6 MODE ANALYSIS

Image from Nelson\Nygaard.

This section seeks to clarify and simplify the decision-making process for selecting a mode of transit. It first identifies a few characteristics of "mode" that are essential to a proper understanding of the concept. It then describes a potential decision-making framework for selection of a mode. Finally, it provides general analysis of transit modes using that framework.

This section presents a conceptual framework and does not represent a final decision-making tool to be used in defining transit modes for Seattle.

6 MODE ANALYSIS

DEFINING MODE

Many tend to refer to transit vehicles and modes interchangeably; however, a transit mode consists of the following elements:

- Right-of-way design and management
- Stop/station design and access requirements
- Service model/operating plan
- Vehicle type

The various transit modes that can be implemented with these components are described below, grouped by the transit vehicle type used to deliver the service.

Bus Modes

Local Bus

Local bus service can be provided by a variety of vehicle types ranging from small cutaway vehicles to 60-foot articulated trolley buses, depending on the operating environment and capacity needs of the area being served. Service levels on local buses do not justify right-of-way treatments or signal priority in most areas, but these treatments may be used at certain locations. Stop spacing on local bus service is typically shorter than other bus modes, which results in better access along the corridor but lower average speed than express bus or bus rapid transit (see below). Seattle is largely served by local bus service. Trolley buses are well-suited to Seattle's topography, do not pollute, and are much quieter than diesel buses; for these reasons trolly buses are used on many local bus routes in Seattle. Trolley technology could be used in a bus rapid transit application.

Express Bus

Like all bus modes, express bus service can be provided by different types of buses (including buses powered by different fuel sources as well as buses of different sizes, interior configurations and comfort levels). However, express bus is differentiated from other modes of bus service by its service design and, in many cases, by the fact that this service operates on highways or limited access rights-of-way. Express buses make few stops and generally make stops at major destinations or intersections rather than the frequent stops typical of local buses. Routes are also typically longer than local- or limited-stop bus routes (or streetcar lines), and nonstop segments are often located along highways or major arterial streets. Many express bus services run only during peak commute hours and tend to have a smaller, but dedicated ridership base.

Bus Rapid Transit (BRT)

Bus rapid transit is the least clearly defined of transit modes; indeed, its definition is a matter of much debate among planners, advocates, and some policy makers. BRT can be broadly defined as "bus service with features designed to improve performance." To improve upon ordinary buses, planners select from a toolbox of elements ranging from distinctly "branded" buses and stops to dedicated rights-of-way, and depending on the extent of their application a BRT line might be a minor improvement over a limited-stop bus route or more like light rail. BRT projects might be said to exist along a continuum, although some planners and advocates have begun to group projects

Bus rapid transit in Eugene, Oregon.

Image from Flickr user functoruser. CC license: http://creativecommons.org/licenses/by-sa/2.0/

into subcategories labeled "light" and "heavy," "partial" and "full" (with the latter term reserved for projects featuring more aggressive treatments, such as dedicated right-of-way and "station-like" stops). King County Metro's RapidRide could be said to fall into the "light" or "partial" category. BRT vehicles are generally either 40- or 60-foot buses, sometimes custom-designed to resemble rail vehicles but often simply painted differently from other buses. And while BRT typically uses diesel-powered vehicles, electric trolleybuses could also be used in Seattle. BRT provides perhaps the best example that "mode" is not the same as "vehicle," as an otherwise robust BRT project using the same buses as local service would nonetheless be of another mode.

Streetcar Modes

Streetcar modes include a wide range of vehicle types, as well as varied concepts for running way operations (e.g., mixed traffic, dedicated lanes, or completely separate right-of-way), passenger amenity offerings, stop spacing, route length, service frequency, and other variables. Streetcar vehicles are generally single-train railcars (not intended to be operated in multi-car trainsets) that operate primarily in a shared right-of-way with general purpose vehicles. There is considerable variability in streetcar vehicle type, as well as in streetcar mode.

Modern streetcar systems such as the Portland Streetcar and Seattle's South Lake Union Streetcar operate using modern vehicles with operations designed to serve short distance circulation trips. Legacy streetcar systems, such as Toronto, Melbourne, Manchester, UK, and Prague are examples of cities that retained their extensive streetcar or tram systems. In these cities, the vehicles have been periodically upgraded and replaced with modern vehicles. Typically, however, the modern vehicles operating on legacy systems are adapted to the legacy track and platform infrastructure, resulting in narrow vehicles with limitations on accessibility.

Streetcar vehicle types include:

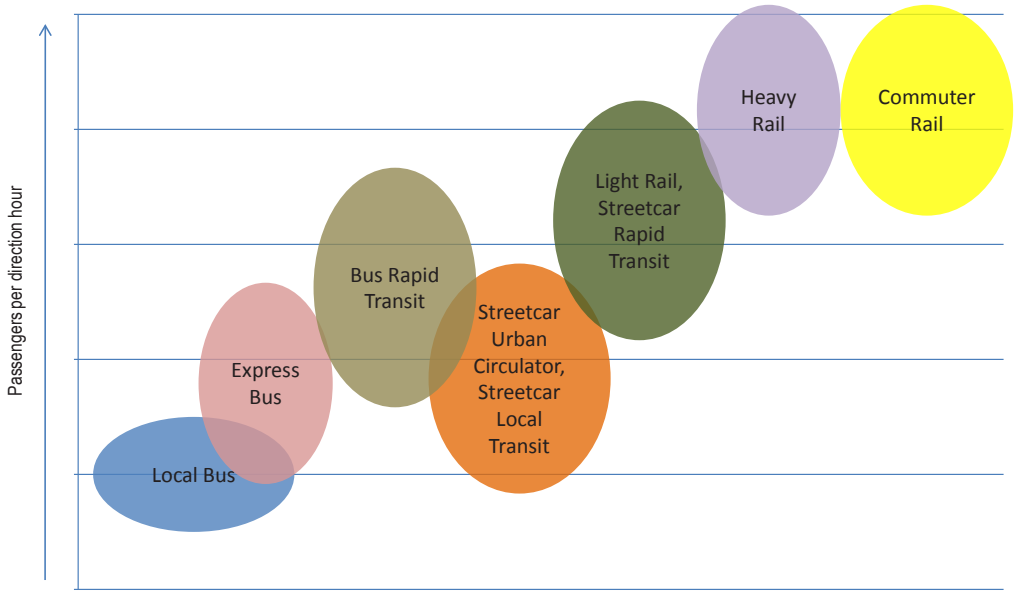
- **Modern streetcar vehicles**: Modern streetcars share most of their technical characteristics with modern light rail vehicles; however, there are some exceptions. Modern streetcar vehicles are limited to a single car length (often articulated) and are not designed for multiple-trainset operations. Additionally, these vehicles are designed for lower maximum speeds; and have lower crashworthiness ratings. Until recently, U.S. streetcar providers needed to acquire foreign made vehicles; however, with the help of grant funding from the federal government, United Streetcar, Inc, in Portland, Oregon is now filling orders for modern vehicles with almost identical specifications to those used in Seattle and Portland.
- **Vintage/Replica Trolleys:** Several U.S. cities offer transit service using vintage trolley cars dating from the early- to mid-twentieth century, or replicas of those cars. For over twenty years, vintage trolley cars from Melbourne, Australia operated as the Waterfront Streetcar in Seattle. Vintage and replica cars feature a high platform that is not universally accessible, and often lack climate control, passenger information systems, and other modern transit vehicle amenities. With these limitations, these systems are often implemented for limited trip purposes such as to accommodate and encourage tourism. Streetcar lines such as the F-market line in San Francisco successfully provide a popular tourist experience and downtown circulation for visitors and locals alike.

