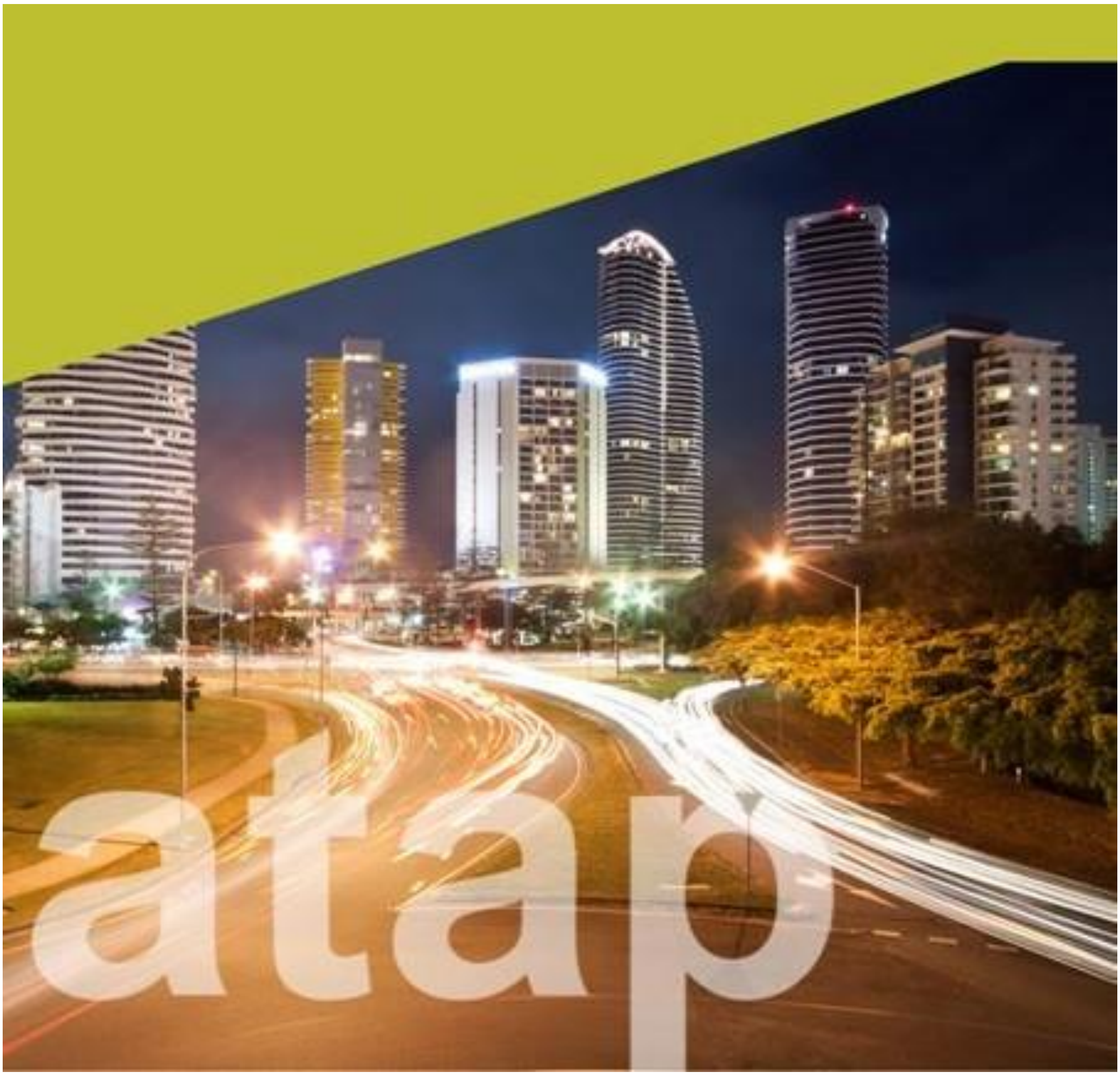
INFRASTRUCTURE AND TRANSPORT MINISTERS

Australian Transport Assessment and Planning Guidelines

O9 BRT and LRT options assessment and cost-benefit analysis

August 2021



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At a glance

- This guidance considers Bus Rapid Transit (BRT) and Light Rail Transit (LRT) initiatives operating within dedicated rights-of-way. The focus is on options generation and cost-benefit analysis, allowing BRT and LRT to be considered as two options for addressing a given problem or opportunity. It complements ATAP Part T1 which considers public transport in general.
- BRT and LRT operating within dedicated rights-of-way are medium capacity transit (MCT). Over the last two decades in Australia and overseas, there has been a significant increase in the use of this type of public transport service provision. As MCT modes, BRT and LRT can be designed to deliver similar capacities, comparable services, and overall comparable customer experience. LRT has higher maximum capacity thresholds both per width of alignment and length of vehicle, but these features come at additional cost.
- Not considered here are: traditional street bus services operating in mixed traffic; tram (streetcar) services in mixed traffic; mass transit services (heavy rail, metro). These are different service level tiers to MCT.
- When MCT is the type of solution required to address a given problem or opportunity, it is important to generate and assess BRT and LRT options in a 'mode-neutral' manner.
- Best practice guidance requires that a wide range of options be considered for addressing a given problem or opportunity (see ATAP F3). In the BRT-LRT setting, genuine options need to be established that are:
  - Mode-neutral: Excluding preconceptions, and allowing evidence-based options assessment to reveal the relative merits of BRT and LRT options for each setting and circumstance.
  - Feasible: This will depend on whether the improvement is an extension to an existing network, or a greenfiled situation, or whether there are other constraints such as curves, gradients or capacity requirements. Whatever the result of options generation, there needs to be documentation of the rationale, with evidence, of why an option is judged to be not feasible. That is, a sound case should be made before a BRT or LRT option is excluded.
  - Comparable and Best-Fit: It some cases it may be possible to generate comparable options, say solving a problem to a given degree. This approach may, however, generate a BRT or LRT option that is not feasible in terms of meeting a particular standard. In this case, that option should be designed on a 'best-fit' basis rather than exclude it from option generation and assessment. Ensuring that best-fit options are considered facilitates a fair comparison between options, allowing the respective strengths of BRT and LRT to be best accommodated. This also provides the decision-maker maximum choice in terms of how they address a problem or opportunity.
- BRT is sometimes proposed as an incremental option towards LRT in future. Assessers of such an option should note that: there are limited cases where this has occurred; there may be upfront costs associated with building in flexibility; and conversion would involve service disruptions.
- New technologies, such as trackless trams, have been noted here, but not discussed in detail.
- Once BRT and LRT options have been generated, demand forecasting and options assessment proceed in line with ATAP Part T2 (cost-benefit analysis) and M1 Public transport.
- The guidance here:
  - Considers the limited information available on demand responsiveness to BRT vs LRT improvements
  - Summarises how sections of T2 and M1 should be applied in a cost-benefit analysis.

There are a number of areas where further research would be beneficial, including the relative impacts of BRT vs LRT with respect to: user and community preferences, demand responsiveness, land use impacts, energy use and emissions. Guidance on assessing construction externalities would also be beneficial.

1. Introduction

ATAP Part M1 provides guidance for public transport in general. This report provides complementary guidance for cases where two specific modes of public transport — bus rapid transit (BRT) and light rail transit (LRT) operating specifically within a dedicated right-of-way — are alternative options for addressing a given problem or opportunity.

For this setting, the primary focus here is on options generation and cost-benefit analysis (CBA). This guidance seeks to assist practitioners in:

1. Generating and scoping feasible options
2. Providing a robust approach to options assessment on a fully consistent basis.

BRT and LRT operating within dedicated rights-of-way are referred to as what is commonly referred to in the industry as medium capacity transit (MCT). The MCT tier of public transport is also sometimes referred to as the Semirapid or Rapid tier (Vuchic 2007 pp50-51), or occasionally Rapid Light Transit (RLT) (i.e.McBrayer 2003). Over the last two decades in Australia and overseas, there has been a significant increase in the use of this type of public transport service provision. As MCT modes, BRT and LRT can be designed to deliver similar capacities, comparable services, and overall comparable customer experience. LRT has higher maximum capacity thresholds both per width of alignment and length of vehicle, but these features come at additional cost.

