther to reach a bus stop, up to a quarter mile farther in some cases and more if the rider is unwilling to backtrack.

Table 2 shows the time required to walk an extra quarter mile at walking speeds of 2mph (slow) to 4 mph (a New York clip) – an extra 4 or 5 minutes for most of us, but closer to 8 minutes for those who cannot go as fast. Treating that access time as being twice as onerous as in-vehicle time means that making up for the longer walk would require time savings between 7-15 minutes, all else being equal. Table 2 also shows in-vehicle time savings that would accrue to a passenger traveling different distances on the bus (shown in 3 mile increments for bus trip lengths of 3-15 miles) to make up for this amount of time, assuming that BRT would increase average bus speeds from 15 mph to 20 mph. The table shows that for the average person (3 mph walker) it would only be for transit trips longer than nine miles that BRT speed would compensate for the added walk time.

Clearly only some passengers would have to walk an additional quarter mile to get to transit, and even then, for longer trips BRT savings would be significant. However, APTA reports that nationwide, the average trip length in a transit vehicle was only 5.2 miles (2007 data, unlinked trips). This suggests that planners need to pay attention to trip lengths in planning BRT services, especially when BRT is to replace existing services, to make sure that they do not inadvertently worsen service for a segment of their ridership.

Note that the benefit also depends on the initial speed of the bus. For a five-mile trip, if BRT increases speeds from 15 mph to 20 mph, in-vehicle time would be reduced from 20 minutes to 15 minutes, for a five-minute savings. A five minute longer walk would more than offset any BRT benefit. However, if bus speeds are only 10 mph and BRT increases them to 15 mph, the savings for the same five mile trip would be 10 minute and the five minute walk would be more than offset by the faster in-vehicle time.

As these examples show, access time can be a significant issue for shorter transit trips. Planning for regional transit networks needs to take both short and longer trips into account. Access planning and urban design around stations can be important strategies to reduce walk times and make walking less onerous, and therefore can be critical to BRT's success. Ways to minimize walk time concerns include the following:

- Locate stops at points along the system with highest demand, adjusting locations to match travel needs rather than following a strict distance-based spacing.
- Improve pedestrian access routes to make them more convenient, comfortable, and safe – to make access time less onerous.
- Develop the area around the station to provide a safe, comfortable, and interesting walking environment, using sidewalks, lighting, and landscaping, building designs and uses, street furnishings and public art as elements promoting walkability.

Minimizing out-of-vehicle time is particularly relevant for travelers who must transfer at least once. Table 1 shows that for work trips, each transfer is about as onerous as five additional minutes on board a bus, or a 2.5 minute longer walk to or from the bus stop: the negatives associated with transfers include not only the physical effort they entail but also the tensions associated with the risk that a connection might be missed. Since in many BRT applications, a significant share of riders will make transfers, explicit planning for transfers can be a key element to BRT success from the traveler's perspective. Ways to make transfers less onerous include the following:

- Design transfers to minimize walk distance. For example, transfer stations may be able to utilize cross platform transfers, end-to-end platform designs, or multilevel designs linked by an easy connection.
- Coordinate schedules to minimize wait times during transfers.
- Have transfers occur indoors or under shelter, or otherwise minimize exposure to the elements.
- Provide services such as vendors and restrooms or amenities such as public art at transfer points to reduce the boredom of waiting.

It is important to also note that travel time savings are usually NOT the only benefits that BRT delivers. Improved stations, well surfaced bus lanes, more comfortable vehicles, up to the minute information systems, etc. also presumably add value. How much value is added is a subject of considerable debate, but surveys suggest that passengers think these features are important. However, more work is needed to determine the extent to which these features affect traveler's actual behavior.

Passengers also value increased reliability, and this could be a highly significant factor in BRT systems that operate in congested corridors. For example, if local buses are caught in traffic some days and not others, a five mile trip could take 30 minutes one day, and 20 minutes the next. For many travelers going to work, school, a medical appointment, etc., being late could have drastically negative consequences; so people tend to build the possibility of delay into their schedules (as do transit operators in planning operations). If BRT can reduce travel time variability, providing far more predictable travel times, transit operators may be able to provide better service with fewer vehicles and passengers may be able to save time by reducing the amount of extra time they allot to travel “just in case”. This is another area where further research is needed, to better understand how people value such time savings and the benefits of reliability.