North American streetcar operations typically fall in one of a few categories:

- **Streetcar Urban Circulators**: The Portland Streetcar and Seattle Streetcar are examples of modern streetcar systems built as urban circulators in these systems. Track and platform infrastructure is adapted to modern streetcars that feature low floors and wide doors for easy boarding, as well as other passenger amenities. In Portland, Seattle, and Tacoma, modern streetcars provide urban circulator service on short, center-city routes with frequent stops. In

South Lake Union Line Streetcar.
Image from Nelson\Nygaard

FIGURE 6-1 TOTAL CAPACITY BY MODE



Portland and Seattle, these streetcars operate primarily in mixed flow at low speeds. In Seattle, the streetcar operates with signal priority on about half the route and features small segments of exclusive right-of-way. In Tacoma, streetcar vehicles are operated as a small light rail system, primarily in exclusive right-of-way with substantial passenger platforms and amenities.

- **Streetcar Local Transit**: In cities such as Toronto, which has an extensive legacy streetcar system, streetcars operate much like the local trolley bus network does in Seattle. Here grades are much flatter, so steel-wheeled vehicles run on overhead catenary wires and provide local stop service. Toronto streetcars run in mixed traffic on arterial streets, have relatively short stop spacing, and stop on demand much like a bus (i.e., they don't stop if no one is waiting or has rung the call button). In various parts of Toronto streetcars also operate as urban circulators and in a rapid transit mode with limited stop spacing and dedicated travel lanes.
- **Streetcar Rapid Transit:** Streetcar network plans in Portland and Seattle both envision the operation of modern streetcars on rapid transit lines, featuring wider stop spacing and more extensive use of exclusive lanes and/or traffic signal priority. Some European tram lines offer these characteristics, as do portions of the San Francisco MUNI and MBTA (Boston) Green Line. These two legacy systems operate on streets, sometimes in exclusive lanes, and in exclusive subway tunnels, serving both urban circulation functions and rapid transit functions.

Light Rail Modes

Light rail vehicles (LRTVs) are somewhat larger than streetcars (80 to 90 feet long), and are often coupled together to form trains that allow a train and operator to carry more passengers. LRTVs are also somewhat faster over long distances that streetcar vehicles (with top speeds of around 65 miles per hour, compared to about 45 miles per hour), although streetcars can accelerate more quickly. LRTVs' greater speed and capacity make them an attractive choice for longer trunk routes or regional intercity services. Light rail vehicles typically operate in their own off-street right-of-way, although they can and sometimes do run in dedicated lanes on city streets. Light rail can be designed with varying service goals, taking on very different service attributes depending on the market to be served. For example, portions of the Sound Transit Link light rail system will be built with attributes of a heavy rail system (e.g., fully exclusive and grade-separated right of way, off-board fare payment, etc.), providing fast travel between Puget Sound cities with very limited stops. Conversely, Muni light rail in San Francisco serves local in-city trips at slower speeds and with much shorter stop spacing (similar to streetcar rapid transit described above). Here much of the system is comprised of relatively short lines operating on city streets where there is less need to achieve the high speeds and competitive travel times required for longer distance service.

Other modes, such as commuter rail and metro (a.k.a. subway or heavy rail) have not been defined here because they are unlikely candidates for local use in Seattle. It should further be noted that "trolley bus" is not a mode; rather, it is a vehicle that can be used to provide different types of bus service (ranging from local bus to full BRT).

Service Characteristics

Transit modes are defined by service characteristics as much as vehicle type. It is most essential that a mode match the needs of the primary markets it is designed to serve. As noted, faster modes (light rail and express bus) are considered more appropriate for longer alignments—and logically so. However, express bus is faster than local or limited-stop bus not because of faster vehicles, but because its operational model has far fewer stops compared to local service.

Similarly, the streetcar rapid transit concept represents an acknowledgement that streetcar vehicles—which are typically associated in North America with local-stop service—may be appropriate in some corridors where capacity need falls between that provided by a 40 foot bus and a multicar light rail train. The vehicle would not change, stops might be no more elaborate, and some elements of the right-of-way design might not change—but other components of mode would, particularly provision of dedicated right-of-way, stop spacing, and intersection priority treatments.

One useful way to think about mode might be to envision spectrums of characteristics associated with modes, rather than well-defined categories. A number of such spectrums exist, as illustrated in Figure 6-1. While this graphic is for illustrative purposes, it shows that partial BRT (like RapidRide) has a capacity range closer to streetcar than "local bus," while streetcar rapid transit can have a similar capacity to light rail.

As the illustration suggests, capacity is associated strongly with vehicle type (a multi-car light rail train may carry hundreds of passengers, several times as many as a 40-foot bus). However, there is substantial overlap, particularly between streetcar and light rail.

Furthermore, elements of mode are interrelated. Overall capacity is a function of both vehicle size and number of vehicles, or frequency of service. Frequency, in turn, is a function of multiple factors with varying relationships to vehicle type, including demand, operating cost, right-of-way and stop design.

It is helpful to think of modes in terms of attributes that are directly related to vehicle type, versus those that are not. Capacity, speed, and ride comfort are strongly associated with vehicle type; to some extent, so is right-of-way (heavy rail vehicles, for example, are powered by an electric third rail that requires the right-of-way to be inaccessible to pedestrians, effectively requiring grade-separation).

However, many elements of mode exist largely independently of vehicle type, and can be applied to multiple vehicle types and modes. Among these are elements contributing to speed and reliability, two of the most important factors in transit performance. It is proven that faster, more reliable service pleases existing users and can attract new riders, if all other factors are equal. Indeed, one of the strongest arguments made by proponents of BRT is that service design, right-of-way design and management, and stop design are each largely independent of vehicle type. Various elements can be applied with equal effect to buses, streetcars, or light rail vehicles. These elements include: limited stop spacing; part-time transit-only lanes to fully grade-separated guide-ways); right-of-way management to reduce other sources of delay (including transit priority at traffic signals); and stop design to reduce "dwell time," or time spent at stops (including level and all-door, prepaid boarding).

In thinking about mode, then, one should always keep in mind the following:

- "Mode" consists of many elements, including but not limited to "vehicle"
- Modes should not be too narrowly defined
- Some elements are characteristic of multiple modes, or are more or less independent of mode (such as right-of-way management, stop design, etc.)
- Many elements are interdependent, resulting in complex relationships that must be considered carefully in local decision-making processes

PROPOSED DECISION-MAKING FRAMEWORK

If a simple formula for selecting a mode exists, it is this: start with a defined set of local goals and objectives, and use them to develop performance measures. Fully grasp the potential performance of each mode, then apply that understanding to the corridor and market in question, working toward service design, vehicle choice, and right-of-way way management (rather than starting with the latter).