There is little practical guidance outside of academic literature for generating and assessing BRT and LRT options side-by-side as two ways of addressing the same problem or opportunity. Providing such guidance is the aim here. The guidance:

- Provides an understanding of the essential elements of BRT and LRT, as well as the similarities and differences between them
- Considers BRT and LRT in a ‘mode-neutral’ manner, allowing the assessment process to identify the preferred option for any given case of addressing an observed problem or opportunity
- Provides detail regarding the complex and multifaceted questions that need to be asked, and decisions that need to be considered and made, in order to identify a preferred option.

The focus here is on BRT and LRT, although brief mention is also made of Trackless Trams and Translohr as two other emerging types of MCT (see section 3.3).

Not considered here are:

- Street bus services: traditional bus services operating in mixed-traffic, including those that have on-road priority measures
- Tram (streetcar) services: Trams operating on-road in mixed traffic, as the Melbourne tram network does predominantly
- Mass transit services: train (heavy rail) and metro services.

Specific ATAP guidance on these other types of services may be provided in future (see Section 7).

1.1 Links to other parts of the Guidelines

The broader framework for assessment of transport projects, including MCT, is provided by Infrastructure Australia (IA) Assessment Framework (2018) and the ATAP Guidelines. The most closely related parts of the Guidelines are:

- F3 Options Generation and Assessment: Provides the general approach and principles for generating options and their assessment. It requires identification of options, and their assessment in a three-stage appraisal process that has a strong focus on CBA and the inclusion of all relevant monetised and non-monetised benefits and costs
- T2 Cost–Benefit Analysis: ATAP's general CBA manual
- M1 Public Transport: Mode-specific guidance that applies F3 and T2 to the assessment of public transport
- T1 Travel demand modelling: Guidance on travel demand modelling for transport project appraisal
- M4 Active travel: Guidance on active travel.

1.2 Structure of this guidance

The remaining chapters are structured as follows:

- Chapter 2 provides a brief summary of the ATAP guidelines approach to options generation and assessment as part of the context setting
- Chapter 3 Overview: outlines the scope of this guidance and provides a brief overview of BRT and LRT
- Chapter 4 Options generation: provides guidance, detail and analysis of the various factors and items that need to be considered in generating genuine BRT or LRT for a given situation
- Chapter 5 Demand estimation: provides an overview of how demand estimation would apply to BRT/LRT options. The general methods of estimating demand for public transport are readily applicable to BRT/LRT options. Care needs to be taken in demand estimation in the instance that BRT/LRT represents a novel mode for a city.
- Chapter 6 Cost benefit analysis: identifies the relevant costs and benefits for BRT/LRT options. Guidance is provided on how these costs and benefits apply to BRT/LRT options in the context of existing ATAP guidance. A discussion on some of the historical biases at play in BRT/LRT is also provided
- Chapter 7 Gaps in knowledge and areas of contention: outlines future work that ATAP will undertake to cover at-present unsolved questions, and other modes of transport
- Appendix A: Glossary: Provides a glossary of terms, as used in this report
- Appendix B: Provides an options identification checklist
- References: Itemised references for citations in this report.

2. The ATAP options approach

This guidance applies the ATAP options generation and assessment approach to BRT and LRT options. Before considering the specifics of BRT and LRT, this chapter provides a brief overview of the ATAP approach to set the context.

The ATAP options generation and assessment approach is presented in Sections 3.2 and 3.3 of ATAP Part F3. It consists of:

- Clarification of relevant jurisdictional goals, transport system objectives and targets — noting it is important to be clear from early in an assessment about which of these are relevant in the given assessment (see ATAP Part F1).
- Clarification of policy choices that have already been made and are part of the context for the assessment (see ATAP Part F0.1 Policy Choices and System Planning).
- Consideration of strategic merit / alignment — the degree of strategic alignment of the initiative being assessed (or the problem being solved) with goals, transport system objectives, targets, policies and strategies.
- Generation of a wide range of options for solving the problem being assessed. Note that IA (2018) require that at least two Project Cases be presented in business cases submitted to them.
- Assessing options through the use of CBA and the Appraisal Summary Table (AST) (see ATAP Part T2). The AST provides the mechanism for presenting all appraisal results — monetised and non-monetised — side-by-side in a single location. This approach recognises that all benefits and costs — monetised and non-monetised — are relevant to the appraisal of initiatives. The distributional (equity) impacts of an option should also be presented to the decision-maker.
- The AST also includes quantitative and qualitative impact descriptions — these are necessary inputs to calculating monetised and non-monetised benefits, costs and impacts. Presentation of these inputs can also be of assistance to the decision-maker. Non-monetised impacts that are non-quantifiable can only be described in qualitative terms.
- The assessment of all options should include an assessment of risk and uncertainty, in order to ensure that the recommended option is robust (see ATAP Part T2 Chapter 11, and forthcoming ATAP Part T7 Risk and Uncertainty).
- Bringing together all aspects of the assessment into a Business Case (see ATAP Part F4).

3. Overview

3.1 What is Medium Capacity Transit (MCT)?

BRT and LRT operating within entirely dedicated rights-of-way are commonly referred to by the industry as medium capacity transit (MCT). Table 1 below briefly compares MCT with other tiers of transit services.

For the purposes of this document, MCT is taken to mean public transport services that are designed and broadly intended to cater primarily, but not exclusively, for passengers whose door-to-door trips each way are between 15 and 35 minutes. This contrasts against other transit tiers which primarily cater to shorter or longer trips. As noted above, the concept of MCT as used here overlaps primarily with Vuchic (2007, pp50-51)'s Semirapid class of transit (i.e. light rail and bus rapid transit), although the travel budget can also capture many transit users on what Vuchic refers to as Rapid transit (i.e. express busways and some scaled-down subway or elevated rail systems). Where necessary, practicioners may refer to these variants as MCT(B) and MCT(A) respectively, reflecting the right-of-way arrangements; note that MCT(C) (i.e. mixed-traffic operation) would be a contradiction, except for very short distances.

Table 1: Comparison of MCT and adjacent transit tiers

Service type	Local Transit	Medium Capacity Transit	Mass Transit
Vehicle type	Traditional on-road services – typically street buses or trams (streetcars)	BRT and LRT; also includes OBahn, Translohr and Trackless Trams	Train (heavy rail) and Metro services
Typical average operating speed	15 to 20 km/h	25 to 30 km/h	35 to 45 km/h
Typical trip time, door-to-door	Up to 20 minutes	15 to 35 minutes	30 to 50 minutes

Travel time is used as the key metric rather than distance, because when people compare transit methods for a particular trip they generally consider time (and to a lesser extent cost) to be more important than distance (Wang *et al.* 2014). This is in addition to trips of a given length requiring provision of certain amentites to provide a comfortable trip. In the case of Local through Mass Transit tiers this usually means the ratio of standing to seated passengers and the provision or otherwise of at-stop/station facilities. Longer travel time brackets can require onboard catering, lavatories and for extreme durations sleeping berths.

The idea of individual travel time budgets dates back to at least 1934 (Mumford, p.272, citing Russel), and is consistently reflected in international studies over the last fifty years – for instance, Zahavi (1974), Metz (2004) and Ellison & Greaves (2011); it can be observed by average travel times for specific journey types being relatively consistent over many decades, while distance and speed of travel have both generally increased. For instance, Marchetti's Constant indicates that commute time averaged across a population will generally be around 30-35 minutes, each way, door-to-door, across a whole society – although that does not necessarily hold true within demographic subsets, i.e. age or income brackets.

Notably, this time bracket includes about a third of all trips made to and from paid employment (HILDA 2012 & BITRE 2016), at least in the pre-Covid-19 environment. However, passengers making trips of other lengths, whether longer or shorter, can and will make use of MCT services if convenient.

Not all of the travel time budget is assumed to be spent on the single BRT/LRT service — other factors that need to be accounted for include use of one or perhaps two other connecting services, active travel to and from the station/s, waiting and interchange time.

To best cater for this specific slice of the total transit market, the best-run MCT systems take on a range of physical and service characteristics – for instance, segregated running to provide a higher average speed than mixed traffic operation, and more reliable services. The most important elements are highlighted in section 3.5, while section 3.6 indicates aspects of other tiers that would negatively impact an MCT-tier service.