In sum, implementing region-wide BRT networks linked to each other, to regional rail systems, and to local feeder services will provide riders with access to an extensive service area and could attract large numbers of new riders to transit. However, to attract new passengers the service needs to be reliable and competitive for the entire trip. This means that for the many passengers who make transfers, transit schedule coordination is critical, so that transfer times are minimized. It also means that access needs to be comfortable and convenient; since BRT usually means longer access time to stops, there must be compensating improvements large enough to outweigh this disutility. Higher speeds can offset longer access times, but BRT designers need to acknowledge that this only works for longer trips or on services that are currently painfully slow. Additional offsetting benefits may be needed, including improved vehicles, better paving in BRT lanes, and increased reliability.

BRT and Urban Development

Bus Rapid Transit can both benefit from and help create transit-oriented development (TOD). Transit-oriented development (TOD) builds markets for transit in both city and suburban locations by creating high-density areas of mixed-use activity within walking distance of transit stations and stops. In turn, TOD can increase revenues for transit by providing joint development opportunities and increasing local property and sales tax revenues, some of which may be available for transit and related infrastructure and service improvements. Along bus rapid transit corridors, TOD can include new housing, jobs and services for a variety of income groups. Implemented as a regional policy together with BRT, TOD can help structure metropolitan growth in ways that support high levels of transit use, biking, and walking. BRT also can reinforce existing development by increasing accessibility and using public investment to stimulate private reinvestment (Carey, 2009; Cervero, 1998, 2004; Currie, 2006; Christopher, 2006; McDonnell et al., 2008).

An important consideration for TOD plans along BRT corridors is how much development can be supported, and what type. The amount of added development could be related to the amount of added transport capacity due to the transit and related access improvements along the corridor. A variety of uses could be suitable along a BRT line: station areas could simply have basic services available nearby such as coffee and newspapers, or could be developed as moderate to high density mixed-use residential, office and retail districts. The mix can vary, with some TODs emphasizing offices, others housing, other shopping and services, still others special activity centers such as universities, medical centers, or sports complexes. The densest nodes could be developed around major stations (e.g., where several transit lines converge) and in central city locations.

TOD can be a critical element of BRT planning if the policy objective is to shape regional growth, guide development in a growing corridor, or to spur urban revitalization in an older area in need of an economic boost. TOD also can be a critical element if BRT is intended to get a corridor rail-ready. In such cases TOD plans for station areas and lines can help build sufficient levels of activity and transit ridership to make the transit capital investment and frequent service cost-effective; in turn, more frequent service will make transit use convenient, attracting riders.

While TOD plans and zoning are a step forward, they cannot guarantee that development will occur. They can make development faster and easier and offer incentives for infill and desired uses and amenities. However, it would be unrealistic to expect that merely planning TOD will assure it will come into being.

First, unless the market is extremely strong in a particular area, TOD cannot be expected to overcome serious urban ills (poverty, crime in the area, dilapidated buildings, outmoded utilities), without added help. A variety of other community development strategies from redevelopment funding to community policing may be needed to help create a safer, more stable urban environment; transit, and TOD, can be part of this strategy.

Second, regional markets for development are not infinitely expandable and implementing TOD around a station probably means less demand for such uses elsewhere in the market area. For this reason, anticipated regional and subarea growth should be taken into consideration in planning for TOD around new transit investments such as BRT, and should be reviewed in the context of potentially competing or conflicting land use plans. For example, if BRT does not serve the main commercial district of a suburban town, TOD along BRT line could compete with "Main Street" in ways that are counter to the city's policies. In such cases a strategy to select appropriate uses and levels of development for each location should be developed. (For an example, see Fleischer, et al., 2009).

Recognizing these limitations, it nonetheless can be beneficial to examine the current and potential transit orientation of corridor development in planning for BRT.

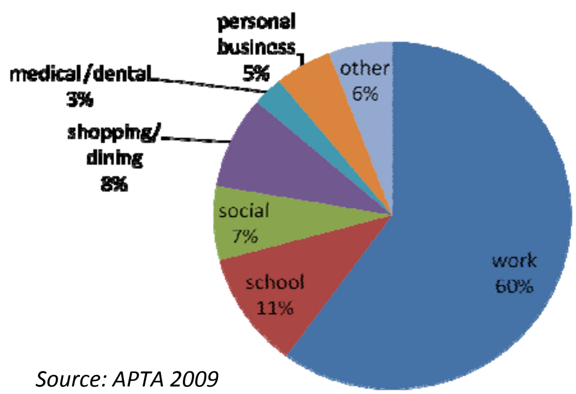
Transit agencies rarely have planning and zoning authority around their lines and stations, so most agencies will need to develop partnerships with local governments if TOD is to be encouraged. Most often, local government partners will take the lead on the TOD components. Partnerships with local agencies (and sometimes regional and state agencies) are also necessary for most access planning - pedestrian, bike, and park and ride.