Planning exercises should always begin with clearly understood high-level goals. Seattle, like many other cities, has transportation and land use planning goals that focus on:

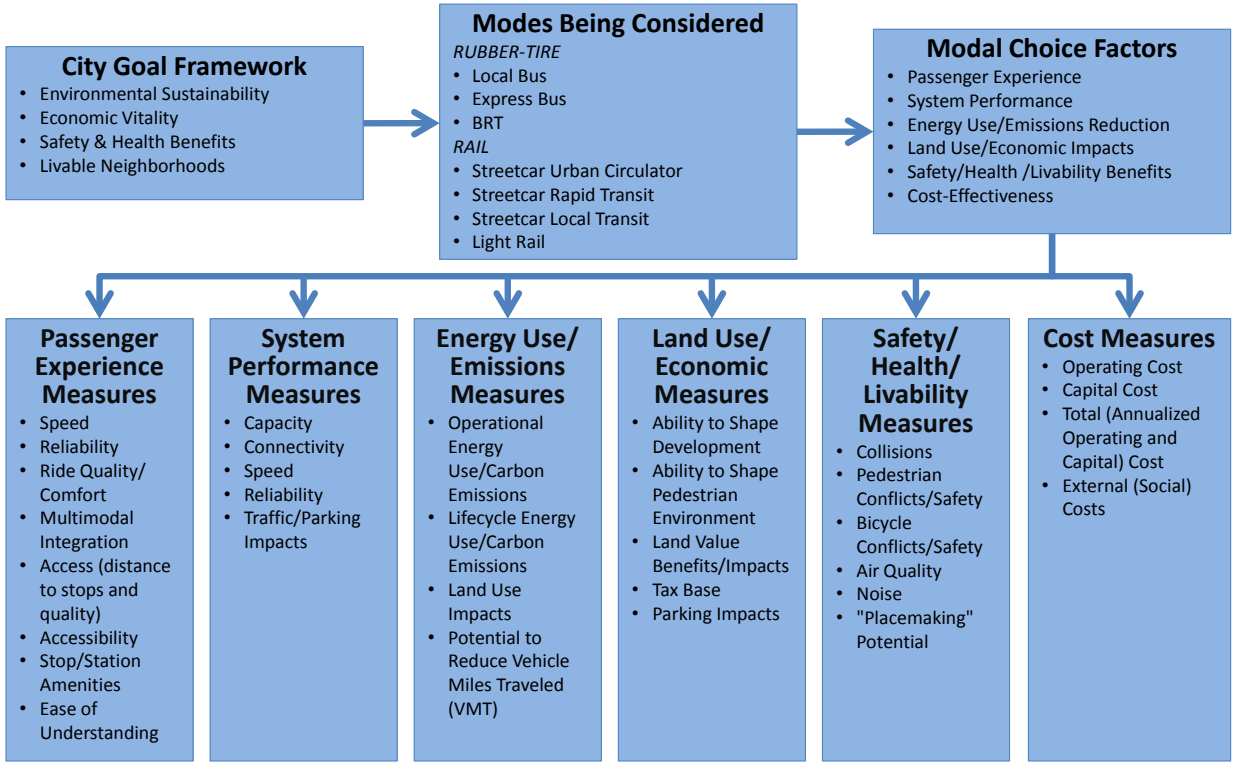
- Environmental Sustainability
- Economic Growth
- Safety and Security
- Public Health
- Livable, Walkable Neighborhood Design

These goals may be broad, but they can be used to develop more detailed categories of performance measures, which may then be applied to an analysis of different modes. These categories might include:

- Passenger Experience
- System Performance
- Energy Use/Emissions Reduction
- Land Use/Economic Impacts
- Safety/Health /Livability Benefits
- Cost-Effectiveness

Finally, a number of potential performance measures can be applied under each category. These are shown in Figure 6-2.

FIGURE 6-2 SAMPLE DECISION MAKING PROCESS FOR SELECTING A MODE



As demonstrated in the following section, even with a defined list of performance measures, mode selection can be complicated. Objectives can conflict with one another, and tradeoffs between modes often require value-based decisions that can't be quantified in clear cost or performance metrics. While such exercises should take into account broader citywide and systemic concerns, they must be tailored to the specific geographic and demographic markets in the corridor. Three markets with special relevance to Seattle and the Transit Master Plan are:

- Center City Circulation. This market includes commuters completing the "last mile" of their trips from elsewhere in the city and region, visitors to the city, and workers on their lunch hour, going to meetings or running errands, shopping or dining after work. Such travelers:
  - may be unfamiliar with the system, so "legibility" is important
  - are making short trips, so speed is less important
  - may have a limited time window in which to travel, and may walk if the wait is too long, making frequency important ("walk-up" headways are also important to those unfamiliar with the system, who cannot be counted on to know schedules)
- Commuters to Center City or University District. This market consists of regular travelers commuting to dense centers where the greatest disincentives to driving exist. These riders:
  - are traveling longer distances, so they value speed
  - are better able to schedule trips, so frequency is less important, but schedule reliability is important
  - are more likely to be regular users with a greater familiarity with and ability to navigate the system
- Neighborhood Connections. This market connects neighborhood mixed use districts outside Center City to each other and to Center City: These riders are:
  - more likely to be traveling off-peak, so appreciate frequent all-day service;
  - are more likely to be making multiple trips, so want reliability and quality service connections
  - are more likely to be making cross-town trips that don't match service designed for commuters
  - travel shorter distances so are more concerned with frequency and directness than with speed

South Lake Union Streetcar provides center city circulation service, moving people short distances within South Lake Union or connecting to downtown.

Source: http://www.seattlestreetcar.org/map

PERFORMANCE MEASURE-BASED ANALYSIS OF MODES

In this section, the following modes are compared:

- Local bus
- Express bus
- Bus Rapid Transit (BRT)
- Streetcar urban circulator
- Streetcar local transit
- Streetcar rapid transit
- Light Rail Transit (LRT, or simply "light rail")

Again, some of the assumed elements of each mode are not necessarily inherent to that mode. Also, to prioritize among conflicting measures, it is important to consider geographic and demographic characteristics of the corridor.

Passenger Experience Measures

Speed is a function of right-of-way design and management, stop design, and vehicle specifications. In an urban environment, the latter may be least important, as top speeds can only be achieved and can only make a substantial difference over relatively long distances. However, all else being equal, in long corridors light rail and full BRT (operating in dedicated right-of-way) can be significantly faster than other modes, including streetcar rapid transit (as streetcars have lower top speeds than light rail vehicles and buses).

Managing auto traffic on 3rd Avenue during peak periods improves transit speed and reliability through downtown.

Image from Nelson\Nygaard

Design strategies to increase speed include:

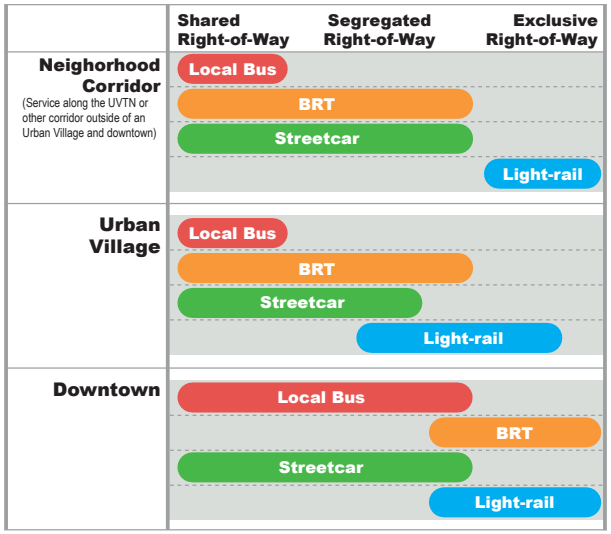
- reducing conflicts with other vehicles and delay while in motion, right-of-way design and management strategies ranging from transit priority at traffic signals to separation of right-of-way
- reducing delay while stopped, stop design features including "level boarding" of vehicles, and prepaid boarding allowing loading through all doors
- fewer stops (wider stop spacing)

Light rail, full BRT, and streetcar rapid transit typically employs all of these strategies to some extent. Partial BRT typically make relatively few stops, and includes signal priority. Streetcar urban circulators and streetcar local transit (as opposed to streetcar rapid transit) typically stop more frequently and do not employ strategies to reduce delay (with the exception of low-floor vehicles allowing "near-level" boarding). Express bus is typically the fastest of all modes simply because it generally makes the fewest stops, but serves many fewer potential riders on route.