There are of course exceptions. For example, in most cities there are at least some on-street, local or feeder-tier bus routes accommodate trip times well in excess of the above suggested 15-20 minutes, at the expense of a positive passenger experience. Note also that multi-modal public transport trips often involve use of a combination of, and transfers between, the modes in these and potentially other tiers (as referenced at the end of Chapter 7).

3.2 Scope and definitions

This guidance uses these terms:

- “Bus” and “Light rail vehicle (LRV)” to refer to vehicle types used in BRT and LRT
- “BRT service” and “LRT service” to refer to their respective service and fixed infrastructure of BRT and LRT (see section 3.5 for the defining features of LRT and BRT services)
- “Street bus services” and “Tram (streetcar)” services to refer to the services and fixed infrastructure of more traditional bus and tram services (see 3.6 for a discussion of what is not BRT/LRT).

Included in the scope of this work are BRT/LRT options that display a range of variations *within the right-of-way*. Examples include, but are not limited to:

- Grade separated BRT or LRT
- BRT or LRT adjacent to roads with some traffic interaction
- Painted bus lanes with well-designed signal priority, segregation from other traffic and substantial stations
- A bus service in a BRT/busway spine, with branches that run on public roads.
- LRV (and/or trams) with dedicated right-of-way for the majority (but not all) of the route

As a rule of thumb only, about half of all passengers on a BRT/LRT service can expect to have a seat for their trip, down to perhaps a quarter during peaks depending on specific vehicle layouts. Most BRT/LRT services operate at an average speed in each direction of between 25-30 km/h, including stops (Douglas & Cockburn 2019, pp35-42). Note this is distinct from averaging the speed of the peak and counterpeak services, if the former runs express or on dedicated infrastructure and the latter is in mixed traffic.

Outside the scope of this work are:

- Services that run almost exclusively in mixed-traffic conditions (rather than dedicated rights-of-way), sharing road space with cars and other vehicles. This includes traditional trams (streetcars) and street buses without sufficient dedicated infrastructure, the latter often erroneously termed “BRT-Lite” (Levine et al. 2018, p.28; Kühn 2002, p.2).
- Other services promoted as BRT or LRT but with most features stripped out, up to and including the exclusive right-of-way, e.g. beyond the South Boston Piers Transitway (tunnel) as seen in Boston’s Silver Line (Weinstock et al. 2011), and highlighted in Paget-Seekins & Munoz (2016).
- Heavy rail, metro and subway systems: These systems typically feature larger, wider, heavier and longer vehicles or consists than MCT systems, providing increased capacity but also increased cost.

- Technology packages that, by definition, require an entirely segregated right-of-way (Vuchic's Category A), for instance traditional monorails which use a thick track beam that could not reasonably be built into a level crossing.
- Freight transport systems that happen to share BRT/LRT infrastructure (i.e. Dresden freight trams, per Metro Report 2017).

For a relatively straightforward test of whether or not a route or service counts as BRT/LRT, consider the guidelines provided in the Institute for Transportation and Development Policy (ITDP)'s "The BRT Standard"; chapter "The BRT Basics" (pp. 26-37 in version 7.75). More detail on features that are mutually exclusive to the categorisation of BRT/LRT can be found in Section 3.5.

Finally, this paper does not specifically consider questions of power supply (i.e. onboard combustion engine vs battery vs overhead power supply) or autonomus operation systems (such as driverless buses or trains operating in a mixed-traffic environment), because these technology packages are still in flux (at time of writing). A future edition of the paper may well have these sections added, as detail on costs, benefits, practicality and applicability becomes available.

3.3 Other methods of providing Medium Capacity Transit

While this document focuses on BRT and LRT, practicioners are reminded that there are other vehicle classes capable of providing MCT services. These generally take aspects of BRT and LRT technologies and combine them to create a composite mode, for instance the Trackless Trams (TTS) and Translohr systems. While a detailed analysis of those systems is outside the scope of this document, the following provides a brief overview of both technologies:

- Trackless Trams (TTS) combine the asphalt or concrete road surface of bus systems with the articulation and bogie systems of LRVs, to provide a hybrid vehicle borrowing from both families. The combined package is effectively an upgraded electric, articulated and potentially driverless bus, using tyres for suspension and traction on gradients while borrowing LRV's concepts of articulated bogies to improve ride quality, the ability to operate in both directions instead of needing a turning loop, and a fixed operating route. As such, the system has improved comfort over normal bus technology and theoretically improved route flexibility over tram technology, but lack of compatibility with existing systems and infrastructrue may be limiting in a wider context.
- Translohr and Guided Light Transit are primarily European systems of articulated trolleybus. The main difference is that instead of using two overhead wires it uses only one above, with electrical return via a central ground-level rail; contact is made either via a single central wheel using flanges on both sides of the railhead, or two wheels offset at an angle to clamp either side of the central rail. Like trolleybuses and trackless trams these have the advantages of traction and intrinsic suspension of road tyres, but the central power rail can force vehicles to follow the exact same path on every trip leading to rutts in the roadway over time. If the roadway isn't resurfaced regularly enough, these rutts can become deep enough to reduce the height between the return contact rail and the undercarriage, risking damage to both.

This guidance seeks to provide practicioners with a practical approach to determining the best transit solution for a specific network demand, based on existing and widely-utilised BRT and LRT technologies. However, Trackless Trams, Translohr and Guided Light Transit, and any other MCT options that arise post-publication, may be worth considering for specific applications depending on the particular alignment and demand profile of a given route, as well as how that route is expected to interact with existing services in the same region.

3.4 BRT and LRT development in Australia

A review of the last ten years (2010-2020) of major transport projects across Australia and New Zealand shows that a range of both BRT and LRT projects have been completed, are under construction or are proposed. These are summarised in Table 2 and Table 3; the tables are illustrative only, not comprehensive, and make no comment as to the success or otherwise of each project or concept.

These tables demonstrate that both BRT and LRT have been, and remain, popular choices for jurisdictions across Australia and New Zealand. Overall, more LRT than BRT projects are proposed, although in practice about the same number of projects are actually delivered (noting size and scale vary considerably between projects).

Table 2: Recent examples of **under-construction** and **completed** LRT and BRT (sorted alphabetically)

Location	Type	History
Adelaide, SA (O-Bahn)	BRT	City extension constructed 2017
Adelaide, SA	LRT	Extension to Adelaide Entertainment Centre completed 2010 Extensions along North Terrace and King William Road completed 2018.
Brisbane Metro, QLD	BRT	Upgrade of existing BRT system, scheduled for completion 2023
Canberra, ACT	LRT	Stage 1 completed 2019 Stage 2a and 2b approved for construction
Eastern Busway, Auckland, NZ	BRT	Panmure to Botany completed 2020 Panmure to Pakuranga scheduled to open 2026
Eastern Busway, Brisbane, QLD	BRT	Extension to Main Avenue completed 2011
Gold Coast, QLD (G:Link)	LRT	Stage 1 completed 2014, Stage 2 completed 2017
Newcastle, NSW	LRT	Completed 2019
Northern Busway, Auckland, NZ	BRT	Extension to Albany scheduled to open 2021
Northern Busway, Brisbane, QLD	BRT	Extension to Kedron completed 2012
Parramatta, NSW	LRT	Stage 1 scheduled for completion 2023
SouthEast Busway, Brisbane, QLD	BRT	Extension to Rochedale completed 2014
Sydney, NSW	LRT	L1 Lilyfield-Dulwich Hill extension completed 2014 L2+3 CBD & South East completed 2020

Table 3: Recent examples of **proposed** LRT and BRT (sorted alphabetically)

Location	Type	History
Auckland, NZ – Airport to CBD	LRT	Originally proposed 2015, postponed 2020.
Auckland, NZ – Northern Busway	BRT	Extension to Silverdale proposed 2008 and again in 2013 (Etheridge 2013).
Darwin, NT	LRT	2014 masterplan proposed inclusion of light rail
Gold Coast, QLD and Tweed Heads, NSW	LRT	Stage 3 extension of GoldLinQ from Broadbeach South to Burleigh Heads planning underway; Stage 4 extension to Tweed Heads (over QLD-NSW border) business case being developed at time of writing.
Hobart, TAS - Riverline	LRT	Originally proposed 2009, feasibility study discarded project in 2014 (discussions ongoing)
Melbourne, VIC - Caulfield to Rowville	LRT	Proposed 2018, no schedule for completion.
Melbourne, VIC - Doncaster Busway	BRT	Market led proposal proposed in 2017, refused.
Perth, WA – Metro Area Express	LRT	Originally proposed 2010, abandoned in 2016.
Perth, WA – Trackless Tram between Scarborough Beach and Glendalouh station	BRT	Study underway as of 2020
Rockingham, WA	LRT	Postponed 2012.
Sunshine Coast, QLD - Maroochydore to Caloundra	LRT or BRT	Strategic Assessment approved 2019, Options Analysis underway at time of writing.
Wellington, NZ	LRT	Proposed most recently in 2019, no progress as of 2021.