With local governments on board, areas within walking distance, ¼ to ½ mile of the station, can be rezoned for TOD, i.e., for mixed-use development at densities higher than would be permitted farther away from the station. Pittsburgh, for example, permits an FAR of 4 around stations and 3 elsewhere (National Bus Rapid Transit Institute, 2009).

Alternatively, rezoning could be limited to parcels fronting along BRT corridor, preserving existing uses off the route. The City of Berkeley, CA employs such zoning along major bus routes including the AC Transit's San Pablo Avenue Rapid line.

A mix of nodal types can help to balance demand along the corridor, and also can help attract mid-day and non-work travel as well as work travel. If demand is unidirectional, the transit agency can have a problem with many unproductive service miles on the return trip (or excessive deadheading) and at the same time may find that additional vehicles are needed on some route segments where demand is concentrated. This is a matter of considerable concern for many transit operators, although optimization strategies for both schedules and station locations can be used to reduce the impacts. Further, if demand is principally for work trips, the fleet size may be far larger than is needed during off peak periods, resulting in underutilized facilities and, under many labor agreements, underutilized drivers. The latter is an important issue for many transit operators; overall, about 70% of US transit trips are to work or school (Figure 23) and these trips tend to be concentrated in the peak periods (APTA 2009). Balancing development along a route can help create a more efficient pattern of fleet utilization; increasing transit-accessible shopping and social-recreational opportunities can improve transit productivity outside of the peak periods (indeed, without such all-day demand, it may be hard to justify the investment in BRT).

Figure 23. Typical Transit Trip Purposes



Source: APTA 2009

Several zoning techniques may be particularly useful for encouraging urban development along a BRT corridor. They include zoning for minimum as well as maximum densities, to prevent inappropriate low density uses from occupying prime sites; form-based codes, which control design details such as height, setback, landscaping, parking location, and window and door treatments; inclusionary zoning, to encourage affordable housing production in otherwise market-rate developments; and incentive zoning, matching public permissions (such as higher densities or reduced parking requirements) to the provision of desired project features ranging from public open space to meeting rooms available to the community.

Adjustments to parking requirements in zoning ordinances may also be appropriate, e.g., lowering parking requirements for both commercial and residential uses, allowing shared parking, and allowing horizontally or vertically (mechanical lift) stacked parking for residential units, in recognition that car use will be lower and transit and walking higher in a BRT corridor with TOD. Such parking changes can result in considerable cost savings for developers, although in some markets it is necessary to educate lenders that reduced parking is a benefit and not a risk.

Car sharing or rental car options may also be integrated into TODs for occasional auto use, allowing households to forego owning a car or to own only one.

Zoning codes for uses along a BRT corridor also might want to disallow auto-dependent uses such as drive-in restaurants and car washes, as well as uses that generate few passenger trips, such as storage facilities. BRT can serve uses that could be incompatible with a pedestrian environment, such as airports or heavy industry, but in such cases it would be unlikely that a TOD overlay would also be used.

Public investments that complement BRT also support complementary urban development. In particular, along with street redesigns to install bus lanes and stations, sidewalks and crosswalks should be improved, and pedestrian-oriented lighting, benches, landscaping, and other amenities such as public art can be installed. The resulting streetscape should be both convenient and comfortable - an asset to the districts and neighborhoods served by BRT.

If certain stations are to be major park-and-ride locations or will have numerous feeder buses converging, the placement and design of the transfer facilities must be done carefully to avoid conflicts between facilities operations and the quality of urban development, including traffic impacts, noise, light pollution, and air pollutant emissions.

While planners can facilitate BRT-related TOD by developing supportive urban plans and zoning ordinances, whether developers will see BRT as a significant incentive is debated, even for areas with no apparent negatives that would deter investment. Numerous studies have reported capitalization of transit investments in property values, but most studies have been around rail rather than BRT. Some studies have reported significant real estate investments around particular BRT lines (e.g., in Ottawa, Pittsburgh, Cleveland, and Boston), but in most cases it is less clear that BRT was the key factor, or even an important factor, in bringing in the investment (Cervero et al, 2004; Levinson et al., 2003, 2004; personal communications with Boston and Cleveland planners, 2009).

Interviews with developers provide some indications of their perspectives. In part the developer response to BRT will likely reflect the extensiveness of the public investment. The more capital investment in the system, the less likely it is that developers will see the bus routes and services as impermanent and subject to change. In addition, the more improvements to the streetscape of the surrounding area, the more value the developer can derive from location near the TOD (Levinson, et al., 2003; Mejias and Deakin, 2004).