Figure 6-3 illustrates the relationship between mode and right-of-way as it might be applied in the context of Seattle. "Exclusive" right-of-way is off-street (e.g., the Downtown Transit Tunnel and tunneled and elevated segments of Central Link). "Segregated" or "dedicated" right-of-way is transit-only, but crosses intersections. As the photo at left illustrates, while right-of-way design is associated with mode, it may be said to exist on a continuum that spans modes, just like capacity.

Although **reliability** (adherence to schedule) is closely related to speed, and relies to some extent on all of the same measures, it is primarily a function of the degree of protection from conflicts with other vehicles granted to transit—in other words, reliability is strongly tied to dedicated right-of-way. Dedicated right-of-way can be applied to any mode, but is most commonly associated with light rail, streetcar rapid transit, full BRT, and to a lesser extent express bus. A number of other design features such as fare collection, intersection design, and stop spacing can impact service reliability.

FIGURE 6-3 RELATIONSHIP BETWEEN MODE AND RIGHT-OF-WAY



Ride quality/comfort is closely related to vehicle. Specifically, any vehicle on rails will not suffer from lateral sway or bumps resulting from tires on uneven pavement. Rail vehicles are often able to accelerate and decelerate more smoothly than buses. Once again, express bus is something of a special case, as it often uses "over-the-road" coaches designed for comfort, with padded, high-backed seats. However, even with highly tailored interior amenities, rubber tired modes are only as stable and comfortable as the pavement on which they operate; rarely can they match the stability and ride quality of a train.

Multimodal integration is closely related to access, another element of passenger experience. However, multimodal integration is somewhat distinct in that it refers specifically to the ability of a mode to serve as one leg of a trip involving multiple modes (as all trips do, including at a minimum the walk to and from stops). Some amount of parking for passengers is typically part of light rail projects, particularly at suburban stations. Parking could be part of a streetcar rapid transit or off-street BRT project, although a BRT project operating on an arterial street would be unlikely to include parking. Park-and-ride lots are central to the concept of express bus.

Bicycle integration is related to vehicle type: railcars can relatively easily accommodate bicycle storage on board, while buses typically include racks on front of the vehicle limiting bikes-on-board to a maximum of three (BRT projects may allow bikes on board and forgo racks in order to speed the boarding process). Bike amenities at stations and stops also improve bicycle access to transit. Bicycle and pedestrian integration is discussed further in Section 7: Best Practices (Bicycle Access to Transit and Pedestrian Access to Transit).

Access can be said to consist of two components: access from the surrounding area to stops, or distance to stops; and direct access to vehicles, or quality of access. Perhaps paradoxically, more elaborate, higher-amenity stations can reduce quality of access, as stops on sidewalks are better integrated into the pedestrian environment. For example, the Sounder platforms at King Street Station are much harder to access than a bus stop on 3rd Avenue. Platforms raised to the level of transit vehicle floors, however, can improve quality of access to vehicles by allowing passengers to walk or roll directly onto or off of vehicles, without benefit of stairs or wheelchair lifts or ramps. Raised platforms are associated with more infrastructure-intensive projects, including light rail, full BRT, and potentially streetcar rapid transit projects, although the latter might forgo platforms or ramps in order to reduce expenses. Sidewalk stops, on the other hand, are typical of streetcar urban circulators, streetcar local transit and partial BRT projects. As for numbers of persons within walking distance of a stop, the wider stop spacing associated with light rail, streetcar rapid transit, full BRT and especially express bus reduces access.

Bike racks on buses improve multimodal access.

Image from Nelson\Nygaard

Raised platforms and level boarding improves accessibility to transit and reduces dwell time.

Image from Nelson\Nygaard

Accessibility for users of wheelchairs or other mobility devices, those with strollers or anyone for whom stepping up or down is a challenge is similarly a function of vehicle floor and platform height, or the availability of a wheelchair ramp at the stop. Raised platforms are independent of vehicle type and ultimately independent of mode, but again, are most strongly associated with light rail, full BRT and possibly streetcar rapid transit projects due to their expense and the amount of space they require—space that is often unavailable on sidewalks.

Stop/Station Amenities such as ticket vending machines, large shelters, lighting, prominent signage and informational displays are similarly associated with the more infrastructure-intensive modes of light rail and full BRT (streetcar rapid transit stops could provide a similar level of amenity). However, streetcar urban circulators, streetcar local transit, partial BRT and even express bus stops often provide amenities such as smaller shelters, seating and wait-time displays.

Ease of Understanding includes components of service design such as direct routes and frequent, "walk-up" headways that reduce or eliminate the need to consult a schedule. It also includes wayfinding elements, such as signage and branding, that convey information and reduce confusion. However, ease of understanding can also relate to infrastructural elements; for instance, with their tracks literally delineating alignments, rail lines have an inherent advantage in terms of legibility. Ease of understanding, then, is most strongly associated with rail modes, although other modes also have infrastructural elements that improve legibility. For example, full BRT and some partial BRT projects are designed with features to improve legibility, such as diagrammatic route maps prominently displayed at stops or special branding that delineates vehicles and stations from the local bus system. In addition, the overhead wires of electric trolleybuses can provide a sense of permanence that promotes legibility and ease of understanding.

Well-designed wayfinding makes transit easier to understand and use.

Image from Nelson\Nygaard

FIGURE 6-4 IMPACT OF FREQUENCY ON CAPACITY

Denver 16th Street Mall shuttles can hold 116 passengers, while Portland streetcars can carry 170. Yet 16th Street shuttles run more than 10 times as often during peak periods—every 75 seconds, compared to every 13 minutes—so the shuttles' total capacity is more than seven times as great (more than 5,500 passengers per hour).

Image on left from Flickr user nmfbihop. License info: http://creativecommons.org/licenses/by/2.0/. Image on right from Nelson\Nygaard.

SYSTEM PERFORMANCE MEASURES

As noted earlier, capacity is a function of both vehicle (or train) size and number of vehicles, or frequency of service. Frequency, in turn, is a function of multiple factors with varying relationships to vehicle type, including demand, operating cost, right-of-way and stop design. The right-of-way and stop design are related to frequency because faster vehicles are able to pass the same point more often, and because reliable vehicles don't impact frequency by falling behind schedule and blocking other vehicles. Speed, reliability, capacity and operating cost, then, are all interrelated. Given a fixed operating budget, a BRT bus operating in bus-only lanes may be able to provide greater frequency and capacity than a larger, higher capacity streetcar in traffic.

Connectivity, or seamlessness, is a factor of existing and planned system design (i.e., a system made up of the same mode provides more seamless connectivity than one made up of several), although there are also other, less obvious factors. Light rail or streetcar rapid transit or full BRT stations set apart from the sidewalk offer less seamless connectivity than streetcar, partial BRT, or local bus stops located on the sidewalk or at street level adjacent to the sidewalk. Design of public space used for horizontal and vertical transfers at key transit hubs also impacts connectivity; for example, a cross-platform transfer is much more convenient than a transfer that requires a street crossing.