3.5 Essential and desirable elements of all BRT/LRT systems

There are several essential and desireable elements required for BRT and LRT. Each of these assists the service in attracting patronage within the target market of door-to-door trips between 15 and 35 minutes each way. While some items may appear to be optional, the impact they have on operations should not be understated. It is therefore recommended that initial route concepts include all of these features, and removal of any one or more be considered in terms of cost-saving against reduced patronage potential. This list (see below) is adapted from the ITDP’s BRT Standard (2016), primarily the “Basics” chapter. Practitioners are encouraged to consider the weightings of various elements in that source, and adapt the phrasing but retain the content to adapt the document for other MCT applications (i.e. “railway” in lieu of “pavement” quality, but still worth two points).

Critical elements that must be in place for a route portion to qualify as BRT/LRT include:

- Dedicated Right-of-Way (ROW): This is vital to ensuring that vehicles can move quickly and unimpeded by congestion. The ROW can run within or parallel to an existing transport corridor, or on an independent alignment. Vuchic (2007, p47) refers to this arrangement as Category B (longitudinally physically separated); Walker (2012, p100) clarifies that this means vehicles should only encounter external delays at stations and intersections/junctions, rather than at all points along the path.
  - Physical design is critical to the self-enforcement of the right-of-way. Dedicated lanes matter the most in heavily congested areas where it is harder to take a lane away from mixed traffic to dedicate it as a busway.

  - Enforcement of the dedicated alignment is different from post-hoc enforcement i.e. via cameras to fine offenders. It is far more effective for the transit route to simply be unaccessible except to certain vehicles. A ballasted tramway alignment down the median of a road practically forbids use by unauthorised vehicles, and similarly, the Adelaide O-Bahn is fitted with sump-busters that attack the oil sump of a vehicle that wrongly enters the alignment. Mechanical bollards may be worth considering provided that their operation does not unduly constrain the service frequency or speed.
  - The path must be dedicated to these transit vehicles, with no routine access by general traffic, cyclists, or pedestrians.
  - Emergency vehicle access may be provided at least for paved-roadway infrastructure types, though whether or not this is a routine use depends on constraints outside the scope of this paper, and such use must not regularly interrupt services.
  - ITDP (2016) recommends that a BRT alignment be placed down the median of a roadway rather than along one side or by the kerbs, as this minimises conflicts with other traffic types; this also opens the opportunity for reverse-running relative to normal traffic, permitting the use of island platforms. Similarly, placing LRT down a central corridor ensures relatively simple turnback arrangements at terminal stations, avoiding or at least minimising conflicts with other traffic.
- Intersection treatments: To provide reasonable service speed and reliability it is recommended that external vehicles turning across the dedicated ROW be forbidden, preferably by provision of an intermediate kerb or other physical obstruction.
  - Forbidding turns across the ROW is demonstrably the most effective method of reducing external impacts on BRT/LRT service reliability. This includes the banning of turning traffic occupying and blocking the transit lane at intersections, as seen with Melbourne's use of hook turns and more generally with bus-only queue-jump lanes.
  - Lower-frequency systems can derive significant benefit from intersection priority systems. Experience on the Gold Coast indicates that this works up to around 10 services per hour each way before the impact on cross traffic builds up. In Melbourne's centre the same sort of threshold tends to apply – intersecting roads can handle up to around 30-40 services per hour each way (longer LRVs means fewer total services and higher net capacity), but those services depart each stop in groups of 2-4 vehicles at a time to reduce the number of traffic light cycles required and impact to other road users. These systems can range from approach-cleared traffic light cycles to boom barriers or gates, depending largely on safety aspects (primarily Overlap, i.e. emergency stopping distance, and Line of Sight, related to reaction time) and what intersecting road users are most likely to expect.
  - BRT/LRT may make use of a Category A ROW (Vuchic 2007 p47), particularly in inner city environments, but this is not a critical component except where required due to service frequency and impacts on cross-flow traffic, or where BRT/LRT vehicle speeds approaching intersections would create excessive risk profiles. Generally speaking, Category B will be sufficient for reliable operation.
  - Intersections and entry/exit ramps or junctions along the right-of-way should be designed to allow transit vehicles to easily enter and exit the dedicated MCT alignment, in order to provide single-vehicle journeys (i.e. trips with fewer interchanges) to as many passengers as possible, balanced against the need to customise vehicle layouts for comfort levels.
- Station or Stop design: To operate efficiently and competitively BRT/LRT must focus on minimising whole-of-journey times, in every aspect, including at and near stations/stops. This means:
  - Minimising vehicle dwell time, by permitting passengers to enter and exit the vehicles at all doors.

  - Have level platforms at the same height as the floor of the vehicles, avoiding both time spent by the vehicle leaning in to the station and/or passengers slowing down on entering/exiting the vehicle due to the risk of tripping – this is especially important for elderly or mobility-impaired passengers, prams, suitcases and luggage, but the impact is notable across all passenger types. ITDP (2016) recommends a maximum horizontal gap of less than 100mm and vertical gap of less than 15mm, but practicioners are reminded that local disability accessibility legislation could require finer tolerances. The use of mechanical deployable systems attached to the vehicle or platform can be considered in extreme circumstances, but is likely to come with a time and reliability penalty.
  - Off-vehicle ticketing is one the most important factors in minimising dwell time, therefore reducing travel time, increasing the potential customer base and improving the passenger experience. This can be done with barriers at the station platforms, separating the paid and unpaid zones. Validation onboard the vehicle, either electronic or by inspectors, risks causing too many delays especially at locations where following vehicles cannot overtake.
  - The BRT Standard v7.75 (ITDP 2016, p.53) recommends that stations be spaced at between 300m and 800m intervals (with a target of 450m), to balance walking distance to/from stations against operating speeds.
  - Unobstructed and clear passenger walkways, keeping inbound and outbound flows separate. Access pathways need to be considered including interchange to/from other modes and walking and cycling time to and from the station, rather than only considering the top speed of the vehicle. This is likely to require footpath upgrades and associated infrastructure (i.e. pedestrian crossings at regular intervals along main roads) to maximise the 10-minute walking time pedshed around each station.
- The frequency of BRT/LRT services is a critical element in minimising wait time at stops. Therefore, high-frequency services are necessary, spanning significant hours of the day (e.g. from early morning right through to late at night), including on weekends.

3.6 What is not BRT/LRT

3.6.1 Local and Feeder tier services

Street bus services, on-road bus lanes

As discussed earlier, street bus services operating in mixed traffic (Vuchic's Category C ROW) do not meet the definition for BRT, even if the service levels and buses are consistent with other BRT characteristics. This includes cases where extensive on-road bus lanes are provided. While bus lanes provide some priority to buses, these do not function as a dedicated running way due to many legitimate and de facto uses of the bus lane by other modes.

These include:

- Vehicles crossing the bus lane to enter or exit driveways or side streets, including driving on and stopping in the bus lane waiting for a gap in traffic.
- Cyclists, motorcyclists, scooters and other personal vehicles using the bus lane, which is allowed in most jurisdictions, and often required by 'keep left where possible' road rules.
- Traffic queues at intersections blocking or queuing along the bus lane, especially for left turn movements.
- Stopping in the bus lane for breakdowns, or by emergency services.