Another factor will be the nature of the buses used. Some communities are concerned about exposure to diesel emissions and to transit vehicle noise. If clean and quiet bus technologies are used, concerns about exposure to bus emissions and noise can be greatly reduced.

Transit operators, regional agencies, and other government agencies could encourage TOD by giving priority to transit and related investments in areas that are already TOD, or are TOD-zoned. In California, the San Francisco Bay Area's Metropolitan Transportation Commission has adopted policies requiring TOD around stations, and recent state legislation (SB375) provides funding and planning process incentives for TOD.

Access Planning; Traffic and Parking Impacts

Special attention must be given to pedestrian and bike access along a BRT corridor. In urban settings, the majority of transit passengers arrive on foot. Their safety and convenience in getting to the stations requires explicit attention, especially if center lane stations are used. Further, all pedestrians, including those not using transit, can be affected by BRT, positive benefits can arise if improvements to sidewalks, crossings, street furnishings and landscaping are made. Negative impacts can occur if sidewalks are blocked by transit users due to inadequate station designs, or if BRT design restricts crossings or narrows sidewalks.

Bicycle access to BRT could be encouraged by installing bike parking at the stations and by including short-term bike rentals. The redesign of the streets to accommodate BRT may also create important opportunities to install or improve bike lanes.

Both urban and suburban BRT applications can entail transfers to rail, local buses or shuttles, or other BRT lines. Planning these transfer points to keep the transfer short, comfortable, and predictable is a key requirement. In suburban locations, park and ride may be a major means of access to BRT. Designing these facilities so that they are comfortable for both pedestrian and bike access can be a challenge, but an important one to take up. In one California study, researchers found that a number of bus users walked to park and ride stations to catch the express bus (Deakin et al., 2006).

While much of the access planning for BRT will be centered on BRT corridor, in some instances BRT can also raise questions about area-wide traffic impacts and therefore require an area-wide traffic or access plan. For example, if BRT removes lanes from general use, traffic may be diverted to alternate routes, and mitigation measures may be needed to manage the resulting changes in traffic volumes. Traffic signals may need to be retimed, for example.

The impacts of developing region-wide BRT networks on travel choices and traffic flows at the regional scale should be carefully considered and modeled. To avoid having BRT services worsen traffic performance, the system needs to attract riders away from single occupancy vehicles (SOVs). It will be important for planners of regional BRT services to consider travel patterns and have updated origin-destination data and forecasts when developing routes.

Interagency Coordination

While BRT is often thought of as the concerted application of advanced transit technologies and operations strategies, it also is an institutional and managerial innovation, and BRT‘s success may well depend more on the latter than on the former.

BRT requires a variety of partnerships between the transit operator and other units of government. BRT may make use of local streets and state highways; it may require the upgrading and retiming of signals owned and operated by state and local agencies and ongoing real-time traffic control; it may require redesign or change in access to state and local streets. If federal aid has been used for the facilities, federal agencies may also have to be involved. While in some cities all transportation functions are under one roof, in many other cities the responsible parties are separate entities with no official ties to the transit operator. If they do not approve the changes the transit operator needs, (e.g., if bus signal priority is not fully implemented or on-street parking is not regulated) BRT performance could be significantly compromised. Thus building effective partnerships is likely to be a prerequisite for BRT.

Partnerships also must be long-term and dynamic. Signal timing, street design and bus operations not only need to be planned together but also need to be actively managed together on an ongoing basis for BRT to work. In addition, there must be a long-term commitment to policy supporting BRT. If any of these elements fails, BRT could also fail. For example, if numerous motor vehicles (BRT, local buses, taxis, electric vehicles…) are allowed to use BRT lanes, BRT performance will degrade. If parking restrictions are not enforced or broken bus detectors not repaired, BRT performance will degrade.

The fact that BRT requires new institutional frameworks and new levels of cooperation is a critical point, and yet it is not always discussed when BRT is proposed. However, it would be perilous to ignore it.

Applicability of BRT to Metro New York

The New York metro area has over a century of investment in significant rail transit facilities as well as decades of investment in local and express buses, bus lanes, and busways. The region is the nation's largest; it is multi-state; it has a strong core area as well as a number of sizeable sub-centers; it will continue to add both population and employment over the next 30 years. By some estimates the greater metropolitan area accounts for more transit riders than the rest of the country's urban areas combined; the New York MTA alone accounts for almost a third of the nation's transit trips, 3.3 billion out of a national 10.1 billion in 2007 (APTA, 2009).