Speed is important both from a passenger experience and from a system performance perspective for the reasons already described under "capacity"—faster

service allows an agency to deliver more frequent service with the same amount of operating funds as the same number of vehicles can provide more service. Greater speed can also lead to less-expensive service as fewer vehicles are required to provide the same frequency of service. Alternatively, the same number of vehicles can cover a longer route, extending the reach of the system and expanding coverage.

Likewise, **reliability** is important from both a passenger and operator perspective, as reliable service gives passengers confidence in the system and ensures more seamless connectivity, including timed transfers.

Traffic and parking impacts are a factor of right-of-way design and management and stop design. Dedicating lanes to transit—and, to a lesser extent, providing transit vehicles with priority at signals—generally reduces auto if not person capacity, although traffic impacts can be mitigated using design elements such as left-turn lanes. Additionally, in a constrained right-of-way, dedicated lanes and island or "bulb-out" sidewalk extension stops may require removal of parking spaces. Like several of the other performance measures already described, traffic and parking impacts are not directly related to mode; or rather, right-of-way design and management strategies are not directly related to mode. That said, on-street light rail, streetcar rapid transit and full BRT projects are more likely to impact parking and traffic than streetcar urban circulators, streetcar local transit, or partial BRT projects. (It should be noted that impacts from island stops can be reduced if vehicles with doors on both sides are used, allowing for shared "center" platforms rather than requiring separate "side" platforms.)

Design constraints on Telegraph Avenue in Oakland, CA (part of the East Bay BRT project) required the removal of some curbside parking.

Source: Nelson\Nygaard

ENERGY USE/ EMISSIONS MEASURES

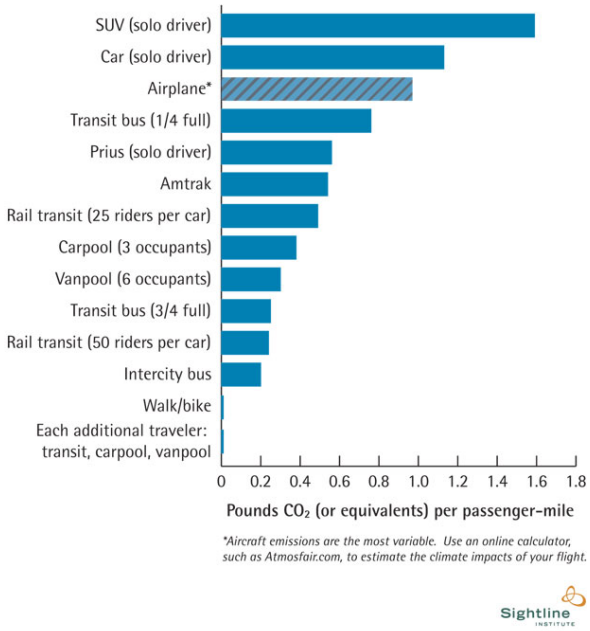
The environmental sustainability of a mode should be measured in terms of net reductions in **energy use and carbon emissions**. This means that potential to replace auto trips—or ridership—must be a factor, and consumption and emissions should be measured on a **per-passenger or per-passenger mile** basis. Measuring emissions on a per capita basis is a meaningful measure, as shorter trips use less energy and generate fewer emissions. This stresses the importance of dense, walkable urban neighborhoods with high levels of access to destinations as a key strategy in reducing carbon footprints. The relative ridership-generating potential of different modes is discussed under "Cost Measures." In general, however, electric rail modes not only generate fewer emissions, but use less energy than diesel bus modes. Since electric engines are significantly more efficient than internal combustion engines, steel wheels on rail generate less friction than tires on pavement, and railcars are able to recapture energy through regenerative braking. In some cases, the "clean" electrical energy used by railcars is derived from "dirty," if remote, sources such as coal-fired power plants. However, Seattle relies heavily on hydroelectric sources, which have a negligible carbon impact.

Energy use and emissions from operations is just one component of a transit project's sustainability. **Lifecycle energy use and carbon emissions** also include the cost in energy and carbon to build and maintain vehicles and infrastructure, as well as the costs of fuel production. Researcher Mikhail Chester[1] analyzed five light, commuter, heavy, and high-speed rail systems in California and Massachusetts (including the proposed California High-Speed Rail system) and found that lifecycle environmental costs were significantly higher than operational costs alone: total energy consumption was 93 to 160 percent higher, and overall carbon emissions were 39 to 150 percent higher. By contrast, the figures for bus were 38 and 43 percent, respectively. In sum, Chester found that "non-operational life-cycle components account for around 50% of total effects (except for CAHSR) meaning that there was a doubling of effects when life-cycle impacts are accounted for. The inclusion of infrastructure components significantly increases the emissions of (criteria air pollutants)." Chester did not analyze BRT as a mode, but in general, projects requiring more extensive construction could be expected to have higher lifecycle costs. For cities such as Seattle that generate electricity from low-polluting sources, total lifecycle emissions would still be lower, but primarily because emissions from operations would be lower. The relative cleanliness of vehicle manufacturing, to take one example, would depend in large part on the source of energy used at the factory, and to produce metals, while the relative cleanliness of running way and station construction would depend in large part on the source of energy used to produce concrete. It should also be noted that even for "clean" fuels such as hydroelectricity, there are "precombustion" energy and emissions costs, including costs to extract, process and transport.

Land use impacts are also important to sustainability, for two reasons. First, the shorter the vehicular trip (by transit or auto), the less energy it will consume and the fewer emissions it will generate—and transit-oriented development, or TOD, can shorten the distances one must travel by increasing the number of destinations available within a given area. The most sustainable trips, however, are nonmotorized ones, and while TOD may be "transit-oriented," when properly designed it is also pedestrian-oriented—so TOD can also increase the share of trips made by walking or by biking. The relative ability to shape development of different modes is discussed in the following section, "Land Use/Economic Measures."

Again, the environmental sustainability of a mode should be measured in terms of net reductions in lifecycle energy use and carbon emissions. This means that **potential to reduce Vehicle Miles Traveled (VMT),** or potential to attract new riders, must be central to any consideration.

FIGURE 6-5 CARBON EMISSIONS BY MODE



Note: Transit bus (1/4 full and 3/4 full) assumes diesel vehicles rather than electric trolley buses that are common in Seattle.

1 Life-cycle Environmental Inventory of Passenger Transportation in the United States, Mikhail V. Chester, Institute of Transportation Studies, Berkeley, 2008.

In addition to providing internal circulation and connections to downtown, Seattle Streetcar has helped catalyze and organize development in the South Lake Union area.

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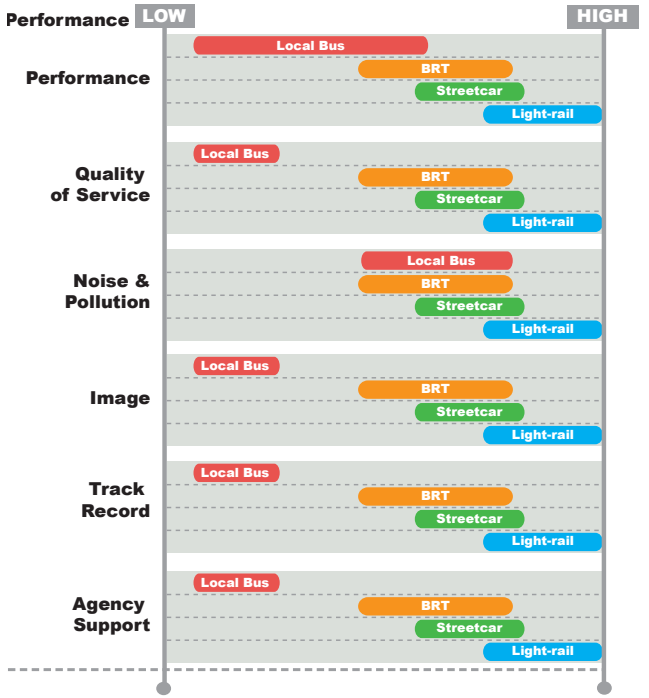
LAND USE/ ECONOMIC MEASURES

Ability to shape development is an important performance measure for two reasons: first, transit-oriented development can contribute to larger economic development and sustainability goals; and second, TOD can improve transit access by increasing the number of destinations in a corridor. Rail modes have a long, proven track record of increasing land value and generating demand for certain types of development (including multifamily housing, retail and office). As a mode with only recent exposure in North America, BRT has a less measurable track record, but studies have begun to find some impact.