- De facto stopping in the bus lane for loading and unloading trucks, couriers, food delivery services, taxis and private vehicles collecting and dropping of passengers. While this stopping activity is prohibited in bus lanes, it can become prevalent where there are a lack of formal alternatives, especially in urban centre environments.
- Temporary or emergency blocking of the bus lane for roadworks, signage, construction works and footpath diversions.

For cases of on-road kerbside or median bus lanes to be classified as being equivalent to BRT would require specific circumstances of physical design, road rules and enforcement to prevent the types of interference discussed above.

However, a physically segregated bus lane on a limited access road without driveways and side streets, where no-stopping rules are strongly enforced, and where cyclists were accommodated in a separate lane, could meet the dedicated running way definition of BRT.

Tram (streetcar) services

- Similarly, tram tracks running in the centre lanes of a road usually do not meet the dedicated running way definition of LRT, particularly where the lanes are shared by general traffic running along the corridor, or where right-turning traffic queues cross the tram tracks.
- Trams with tracks physically separated from traffic lanes (either by a median or being raised above the surface of the road) may be defined as LRT if they have the appropriate service levels and vehicle characteristics.
- Notably, this means that Sydney’s George Street, Melbourne’s Bourke Street and Adelaide’s Moseley Square (Glenelg) pedestrianised tramlines do not qualify as light rail in their own right, because vehicle speeds are constrained by conflicting pedestrian movements. However, from a whole-of-corridor persepective these sections are not long enough to significantly penalise the average speed of the whole route, and therefore these may still be considered parts of a wider LRT system.

With that said, a route needs to be considered as a whole; if parts of the route meet the standard and others do not, then a weighted average qualification could be considered measured by route-KM or typical travel time.

As per Chapter 7, Local and Feeder tier services may be addressed in more detail in a future ATAP publication.

3.6.2 Metro tier services

Just as MCT has a lower threshold beyond which the service is classified as Local or Feeder, there is also an upper threshold. As noted in Section 3.1 and Appendix A, the primary qualifier is which bracket of the passenger trip-time (door-to-door) market that the service is intended for. This is expressed in many ways, but the most visible factors are:

- Vehicles – degree of comfort, i.e. seated to standing passenger ratios
- Service levels – frequency of service, particularly in peak hours
- Infrastructure – degree of necessary separation from conflicting traffic flows, i.e. traffic light phase control vs full grade separation.

Service frequency tends to be inversely related to maximum speed, as faster vehicles will need more space to safely brake before an obstruction or the previous vehicle. For this reason, Metro-tier services almost always require full segregation from all conflicting traffic and pedestrian movements (Vuchic's Category A), contrasting with BRT/LRT services where intersection priority will usually suffice for most (not all) potential intersections on a given route.

Notably, because this absolute segregation from potentially conflicting traffic makes it much easier to apply autonomus vehicle technology in the Metro tier than in the MCT tier; the operating environment can be fully sealed either way, but the higher patronage makes the additional cost (at time of writing) easier to justify.

Metro-tier services compensate for this by using longer vehicles than a BRT/LRT would use, i.e. multi-articulated buses or train sets comprised of multiple carriages, so the lower maximum frequency will still provide a higher net hourly capacity.

As per Chapter 7, Metro tier services may be addressed in more detail in a future ATAP publication.

3.7 Similarities between BRT and LRT, as types of MCT

BRT and LRT are similar in many characteristics of design and operations. For a given service to qualify as BRT or LRT, it must rank highly on the following primary metrics (adapted from the BRT Standard (ITDP 2016) Basics category:

- Both run in a dedicated right-of-way, either Category A or B as required by frequency, for the vast majority of route length, with minimal allowance for Category C (mixed traffic) operation.
- Net passenger capacity over a time period, i.e. hourly or in a specific peak period;
- Comfort levels, relative to expected time-in-vehicle per passenger, and
- Average trip time, including stops

BRT and LRT both seek to provide a transport solution for medium to high density populated urban areas, and therefore are almost always constructed in brownfield conditions. They are usually targeted at trunk routes on higher demand corridors where:

- Existing on-road public transport options (including street bus and/or tram) that share road space with cars and trucks are insufficient, on measures of either or both of performance and capacity; but
- Very high performance and capacity systems, i.e. heavy rail and metro options, would provide more capacity than necessary in the forseeable future, with poor return on investment (in terms of benefits compared to both capital and operating costs).

3.8 Differences between BRT and LRT, as types of MCT

While there are similarities between BRT and LRT services, there are also fundamental differences that can influence the preferred mode for a specific application, and can create a series of benefits and/or constraints for each mode depending on the specific application. Table 4 discusses these differences, as they apply to vehicles, route, service and station designs, although many of the elements apply to more than one of these categories. Note that the table only represents practical issues that can influence BRT vs LRT technology selection. Refer to Section 4.13.1 for a discussion on the perception elements, and section 4.13.1 for issues around access for mobility devices.

Table 4: Comparison of characteristics

Element	BRT (using buses on asphalt/concrete)	LRT (using LRVs on rails)
Vehicle designs	BRT can use either standard or specialised buses, the latter with design features such as high capacity interior layouts, wider doors and level floors. However, buses generally have less internal space than LRVs for a given set of external dimensions, due to the need to incorporate steering systems and the engine.	Rail tracks provide route guidance, so the underfloor steering mechanism of buses is not required and this can give more space inside each vehicle. This also allows for more doors per side, which can reduce dwell time at stations. Rail operation also makes it easier to design longer, multi-section articulated vehicles.
Vehicle size and capacity	Vehicles are relatively standard and cheaper to obtain. Less capacity per maximum-length vehicle than a maximum-length LRV. Most buses on BRT systems have maximum lengths and widths because they operate on routes beyond the end of the dedicated infrastructure. However, even specialist BRT buses are limited in overall length and passenger capacity by the need to be steered; this is a critical consideration for articulated vehicles. Double deck buses are an option, although attention must be paid to dwell times at stops. BRT systems require higher frequency services than LRT to provide equivalent capacity, which can lead to large-footprint stations and complex grade-separated intersections rather than relying on level crossings or priority at traffic signal intersections.	Vehicles can be provided by a range of suppliers, but factors like loading gauge, power supply method and voltage and curves and gradients of the route need to be considered. Vehicles can be longer and therefore have higher capacity than BRT systems because the guidance provided by rails reduces potential flexing between articulated sections. However, vehicle length and performance characteristics may be limited if parts of a route operate in mixed traffic beyond the extent of the dedicated infrastructure. LRT can deliver high capacity at moderately high frequencies. This allows high passenger volumes in a compact twin-track corridor with inline stations and at-grade crossings, or very high capacity in a grade-separated corridor.
Service capacity	At moderate demand levels, BRT can operate with similar headways to LRT while better matching vehicle size to demand, including the ability to use inline stops. However, at high demand levels BRT requires offline stations with passing bays or double lanes to stop multiple buses simultaneously, and signal pre-emption systems may cease to function with high frequencies through at-grade intersections. Where MCT is earmarked for an existing street or corridor with a constrained width available for lanes and platforms, the capacity limit of BRT will be reached before that of LRT.	At low to moderate demand levels, LRT headways may be determined by minimum service standards intended to avoid lengthy wait times, rather than capacity requirements. This may result in poor utilisation of vehicle capacity and high operating costs per passenger. LRT can deliver high capacity at moderate headways, allowing high capacity while using inline platforms and retaining functional signal priority at at-grade crossings.
Stopping patterns	A variety of stopping patterns can be used where appropriate, as express, limited stops and all-stops services can pass each other at stations with overtaking lanes.	Generally limited to a stopping-all-stations operating pattern, as vehicles cannot overtake one another. Overtaking lanes at stations, or passing loops between them, are possible but expensive and require signalling and interlocking systems to work safely; this imposes an artificial cap on maximum service frequency.
Number of routes	Far more routes can be accommodated, because of the ability to spread out among the pre-existing road network.	Fewer routes (because each branching route needs its own infrastructure), but higher capacity on each.
Power supply and traction	Most BRT systems use diesel buses with onboard engines and fuel tanks, creating higher noise and introducing vibration and tailpipe emissions.	LRT is traditionally powered electrically through a single overhead wire and a ground return through steel wheels and rails. Some systems use onboard batteries or a ground-level power supply using a third rail, particularly where overhead wires would reduce local amenity.