In this transit-rich metropolitan region, what does BRT have to offer? The fact is that as the region has grown and changed, new corridors with little transit have become part of the region. Existing corridors have seen traffic changes and service problems. Travel patterns have shifted, and consumer expectations have heightened. For all these reasons, in studies done for New York City, New Jersey Transit, Westchester County, Long Island Transit, and others, a variety of opportunities for BRT have been identified, from making improvements to congested bus corridors to adding services designed to entice auto users to transit in the suburbs (Paaswell, et al., 2004, City of New York, 2007).

Possibilities for further application of BRT in the New York metropolitan area are numerous. BRT could improve transit in built-up urban corridors by allowing bus riders to bypass congestion, improving travel speed and reliability. Applications in suburban corridors could provide direct links to major suburban destinations or fast links to rail service connecting to the entire region. BRT lines could be designed as long-term improvements to existing bus services or as a strategy to grow ridership for eventual light rail implementation.

In a separate paper for this conference, Herbert Levinson discusses the potential of BRT for the New York Metropolitan Area in more detail. Levinson recommends minimum criteria for BRT corridors: they should serve at least one major "anchor" (e.g., major employment center, major transport hub); they should have sufficient demand to justify all day service at 7-12 minute headways, generally 15,000 riders a day in Manhattan and 8-12 thousand a day in the suburbs; they should complement rather than compete with rail lines; they should be at least 5-6 miles long to be able to produce useful time savings.

BRT for Metro New York, Levinson argues, could come in a number of varieties and ideally should include improved bus lanes, stations, vehicles, and operations. However, recognizing that there will not always be room for a full treatment, he recommends that New York BRT simply accommodate as many improvements as is practicable on a corridor-by-corridor basis. Because much delay is related to stops and passenger boarding and alighting, he recommends stop spacing of .6 to 1.5 miles, off-board payment, multi-door vehicles and all door boardings. He also recommends exclusive lanes where feasible and priority signal timing, but expects that bus lanes will speed up operations only by 1 to 1.5 mph and improved signal treatments will add only a few seconds per signalized intersection.

Levinson identifies potential corridors for BRT both in the city and the various suburban markets. He also sees potential for ROW preservation, infill development, and other benefits from BRT, while noting that it is not a panacea nor can it work without the cooperation of many actors both in and outside of transport agencies.

While further corridor level investigations would surely be useful, a complementary planning endeavor would be to identify BRT investments that could enhance connectivity and mobility at a regional scale. Regional analyses and forecasts could be used to identify areas with limited transit access to major trip destinations (jobs, education, shopping, healthcare), as well as to identify major trip origin-destination linkages where transit travel times need improvement. Corridors then could be evaluated on a case-by-case basis to diagnose specific problems and identify opportunities for establishing better connections to major destinations. Future potential for growth and development could also be incorporated into the analysis and the resulting service needs and opportunities built into the plan. Funding priority then can be given to corridors where investments in BRT would have the greatest impact across the region.

Summary of Key Findings and Commentary

The literature on BRT provides substantial guidance for planners and policy makers, but tends to focus on individual corridors. By combining evidence from the literature with a systems perspective and an understanding of travel demand, we can begin to distinguish the key considerations, to identify areas that need further study, and to move toward a more comprehensive, systems view of BRT and it s role in the metropolitan region.

1) BRT is an economical alternative to rail, but how much more economical depends on a number of factors: BRT systems often can be delivered for a fraction of the cost of a light rail system (savings up to 90% compared to rail systems have been reported!) However, comparisons of bus operating costs vs. those of rail require going beyond a comparison of initial costs to consideration of lifecycle costs, accounting (e.g., for the useful life of the respective vehicles and guideways, pavements vs. rails, etc). Cost comparisons also can be expanded to include externalities such as air pollution. Time savings in project delivery may be a major benefit for BRT and should be accounted for in a comparison (but may not accrue if the project becomes controversial).

Clearly, the more similar BRT actually is to rail, and the more advanced system elements that are added to it, the smaller the cost difference. Some, but not all of the options are needed to optimize performance; others may be needed to maximize ridership; and there are questions about the importance of certain features, such as how important designer buses and stations actually are in attracting ridership. This is a topic that needs more research since there are many assertions that support or disagree, but the evidence on either side is sparse.

2) **Operating and maintenance costs of BRT are not just for BRT:** BRT systems can save bus operators money through more efficient bus operations, allowing service to be provided with fewer vehicles and bus hours and lowering fuel consumption due to fewer stops and delays. However, costs of maintaining specialized buses and more elaborate stations, information systems, etc. can offset some or all of these savings. In US big-city, peak-period applications, comparisons of operating and maintenance costs of BRT vs. rail may depend heavily on the size of buses that can be operated (and therefore the number of drivers needed), since labor is a major element of operating cost.