As Figure 6-6 illustrates, a number of factors can contribute to the developmental appeal of a transit project. In the case of land use impacts, more direct relationships to mode exist than for some other elements. Tracks, for example, are a highly visible, long-term public investment in infrastructure—and private investors have been shown to respond in kind to such financial and political commitments. BRT lacks tracks, but to the extent that infrastructure is clearly permanent in the form of physically separated right-of-way and "station-like" stops, it can have a similar effect on development. Notably, streetcar has been shown to attract development despite being different in terms of mobility from local bus. For this reason, streetcar is often considered as much an economic development as a mobility tool.

FIGURE 6-6 RELATIONSHIP BETWEEN TRANSIT ELEMENTS AND ECONOMIC DEVELOPMENT IMPACT



Stop spacing affects transit's role as a catalyst for urban development. The development impacts of transit tend to extend only a short walking distance from stops. The impacts certainly extend within a quarter-mile radius (roughly a 5-minute walk), but somewhat less so within a half-mile radius (a 10-minute walk), and these impacts can further be muted by circuitous or indirect pedestrian paths or steep grades. For this reason, light rail, streetcar and full BRT are likely to encourage development strongly focused in more widely spaced nodes, while street-cars with stops spaced every two or three blocks may produce a more linear benefit along a corridor.

Different modes are likely to influence different scales of development. Studies have found that heavy rail has a greater catalyzing effect on development than other rail modes; nonetheless, light rail, streetcar and to a lesser extent BRT can all be expected to attract and support relatively dense development—and indeed, relatively dense development may be required to generate the high ridership needed to justify investments in rail or BRT projects. It is difficult to say with any certainty just how dense development must be for different modes, as numerous factors contribute, including all of the factors previously identified (permanence, quality of service, street connectivity, pedstrian conditions, etc.), as well as zoning, market, and policy considerations that don't relate directly to transit. However, Figure 6-7 summarizes national research into the minimum densities that may be required to support investments in different modes. It is representative of industry standard densities in station areas or corridors for the various modes. These figures should not be taken too literally; depending on the amount of ridership one requires and cost one is willing to take on, lower densities may be acceptable. We know that in cities such as Portland, Seattle and Vancouver, B.C., lower density residential neighborhoods organized on grid streets and that have good pedestrian conditions and connectivity tend to produce higher ridership than would be expected based on this national research. Figure 6-7 demonstrates relative relationships between mode and land use. Of the modes under discussion here, light rail is related to the highest densities while streetcar urban circulators and streetcar local transit might fall somewhere between streetcar rapid transit and full BRT.

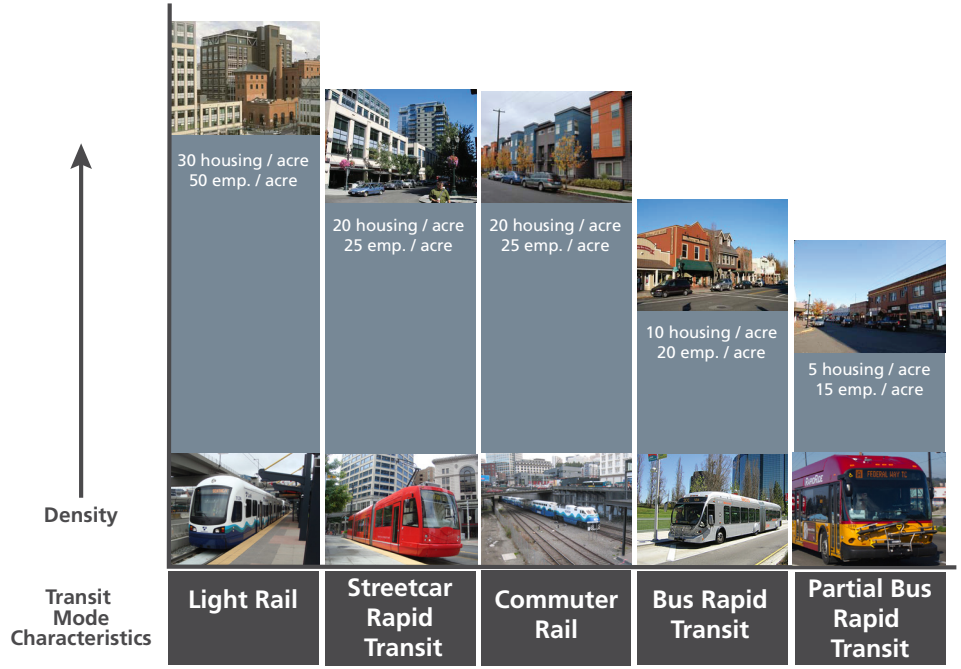
Ability to shape pedestrian environment is largely a byproduct of ability to shape development (specifically, denser types of development that are likely to contribute to demand for pedestrian improvements), although there is an additional component: Many rail and BRT projects increase space for walking by moving waiting passengers off of the sidewalk and onto "bulb-out" sidewalk extension or island stops, and many include funding for additional streetscape improvements in the corridor such as corner bulb-outs and median refuges or safety islands. It should be emphasized that pedestrian environment is not just influenced by transit service, but is key to supporting successful transit service—so a virtuous cycle can be said to exist.

Land value benefits and impacts are likewise closely related to ability to shape development, although owners of existing developments and parcels, are among the beneficiaries.

Tax base impacts, too, are closely related to development impacts.

Parking impacts, as previously noted, are largely a factor of right-of-way and stop design, which in turn are only somewhat directly related to mode. Parking removal is often among the most contentious elements of proposed transit projects; however, impacts on retailers are likely to vary depending on the type of business, as businesses that stand to benefit from more walk-up traffic will gain from increased transit ridership. Effective off-street parking management can mitigate reductions in curb-parking supply. In many cases, political resistance to creating fully dedicated center transit lanes for bus modes leads to more significant and more confusing parking takes at the curb.

FIGURE 6-7 DENSITIES THAT SUPPORT INVESTMENTS IN DIFFERENT MODES



SAFETY/ HEALTH/ LIVABILITY MEASURES

Like other elements, **collisions** are primarily a factor of right-of-way design and management, which is not directly related to mode. In theory, rail modes should be safer in this regard than bus modes, as trains and tracks are more visible, and in practice, light rail vehicles rarely operate in traffic. However, like streetcar rapid transit, streetcar local transit, and streetcar urban circulators, light rail trains often operate in on-street right-of-way requiring at-grade crossings of intersections, where turns take place and where collisions are most likely to occur. Transit-only traffic signal phases can be confusing to motorists and peak period curb parking restrictions for transit can be confusing and reduce pedestrian comfort on adjacent sidewalks. Such risks can be offset by reconfiguration of right-of-way to reduce speeding and reckless driving. If additional transit vehicles will by definition increase the risk of collisions between transit and other vehicles, well-designed transit projects can calm traffic and reduce collisions between autos. Furthermore, transit is a safer mode than auto, so any project that increases transit and decreases auto use will have a net positive impact on road safety.