Element	BRT (using buses on asphalt/concrete)	LRT (using LRVs on rails)
	Nonetheless, some older BRT systems use fully electric trolleybuses, with the downside of a more complex, visually intrusive and less reliable double overhead line, while newer systems may use battery-electric and hydrogen fuel cell buses instead. As a result, the distinction of motive power methods is becoming less critical with time.	Electric power allows for low noise and vibration, and zero local emissions.
Customer perception	Buses are seen by some as the poorer class of public transport; this is a short-term effect that evaporates as newer, better services are introduced.	Modern LRVs generally have a better public perception than standard buses, and that bleeds over to perception of BRT in cities where no respectable BRT service currently exists. Refer page 39.
Customer experience	Ride quality is impacted by onboard internal combustion engine and pavement quality. The Trackless Tram claims to overcome this problem by using bogie suspension systems similar to tram technology, but the degree to which this impacts ride quality is not yet clear. Fewer standing passengers reduces net vehicle capacity, but more passengers tend to have a seat as a proportion of the total. Depending on the alignment quality this could have either a positive or negative impact on the user.	Ride quality is usually above a minimum threshold because of the cost and disruption that a derailment would cause. As a result, the lower bound for track quality is probably higher than for pavement quality. A side effect is that more passengers may be willing to stand for the length of their trip, depending on the rate and frequency of sharp decelerations.
Fleet size and operating costs	More vehicles required to match the absolute capacity available to an LRT system, if that is even possible. Such attempts add to incremental costs and expenses associated with more drivers and maintenance staff being employed. This results in greater frequency, and a higher chance of the minimum frequency being above the Turn Up And Go (TUAG) threshold.	Larger vehicles could mean emptier services outside of peak hours, while providing a minimum service frequency. At higher frequencies TUAG is also more likely for LRT. Note that as per Figure 2, below a certain service frequency, passenger behaviour changes from random arrivals at the transit stop/station (i.e. turn up and go) to planned arrivals, attempting to minimise waiting time.
Reliability	With more buses joining and exiting the busway at various points, and lots of buses at the stations, there are more opportunities for delays and variability to be introduced. However, larger fleet means fewer spares are needed, proportionally.	With just one or two services using the line for large distances, and inline stops, services are very reliable. Because overtaking is difficult or impossible, a failure can block large sections of the route.
Boarding experience and access	Guided bus systems may not be provided through stations. In that case the gap between the vehicle and platform could vary.	While no LRVs are known to exist with lean-to-kerb functions, this might be possible as long as there is no risk of pantographs being tangled in the overhead wires.
Intersection timing and light cycles	Shorter vehicles theoretically mean that each vehicle occupies an intersection for less time, though this will rarely be significant. Depending on space available, there may be an opportunity for BRT lanes bifurcating on approach to intersections, allowing parallel queueing of vehicles which re-merge at the far side. However, at high frequencies bunching of services is essentially guaranteed.	Longer vehicles can have a greater impact on traffic light cycle timing, limiting the practicality of approach-cleared signal priority. In the Gold Coast the limit appears to be roughly one vehicle each way every 6 minutes. Notably, level crossings on heavy rail networks do not have this limit – they simply interrupt the traffic flow as required, and force adjacent intersections to handle the resulting congestion. This is very much a last resort only.

Element	BRT (using buses on asphalt/concrete)	LRT (using LRVs on rails)
Intersection layout and signal priority	Depending on signal cycles, a group of vehicles could depart in sequence and 'zipper' apart at the appropriate location; the same may apply where multiple routes converge, though at lower speeds.	Junctions should include some form of interlocking to make sure that the points/switches are set and locked for an approaching vehicle, for a length in advance of every LRV equal to the vehicle's emergency stopping distance from its maximum authorised speed (plus an allowance for overspeed) at that location. This length is called the Overlap and is used to avoid derailments and conflicting movements. If multiple vehicles are (or may in the future) be coupled and operated as a single service then platforms and traffic signal cycles must take this into account.
Vehicle detection for intersection control purposes	Easy to provide via in-road vehicle detection, using whatever system is preferred by the local road authority.	Vehicle detection loops may work; alternatively axle counting or track circuit technology can be investigated, depending on interactions with tractive power supply, or a balise-type system.
Alignment, grades and curves	Individual classes of buses may have different constraints for curves and graidents, largely tied to the tractive power available and the flexibility of any articulated sections; but these limits are likely to be far more lenient than any comparable LRT option. Unguided bus alignments tend to be wider than LRT alignments to allow for individual driver and vehicle characteristics; even a mechanically guided busway will be wider than an equivalent LRT, although this may not apply to optical guidance. Where width is a problem, peak-direction-only operation may be considered with counterpeak traffic via normal roadways but this leads to average travel time penalties, halving the overall benefit of the service. This is less of a problem for express busways outside the MCT tier if they have very heavy peak-direction flow and low counterpeak flow.	Curve radius and gradients over hills need to be considered at the design phase, including future-proofing for likely extensions. Note that while these restrictions are nowhere near as impactful as heavy rail, they are generally still more constraining than the design requirements for a BRT route. Use of any track gauge other than 1,435mm restricts supply to far fewer manufacturers and designs. Tracks must be laid everywhere the LRT is expected to operate, vs BRT where buses can operate in an Open environment beyond the limits of the dedicated infrastructure.
Stations and terminals	All buses commonly available for the Australian market are single ended, with doors on the curb side only. While some specialist BRT models can be delivered with doors on both sides (at the cost of in-vehicle capacity), double ended buses are not in service anywhere in the world. Automonus vehicles would make this factor a moot point, provided that passengers are comfortable travelling facing in both directions. Although vehicles are low cost and readily available, this means that BRT stations are generally constrained to having curb side platforms only, which can complicate stop and lane design in existing road corridors (island platforms are possible but complicated to provide, as seen on the Sydney M2 between Windsor Road and Epping).	Typical LRVs are double ended with doors on both sides (while many single ended and single sided vehicle models exist, these are primarily intended for legacy systems with historical network constraints). This allows LRT stations to have either side or central platforms depending on the context of each stop, provided that passenger and pedestrian flows in the area can be reasonably managed without congestion impacting safety or reliability of the LRT service. Furthermore, the ability for LRVs to operate in both directions avoids the need for a separate route to turn the vehicles around at the end of the line (provided that arriving and departing vehicles do not block each other), while using high capacity vehicles running at relatively broad headways can avoid the need to leave the passenger platform to undertake timekeeping and layover stops.

Element	BRT (using buses on asphalt/concrete)	LRT (using LRVs on rails)
	Furthermore, the need to turn buses at the end of each run means that BRT lines must include a pathway to circulate and reposition for a return run, as well as space for multiple buses to undertake timekeeping and layover stops simultaneously. This is usually not a problem at lower bus volumes, or on BRT corridors where all bus routes spread out to the surrounding road network at either end, but with high volumes a BRT end-of-line station can require a very large footprint with dozens of passenger and layover bays across multiple platforms and complex pedestrian and vehicle circulation paths between them	In practice, a moderate to high demand LRT corridor can accommodate all its terminal functions in the footprint of a standard twin-track station in the road corridor. If more capacity is needed there are a few options available, including addition of sidings beyond the terminal for shunting and storage, a third track and platform and/or platforms on both sides of each track (the “Spanish Solution”) to separate flows of passengers entering and exiting the vehicle (Smiler 2018).
Dwell time (at stations)	Most cities’ fare policies encourage or require passengers to only board buses at the front door, and on-board fare collection. This is not necessary on a BRT but may require education programs and additional signage to minimise dwell times.	All-door boarding is the societal norm. Off-board fare collection may be easier to introduce if parallels to heavy rail systems are encouraged through marketing.
Stop layout	Stop design can be more flexible, but more platforms or bays will be needed for a given number of passengers per hour because vehicles have less total capacity. Also, overtaking lanes must be provided so that a vehicle stopped in the first bay at a station doesn’t delay following services.	More likely to have doors both sides allowing island and Spanish Solution platforms. However, if multiple parallel platforms are used, vehicles must not be allowed to approach at speed until the previous vehicle passes the junction, the track is released, changed, re-locked and detected as locked; then there is the additional time and distance (“overlap”) equal to braking length, before the next vehicle can pass over that location.
Station size	Potentially large stations because the large number of services using the busway requires more stopping bays/platforms (longer) as well as parallel platforms or passing lanes (wider).	Smaller and shorter stations are normal, both due to island platforms being more common and higher capacity per vehicle. Smaller stations require less land acquisition and construction costs, and provide for improved urban integration. However, active provision for longer platforms should be included at the design stage, to permit coupling of vehicles.
Depot design	Generally needs less space because buses have smaller turning circles, so access to each parking space or facility within the depot can be done more compactly. Vehicles can also be packed more tightly if they only have doors on one side.	Depot will need to be longer to accommodate the yard throat trackwork (where one track splits into multiples), although a traverser might speed this up. Underfloor vehicle maintenance is made easier with pits between the rails allowing staff to safely walk under the LRV, and bidirectional LRVs can enter and exit the depot from one end instead of needing a separate entrance/exit or the ability to turn around.