In addition, some elements of BRT including traffic signal timing and maintenance, road maintenance, sidewalk and streetscape, etc. are the responsibility of other organizations so their ongoing management partnerships and financial participation are needed and these costs need to be accounted for.

3) **Ridership and mode shift both matter:** BRT projects in the US aim to improve services for existing riders while lowering operating costs, and also to attract new riders, especially those who might otherwise make the trip by automobile. One issue is that few BRT operators in the US have done comprehensive before-after/with-without studies. Current ridership data reports combine previous riders on the line, riders that shifted from parallel lines, riders new to the area who would have used transit even without BRT improvement, and riders who would not have used transit but for BRT. It is only this latter category of riders that helps reduce auto use

and its impacts. Since both ridership and mode shift are important policy objectives, data collection and analysis that would allow the two to be distinguished are needed. The data should then be analyzed in terms of the extent and quality of service that existed before BRT services were introduced, the trip lengths and travel patterns on the corridors served, and the advantages that BRT offers over competing modes (auto, other transit services).

4) **System design includes network linkages:** BRT ridership is likely to depend not just on the design of BRT itself but also on its accessibility by walking, biking, other transit services, and park and ride – ridership will reflect the level of service door-to-door. Network effects are important: ridership will be higher if BRT corridors are well integrated with both feeder services and regional and metro rail systems (where the latter exist). In major metropolitan areas, delivering well integrated systems is likely to require concerted action to achieve convenient timed transfers between lines and companies, and to minimize access times; an effort to rationalize and simplify fares for rides requiring transfers among companies also may be in order.

5) Ridership depends on user time savings, comfort and convenience: Bus travel times faster than on conventional buses by 10%-15% or more have been reported for BRT, and travel time reliability appears to be higher on BRT than on unprotected limited stop services that operate without priority treatments. These benefits accrue to both the operator and the user, but not identically. The higher speeds and reliability are a function of increased spacing between stops and, where prepayment, multi-door buses, and level or near level boarding and alighting have been implemented, shorter dwell times (i.e., faster boarding and alighting). Reduced dwell time should increase user satisfaction, but longer spacing between stops will increase walk time for some riders, and walk time is considerably more onerous than in-vehicle time. Therefore travel time savings must be sufficient to offset the longer walk times, or other compensating benefits must accrue to users. Improved reliability could be a key factor here, but more work should be done to understand its value. Also, more comfortable buses, stations, and access routes could increase user satisfaction. However, comfort depends not only on vehicle and station design but also on such factors as pavement quality and how the bus is driven (fast speeds, abrupt accelerations and decelerations, and bouncing over potholes can be uncomfortable and even dangerous to standing passengers). Research designed to better understand the roles of reliability, comfort and convenience in mode choice would be a good investment.

6) Urban development choices shape ridership and vice versa: Urban development along a BRT corridor strongly affects ridership: if transit-oriented uses are located in the corridor, higher ridership can be expected. Further, such development may be necessary to produce the balanced loads needed to manage costs and the off-peak ridership needed to justify frequent all day service and significant investments in capital improvements and operations.

Conversely, BRT lines with high quality, frequent service may increase the attractiveness of the corridor as a location for residents and businesses, attracting new development, encouraging refurbishment and reinvestment in existing properties, and attracting businesses that will provide more jobs, higher sales revenues, greater rent capacities, etc. In some cases joint development may also be a possibility. Transit centers or stations could be integrated into mixed-use development, and street redesign could be integrated into BRT corridor planning. Thus BRT lines can be an asset for encouraging sustainable development both through the higher level of accessibility they provide and by the markets for housing, jobs and services they support. Nevertheless BRT cannot be expected to overcome serious barriers to development without many other interventions to supplement it. In addition, in some circumstances TOD around BRT may compete with development aspirations in other corridors.

7) Interagency cooperation is a critical factor in BRT success: BRT systems involve bus operations planning, bus design and fuel choice, stop design, traffic signal timing, street design and regulation, pedestrian and bike facilities, and more. While in some cities these functions are consolidated in a single department, in many other cities several departments and agencies would have to be involved. State and federal agencies also may be stakeholders and decision-makers. Further, because BRT requires ongoing active street signal management as well as bus supervision, continued involvement of the stakeholders is needed. The requirement for long-term commitment and engagement should not be underestimated.