Pedestrian conflicts are similarly a factor of right-of-way design, including crosswalk design and location and whether a sidewalk "buffer" or curbside parking exists. However, as is the case with auto conflicts, a well-designed project can reduce conflicts between non-transit users—in this case, between pedestrians and autos—by redesigning the street in a way that calms traffic. "Calm" traffic is not the same thing as congested traffic; calming merely means that motorists are discouraged or prevented from speeding and reckless driving.

Seattle Streetcar operating in mixed flow traffic.
Image from Nelson\Nygaard

At-grade light rail crossings are an important design consideration.
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Bicycle conflicts with transit and other vehicles can similarly be reduced or eliminated with good design and system planning that develops bicycle facilities in-corridor or on parallel roadways. However, rails can be a hazard for cyclists, while buses can collide with cyclists if the latter are in an operator's "blind spot." Significant care is needed to design street-running rail where roadways are shared with bicycles. Seattle and other cities are creating "smarter" designs to ensure that bicycle crossings of in-street trackway are made perpendicularly and that street designs do not promote shallow turns across track that would create risk of tires catching in the trackway.

Air quality benefits and impacts from a transit project derive from two sources: emissions from the transit vehicle itself and, perhaps more importantly, emissions from private vehicles. To the extent a transit project can attract former motorists and reduce vehicle miles traveled, emissions can be reduced. For this reason, and because light rail vehicles are electrically powered (there may still be emissions generated, but not locally), operating at full capacity, light rail should have the greatest benefit for air quality, followed by streetcar rapid transit, streetcar urban circulator, and streetcar local transit.

Noise is one measure that is largely dependent on vehicle, as electric rail vehicles (streetcar and light rail) are, despite some "rumble" effect, quieter than diesel buses typically used in BRT and express bus, which are especially loud when pulling away from stops. Electric trolleybuses, currently used on a number of Seattle bus routes, are very quiet, even when accelerating up steep grades. Despite their name, light rail vehicles are heavier and thus louder than streetcars. Noise also depends to some extent on right-of-way, as railcars turning corners can produce a squealing noise.

First Hill Streetcar concept at Broadway and Denny Way."

Image from URS

"Placemaking" potential is a measure that is impossible to quantify and difficult to define, yet is nonetheless important. "Sense of place" may be a matter of perception, but people clearly value places with a strong identity. One way to develop or reinforce such an identity, and one way that transit can contribute to a sense of place, is to offer a focal point. Just as with ability to shape development, rail modes have a proven record of generating development around stops, and can similarly generate demand for pedestrian improvements. Studies have also begun to find similar developmental impacts from BRT.

Electric light-rail or streetcar corridors have less of a noise impact on surrounding land uses than diesel buses.

Image from Nelson\Nygaard

COST MEASURES

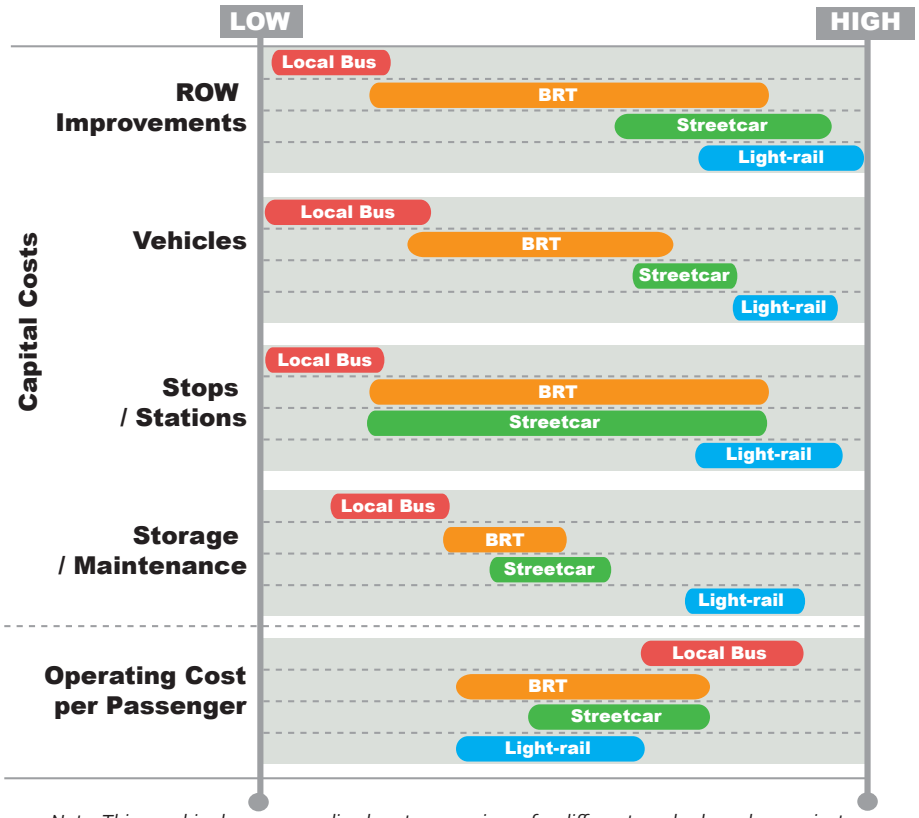
When discussing the cost of a transit service—**operating cost or capital—**it is important to think in terms of cost-benefit or cost-effectiveness. Transit services require subsidy; essentially, the public buys a package of benefits. Whether such a purchase is a good deal or not depends, in large part, on how well it is used—in other words ridership. In discussing operating cost, then, the most useful metrics may be **per passenger** measures, although **per hour, per mile** or **per passenger mile** also have some use. Key factors in generating ridership include land use (including density as well as mix of uses and pedestrian environment), service quality (including frequency, span of service, speed and reliability), and ease of use (including a range of performance measures already identified, such as access, ride quality/comfort and legibility/ease of understanding). In general, rail modes have proven to attract more riders than bus modes, although there is a great deal of debate whether BRT, if made comparable to rail in ways other than vehicle type, can attract similar ridership (full BRT and partial BRT have been shown to attract many more riders than local bus). In terms of raw cost, larger vehicles are more expensive to operate but can result in lower labor costs per passenger if capacity reflects demand as operator wages and benefits are typically the largest operating cost drivers for transit. In general, electrically powered vehicles are less expensive to operate than diesel or other fossil fuel powered vehicles, and diesel costs have also been highly volatile in recent years. Finally, shorter trips are less expensive to serve than longer trips, so costs per passenger may be higher for modes serving longer-distance trips, while without distance-based fares, subsidies per passenger may be significantly higher.