3.9 Vehicle specifications

A range of vehicles exist within the BRT and LRT categories. Table 5 and Table 6: provide a summary of vehicle types to provide practitioners with an indicaton of the range of vehicles by specification available.

Practitioners are reminded that vehicles with onboard fuel or power storage can have a limtied range between refuelling/recharging. Therefore when selecting a vehicle class and power supply type it is necessary to consider the typical trip lengths and range available, taking into account terrain and stop spacing.

Table 5: Specifications of typical BRT-capable buses

Class	Standard "large" bus	Standard "extra-large" bus	Special "extra-large" bus	Double-deck bus	Single articulated bus	Double articulated bus	ART 'trackless tram'
Vehicle Configuration	Single section rigid bus	Single section long rigid bus	Single section long rigid bus	Single-section double-deck rigid bus	Two section articulated bus	Three section double-articulated bus	Three section rail-chassis double-ended road vehicle
Number of Axles	Two axles	Three (dual rear axles)	Three	Three	Three (two front section, one rear section, rear steer)	Four (two front section, one mid section, one rear section, rear steer)	Six (two bogies per section)
Length	11.3m	13.5m or 14.5m (tag-steer)		12.8m (4.1m tall)	18.6m	23.8m	31.6m
Weight (incl. pax @ 75kg ea.)	17 tonnes (13 tonnes curb weight + 4 ton passenger weight)	23 tonnes (18 tonnes curb weight + 5 ton passenger weight)	24 tonnes (18 tonnes curb weight + 6 ton passenger weight)	26 tonnes (19 tonnes curb weight + 6 tonnes passenger weight)	27 tonnes (18.5 ton curb weight + 8.5 ton passenger weight)	34.5 tonnes (24 ton curb weight + 10.5 ton passenger weight)	51 tonnes max laden weight (operator specification)
Example Model	ADL Enviro 200	Scania K2	Scania K2	ADL Enviro 500	VanHool Exquicity 18	VanHool Exquicity 24	CRRC ART

Class	Standard "large" bus	Standard "extra-large" bus	Special "extra-large" bus	Double-deck bus	Single articulated bus	Double articulated bus	ART 'trackless tram'
Door configuration	2 on kerb-side (double front, single rear).	2 on kerb-side (double front, double or single rear).	3 on kerb-side (double front, middle and rear).	2 on kerb-side (double-front, double-rear)	3 on kerb-side (double front, middle and rear).	4 on kerb-side (2x double front, 1 middle and rear).	6 each side, (2 each front, middle and rear)
Seating config.	Standard: Transverse seating maximised, standing in aisle only.		Urban: Mix of transverse and longitudinal seating. Dedicated standing areas (lower deck only for double-deck vehicle)				
Interior/ luggage	Narrow aisles, limited luggage over wheel wells.	Narrow aisles, limited luggage over wheel wells, or option with luggage rack		Narrow aisles, limited luggage over wheel whells. Stairwell occupies some passenger space,	Broad aisles/ vestibule spaces at doors. Additional floor space/luggage racks.		Broad aisles/ vestibule spaces at doors. Luggage space over wheel wells (x12)
Seating Capacity	37	49	39	85	44	61	44
Standing Capacity (4 pax/m^2)	18	18	43	18	69	78	116
Total Capacity	55	67	82	103	113	139	160
Max service speed	80 km/h						70 km/h
Platform height for level boarding	300mm to 370mm with kneeling/front flip ramp				330mm fixed		350mm fixed
Data source	NZTA requirements for urban buses				Manufacturer's specification		

Table 6: Specifications of typical LRT-capable vehicles:

Manufacturer	Bombardier		CAF	Škoda	Alstom		Siemens	
Class	**Flexity Swift**	**Flexity 2**	**Urbos 100**	**ForCity**	**Citadis**		**Combino**	
Vehicle Configuration @	3 car	7 car	3 to 9 car	2 to 5 car	3 to 9 car		3 to 7 car	
Example Model	Melbourne E Class	G:Link	Newcastle, NSW	Alpha 15T, Prague	Melbourne C2 class (302)	Sydney 305	Melbourne D2 class	Potsam Avenio M
Wheel arrangement^	B’B’2’B	B’B’2’B	Bo’2’Bo	Bo’2’2’Bo	B’2’B	Bo’2’Bo	Bo’2’Bo	Bo’2’2’Bo
Length	33.5m	43.5m	33.0m	31.4m	32.5m	33.5m#	29.85m	41.63m
Width	2.65m	2.65m	2.65m	2.46m	2.65m	2.65m	2.65m	2.3m
Weight (incl. pax @ 75kg ea.)	62 tonnes	60 tonnes	47 tonnes	42 tonnes	40 tonnes	TBC	35 tonnes	45 tonnes
Door config.	5 pairs double doors per side	6 pairs and 2 single doors per side	4 pairs and 2 single doors per side	6 doors per side	4 pairs and 2 single doors per side*	6 pairs per side	3 pairs and 1 single per side	6 pairs and 1 single per side
Seating configuration	Mix transverse & longitudinal	Transverse only	Mix of transverse and longitudinal seating.					
Interior/ luggage	No dedicated provision	Surfboard storage		No dedicated provision				
Seating Capacity	64	80	60	61	54	48	56	77
Standing Capacity (4 pax/m^2)	146	229	216	239	150	185	130	169
Total Capacity	210	309	276	300	204	233	186	246
Max service speed	80 km/h	70 km/h	70 km/h	80 km/h	70 km/h	80 km/h	70 km/h	70 km/h

Manufacturer	Bombardier		CAF	Škoda	Alstom		Siemens	
Class	**Flexity Swift**	**Flexity 2**	**Urbos 100**	**ForCity**	**Citadis**		**Combino**	
Platform height for level boarding	265mm	230mm	356mm	350mm	330mm		300mm	
Data source	Vicsig.net; height from ground by measure in-field	Hansard; RailExpress	Vicsig.net	Wikipedia; tdu.to/153173.msg	Vicsig.net	Engineers Australia presentation & Railway-Technology article	Vicsig.net	Manufacturer's specification

Notes:

^ *"Bo'2'Bo" means two motorised (B), individially-driven (o) axles at each end, with a set of unmotorised axles (2) in the middle.*

* *Melbourne C2 tram vehicles have the rear single door sealed permanently due to the length of certain platforms.*

Sydney Citadis 305 tram vehicles operate in semi-permanently coupled pairs; the numbers provided are for a single five-piece unit only.

@ *Unlike BRT vehicles, many LRV manufactures design their units to be extended at a later date, i.e. extending a 3-car LRV to 5, 7 or even 9 cars as patronage grows.*

4. Options generation

Options generation follows the problem or opportunity identification stage. The aim is to generate genuine options in a way that provides a meaningful comparison between options, and provides decision makers with real choices, for addressing the identified problem.

This chapter discusses the generation of BRT/LRT options. The first section provides the overall context, the second discusses the process, and the remaining sections discuss a series of key considerations that need to be considered.