8) **Environmental impact can be positive or negative, depending on design choices and the scope of intervention:** Any bus system will have both positive and negative environmental impacts, and BRT is no exception. The balance will depend on design choices and the way the problem is defined and tackled. Benefits due to mode shifts from auto to transit could produce increased safety, reduced emissions and fuel use, and lower congestion. On the other hand, bus systems can be noisy, consume a great deal of fuel (a concern if services are not fully utilized, as can happen in some US applications), and if diesel buses are used, they can produce worrisome air pollution including toxics and ultrafine particulates. While there may be some savings of auto emissions if passengers switch to BRT, this may be partially offset by additional emissions due to delays to other vehicles caused by bus priority treatments. Also, in some cases, station area noise, visual intrusion, and loss of access across BRT ROW may rise to a level of environmental significance.

Bus emissions can be reduced if new buses are utilized, or operators select lower emissions fuels and propulsion systems (e.g., biodiesel, electric, fuel cell, or hybrid vehicles). Fewer stops and delays should also reduce bus emissions compared to conventional operations. Traffic management on an area-wide scale, not just along the corridor, can successfully address concerns about shifting traffic and added delay.

9) **Public acceptability may depend on access changes as well as project features:** In the US, BRT is most often implemented in existing ROWs. However, the installation of exclusive bus lanes and BRT stations may require additional land acquisition, reallocation of lane designations, narrowing of lanes, or removal of mixed-use lanes, medians, parking lanes, etc. These actions can be politically controversial. For example, parking removal may generate opposition from both residents and merchants. In addition, priority treatment for buses can raise concerns if it causes excessive delay to other vehicles, even in cases where the priority treatment allocates priority MORE fairly from a persons-served perspective.

Access changes for cars, pedestrians, bikes, etc. also can be controversial. While concerns about these issues may lead to some opposition to BRT, support also can be forthcoming from riders whose services will be improved as well as environmental and neighborhood groups who seek to moderate car traffic and its impacts. When BRT project incorporates pedestrian and bike access improvements and attractive lighting and landscaping, these features also attract support for the project. Mitigation for traffic impacts can be built into the project, such as traffic signal timing. Other improvements to traffic flow on other streets not carrying BRT can be implemented, and replacement parking can be located.

10) **Regional considerations call for expanded planning horizons:** BRT investments could enhance connectivity and mobility at a regional scale, but this will require a different style of planning than has been done for most BRT projects to date. A BRT system scaled to the region would have to address access time, transfer time, and fare policy issues across operators. In addition to corridor studies, regional analyses could identify new corridors and desirable changes to existing services. Regional analyses might be able to address mitigation strategies more effectively than corridor plans.

In summary, BRT offers both significant opportunities and significant challenges, and these are not just technical but also institutional. A regional perspective could help build new markets for transit, and could encourage and support design choices and broader planning efforts that address rider needs and consider network effects, especially for the many transit passengers who have to make transfers.

Acknowledgments

This paper has benefitted from Herb Levinson's comments on the initial outline, as well as from suggestions on the first draft offered by Dr. Marta Panero of the NYU Rudin Center.

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STAN bus (Nancy, France) from http://commons.wikimedia.org/wiki/File:Stan-Bus-Bahn-Nancy.jpg

Curitiba BRT and high-rise development photo from http://www.pps.org/general-images/slideshow?&on_which_table=public%5fplaces&on_what_id=613&title=Curitiba%20Bus%20Rapid%20Transit%20System&image_id=4367

San Francisco Proposed BRT renderings from Metropolitan Transportation Authority (SFMTA), Preferential Streets Program, http://www.sfmta.com/cms/mtps/tpsover.htm

Table 1. Illustrative Coefficients in the Mode Choice Model

Attribute /Units	Coefficients by Trip Type: home based work	home based other	non-home based
In-vehicle time for (most) transit modes / Minutes	-0.02	-0.01	-0.02
In-vehicle time for commuter rail / Minutes	-0.016	-0.008	-0.016
All out-of-vehicle time / Minutes	-0.04	-0.02	-0.04
Drive-access time / Minutes	-0.04	-0.02	-0.04
Transfers / Number	-0.1	-0.05	-0.1
Fares / Cents	-0.003	-0.0015	-0.0015

Source: TCRP Report 118, Exhibit 3-14

Table 2. Effects of An Additional Quarter Mile Walk to BRT

Walk speed (mph)	2	3	4		
Feet per min	176	264	352		
Time to walk extra 1/4 mi	7.5	5	3.75		
Equiv. in-veh time if walk~ twice as onerous	15	10	7.5		
distance on bus (mi)	3	6	9	12	15
on board travel time at 15 mph	12	24	36	48	60
on board time at 20 mph	9	18	27	36	45
time savings	3	6	9	12	15
on board time at 25 mph	7.2	14.4	21.6	28.8	36
time savings	4.8	9.6	14.4	19.2	24
on board time at 30 mph	6	12	18	24	30
time savings	6	12	18	24	30