Capital cost is, again, a measure that should be thought of in terms of cost-effectiveness—and indeed, one standard used to prioritize funding for transit projects is the projected "cost per new rider." In general, rail projects, due to their much higher capital cost, will not perform as well in this regard as BRT projects. Light rail in particular can be very expensive to build, although most projects are not as expensive as Central Link, which included tunnels and long elevated segments. Typically, light rail projects cost between $50 and $100 million per mile, streetcar projects $25 to $50 million per mile, and partial BRT less than $1 million per mile. Costs can be substantially higher where tunneling, elevated structure or bridge construction is required. Costs for BRT projects can vary widely depending on their infrastructure intensiveness, ranging from as little as a few million dollars per mile to more than $50 million per mile if grade separation or property acquisition is necessary. Indeed, one of the arguments made by BRT skeptics is that a full BRT project comparable to rail in terms of infrastructure will be nearly as expensive, and that most capital cost savings from BRT are derived from a reduced investment in right-of-way, property acquisition and stations.

Ultimately, one should think in terms of **total cost**, or annualized operating and capital costs. While rail projects can incur significantly higher initial expense, lifecycle costs can be competitive with BRT projects due to the greater durability and longer lifespan of rail vehicles. Labor and fuel costs may also increase significantly over time, so any mode that reduces exposure in those areas (specifically, larger, electric vehicles) may prove less expensive in the long term.

In addition to monetary costs, **external or social costs** must also be taken into account. One of the benefits of transit in general is that it produces fewer negative externalities than auto use, including health and safety impacts, carbon emissions, and the opportunity costs of using valuable real estate for roads and parking. However, relative reductions in these costs, and impacts from transit itself (such as the safety concerns discussed under "Safety/Health/Livability Measures") will vary by mode. In general, projects promising the greatest reduction in VMT should provide the greatest benefit in terms of externalities, although right-of-way design that increases traffic congestion and reduces parking availability may have localized negative impacts on VMT, air quality, and other areas.

FIGURE 6-8 GENERALIZED COST COMPARISON BY MODE



Note: This graphic shows generalized cost comparisons for different modes based on projects from around the country. Actual vehicle costs and total capital costs per track or lane mile is presented below for several BRT, streetcar and light rail projects.

System	Cost per Vehicle	Capital Cost per Track/Lane Mile *
Seattle South Lake Union Streetcar	$3.1 M	$20.8 M
Sound Transit Central Link Light Rail	$4.0 M	$81 M
Metro Rapid Ride BRT	$1.0 M	$1.8 M
Portland Streetcar - Westside	$3.5 M	$12-13 M
Portland Streetcar - Eastside Loop	$3.5 M	$22.4 M
Portland Milwaukie Light Rail	$4.3 M	$95 M
Eugene EmX BRT	$1.0 M	$2.0-3.0 M

** Includes all capital costs, including vehicles*

CONCLUSION

In transit, the type of vehicle matters. Vehicles are of a certain size; they can go a certain speed; they draw power from a certain source.

Yet both buses and trains can be stuck in traffic—or be protected from traffic. Right-of-way design and management matters greatly, and is not tied to mode. In Seattle, for instance, even local bus lines use dedicated lanes.

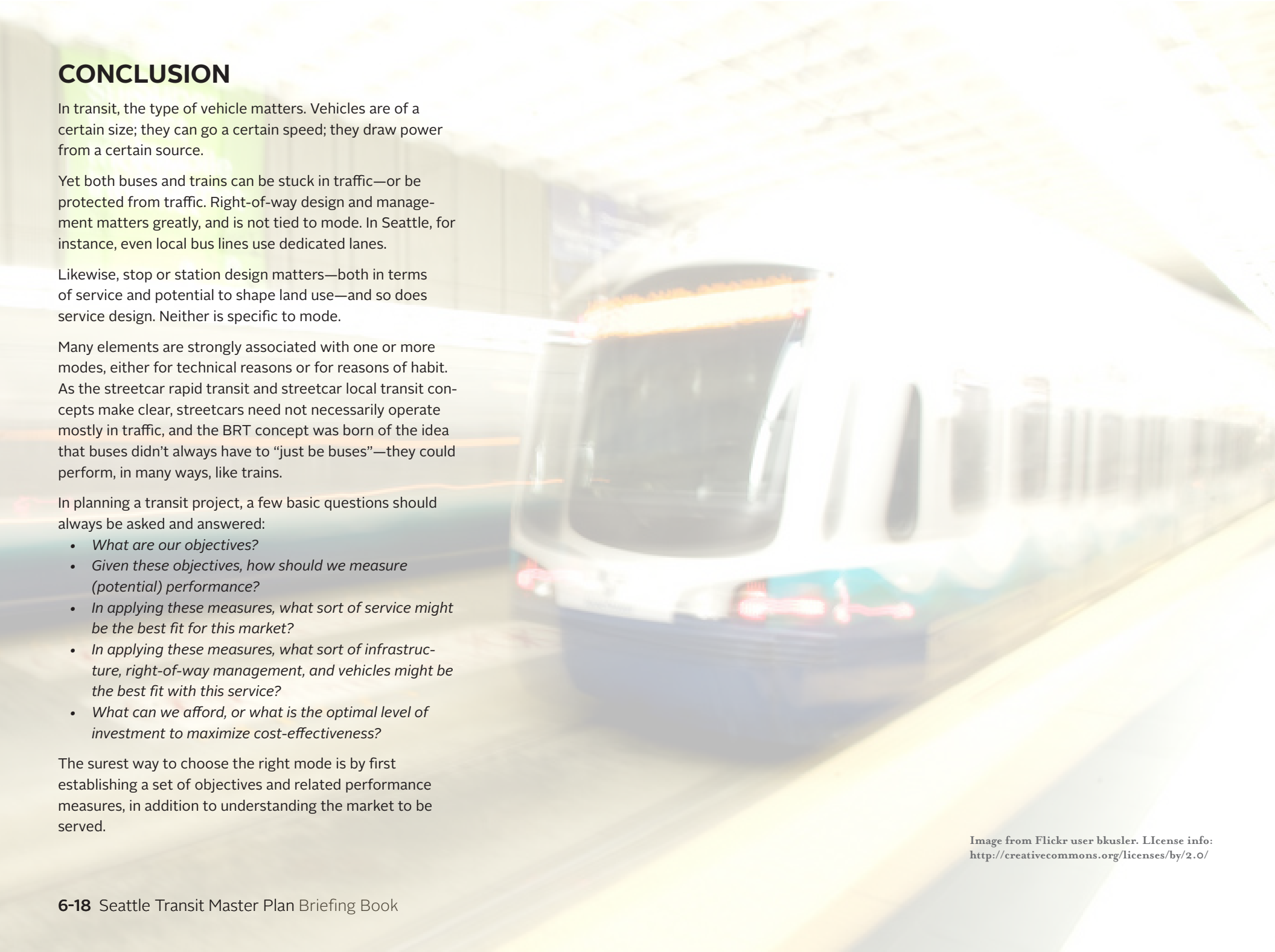
Likewise, stop or station design matters—both in terms of service and potential to shape land use—and so does service design. Neither is specific to mode.

Many elements are strongly associated with one or more modes, either for technical reasons or for reasons of habit. As the streetcar rapid transit and streetcar local transit concepts make clear, streetcars need not necessarily operate mostly in traffic, and the BRT concept was born of the idea that buses didn't always have to "just be buses"—they could perform, in many ways, like trains.

In planning a transit project, a few basic questions should always be asked and answered:

- *What are our objectives?*
- *Given these objectives, how should we measure (potential) performance?*
- *In applying these measures, what sort of service might be the best fit for this market?*
- *In applying these measures, what sort of infrastructure, right-of-way management, and vehicles might be the best fit with this service?*
- *What can we afford, or what is the optimal level of investment to maximize cost-effectiveness?*

The surest way to choose the right mode is by first establishing a set of objectives and related performance measures, in addition to understanding the market to be served.



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