Bus Rapid Transit: A Brief Review and Commentary on Prospects for the New York Metropolitan Area

E. Deakin 2-2010

Figure 1: Curitiba, Brazil BRT with Adjoining High-Rise Development

Figure 2: Bogota, Colombia Transmilenio Station on Major Arterial

Figure 3: LA Rapid Bus

Figure 4: Phileas – Eindhoven, NL

Figure 5: Las Vegas - MAX

Figure 6: Leeds, UK Double Decker Bus

Figure 7: Rubber Tires and Rail Guide: Nancy, France

Figure 8: Pittsburgh Busway

Figure 9: Leeds Guided Busway

Figure 10: Leeds- Guidance Device

Figure 11: Ipswich Busway Design to Prevent Auto Access

Figure 12: Leeds Superbus CBD Operation

Figure 13: Orlando, FL BRT

Figure 14: Orlando – curbside stop

Figure 15: Orlando- Center Lane Stop

Figure 16: LA Rapid Station

Figure 17: LA Rapid- Suburban Stop

Figure 18: Pittsburgh- Park and Ride Station

Figure 19: SF Geary BRT (Rendering)

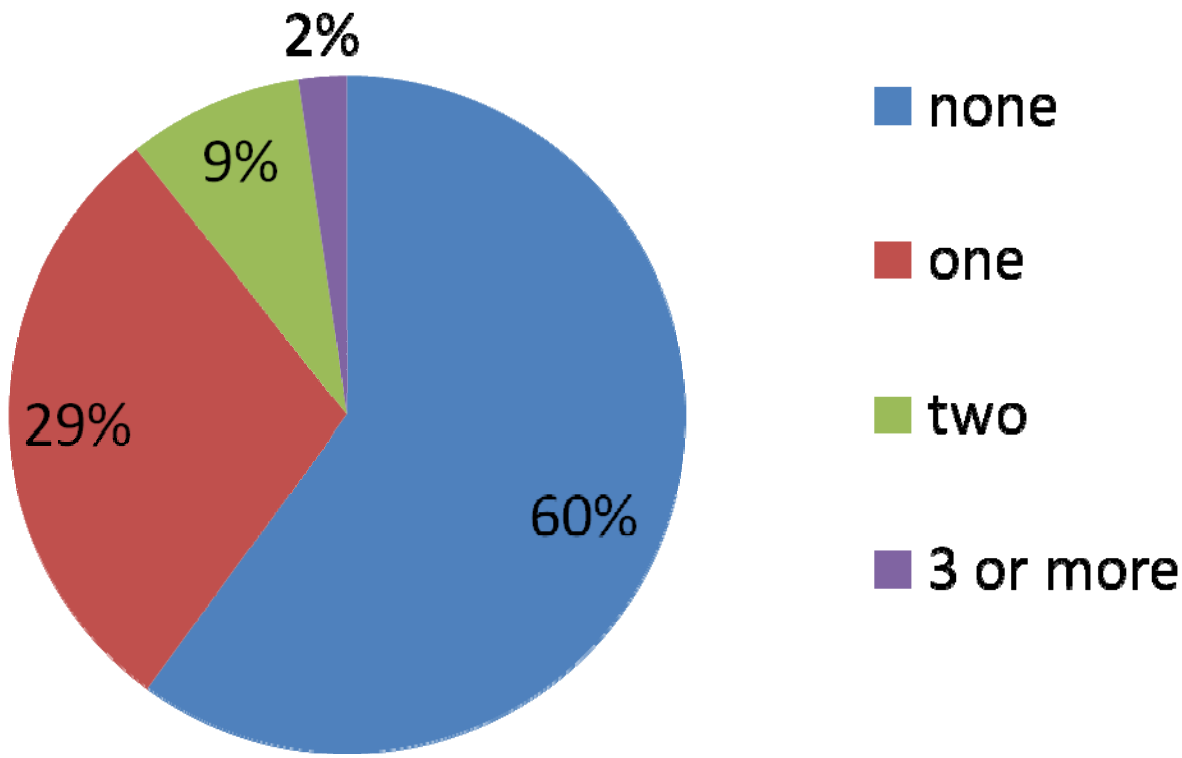
Figure 20: SF Van Ness BRT (Rendering)

Figure 21: Transbay Terminal Design, San Francisco

Cross section

Exterior view

Figure 21. Number of Transfers to Make the Typical Transit Trip



Source: APTA 2009

Figure 22. Typical Transit Trip Purposes