4.1 Establishing genuine options

4.1.1 Mode-neutrality

The ATAP options generation process requires mode-neutrality. Some have observed that this is not always the case in practice. For example, Hensher (2016) notes community bias against BRT and favouring LRT (termed the 'rail factor').

In a study in 2015, Hensher and Mulley demonstrated community preference for LRT over BRT(Hensher, Mulley 2015). This may lead option generation processes to prefer LRT over BRT early in the process. However, as outlined in Section 4.11.1, the reported community preference may simply reflect the tendency for LRT projects to be larger in scope, with more extensive infrastructure provision and higher service frequencies. Community preference may also vary between locations and jurisdictions.

Therefore, a best practice options generation process should exclude such preconceptions, and allow an evidence-based options assessment to reveal the relative merits of BRT and LRT options for each setting and circumstance.

4.1.2 Feasible options

Whether both BRT and LRT are technically and operationally feasible options in addressing a given problem or opportunity will depend on the specific settings. Several key questions need to be considered:

- Is the improvement an extension of an existing extensive network of BRT or LRT?
- Is this a greenfields situation, where there are less restrictions in place, and therefore either BRT or LRT could be introduced?
- Are there other constraints or considerations that make either BRT or LRT not feasible? For example, necessary curves and/or gradients, or vehicle capacity?

Depending on the answers to the above, there will be circumstances where:

1. Only BRT is feasible
2. Only LRT is feasible
3. Both BRT and LRT are feasible.

The guidance provided in this chapter can assist in identifying which of these cases apply in a given situation.

A critical point is that there needs to be documentation of the rationale, with evidence, of why an option is judged to be not feasible. That is, a sound case should be made before a BRT or LRT option is excluded.

4.1.3 Comparable options

If BRT and LRT are both feasible options for addressing a given problem or opportunity, the next step is to consider whether comparable options can be generated. The conventional approach is to generate options to address the problem to a given degree. Typically, options are designed to overcome a deficient aspect of level of service by a specified amount, or to prevent the problem recurring until a future planning horizon year.

Applying this approach when BRT and LRT are alternative options for addressing a problem or opportunity, options can be designed by targeting specific service aspects in an equivalent manner:

- Equivalent transport outcomes:
  - Equivalent on passenger capacity: Compare BRT and LRT options that deliver the same passenger capacity. This could include comparing the same capacity at a peak load point at peak times (passengers per hour per direction), or a comparison of total capacity (passengers per day).
  - Equivalent on service levels: Compare BRT and LRT options that deliver the same standards of travel speed, service frequency and hours of operation, to reflect the same service offering to passengers.
- Equivalent on wider impacts and benefits:
  - Equivalent on spatial footprint / land impacts: Compare BRT and LRT options that are constrained to the same width of corridor and/or footprint of stations. This would be particularly relevant for existing corridors or roads where widening is infeasible.
  - Equivalent on benefit realisation/patronage generation: Compare BRT and LRT options that are assessed as generating the same level of patronage outcomes, or other strategic benefits such as land value uplift or property development.

4.1.4 Best-fit options

Given the range of differences between LRT and BRT, using the comparable options approach may produce a LRT or BRT option that is not feasible. For example, to deliver options of similar service capacity, the BRT option frequency may need to be significantly higher than for LRT. This may, however, create design issues for the BRT option, e.g. it may significantly expand the footprint of the BRT stops. However, if there is a footprint constraint, should the BRT option be dismissed? The preference in these guidelines is to design the BRT option as a ‘best fit’ option rather than dismiss it.

In the example, the best-fit option would consist of maximising the BRT capacity subject to not breaching the footprint constraint. The lower capacity of the BRT option compared to the LRT option would result in in-vehicle crowding problems arising in future more quickly with BRT than LRT. However, the BRT option may still perform as well as the LRT option when taken through the full options assessment process, taking all considerations into account.

As another example, an LRT option may require extended lengths of viaducts or tunnelling to compensate for gradients that a BRT route could manage, and this could constrain selection of viable station locations. Despite this, the LRT option should still be taken through the options assessment process, allowing both positive and negative effects to be accounted for.

The preference here is therefore to not exclude options on the basis of not achieving option equivalence. Instead, the best-fit option for each mode (BRT and LRT) should be designed and be allowed to progress through to the assessment process, and allow the assessment results to be the basis for choosing a preferred option.

Ensuring that best-fit options are identified facilitates a fair comparison between options, allowing the respective strengths of BRT and LRT to be best accommodated.

4.1.5 BRT as an incremental or intermediate option

One feature of BRT that is sometimes mentioned is that it facilitates conversion up to LRT at some stage in the future if that becomes necessary or desirable. The thought process behind this approach is that:

- For a given scope and quality, BRT costs less to implement than LRT
- So, in the early stages of land development of a region, BRT could meet demand at a lower cost, but that LRT may be the preferred option in future stages of land development.

In this sense, BRT can be considered an incremental or intermediate option, towards a long term solution that may eventually require conversion to LRT at some stage in future. This approach is also consistent with the concept of adopting ‘real options’ when faced with future uncertainty. With real options, the option implemented now has sufficient flexibility so that it can be varied in future when there more certainty about the future is known. In the BRT/LRT case, a lower cost BRT option could be introduced now, with the option of upgrading to LRT in future if demand growth requires it.

ATAP Part T8 provides guidance on Real Options Assessment.

In appraising the merits of scaling from BRT to LRT over time, a number of key considerations should be noted, and considered in a robust assessment:

- To date there are limited experiences around the world in doing this. A case where it occurred was Ottawa, with part of one of the lines of the Ottawa Transitway network
- Additional upfront costs may need to be incurred to build flexibility into the system to facilitate the future change
- The conversion process would have associated service disruptions to users.

4.2 The process

Chapter 2 outlined the ATAP approach to options generation. It requires that options generation consider a wide range of options for addressing the problem being addressed. ATAP F3 Chapter 2 indicates that both non-capital and capital investment options should be considered.

For this guidance, it is assumed that the initial stage of options assessment, where the wide range of options is considered, has:

- Already been undertaken
- Resulted in the preferred options being the use of either BRT or LRT in a dedicated right-of-way.

The guidance that follows here is therefore focused on generating and assessing BRT and LRT options.

The proposed steps of the process are:

1. Establish the strategic context.
2. Define the problem: What problem is being addressed, and which service would be improved. For example, the following questions should be asked at the outset; for example, is the intention to:
   - Provide a viable means of transport?
   - Improve travel times or reliability?
   - Improve accessibility, e.g. new stations?
   - Relieve service overcrowding, or provide a new corridor?
   - Relieve traffic congestion?
   - Enable development?
   - Increase network compliance with disability discrimination legislation?
3. Establish KPIs for measuring how options will impact the problem.
4. Outline known constraints, limitations including budgets and timeframes etc
5. Generate best-fit options by:
   - Identifying the corridors and stations locations to be assessed within constraints, including likely curves and gradients to be encountered.
   - Estimating the required peak and off-peak demand, as a sensitivity range for a future period.
   - Establishing the vehicle and service frequency options that deliver in the corridor, and the required corridor width, station footprints and impacts.
   - Taking into account any other constraints.
6. Estimate operating cost and capital cost for each option.
7. Consider whether staging from BRT to LRT over time is required as an option.

The process is expanded in Appendix B which provides an ATAP BRT/LRT Options Identification Checklist.

The remaining sections of this Chapter discuss the range of key considerations that practicioners will need to consider when applying the above approach.

4.3 Demands and demand growth

In option identification, consideration should be given to differences in passenger demand across time, and the potential for projected demands to grow faster or slower over time due to factors such as population growth, demographic changes, changes in travel patterns and behaviours, and increases or decreases in traffic or parking costs. Consideration should also be given to the potential for a new BRT or LRT line to stimulate land development and intensification within the catchment of the line and induce further patronage demand within the corridor.

Table 7 compares the similarities and differences of BRT and LRT specifically in response to potential demand and growth characteristics; the data could be considered a subset of the discussion provided above in Table 4.

Table 7: Comparison of BRT and LRT responses to demand patterns

Factor	Similarities	BRT	LRT
Peak and off-peak demands	BRT/LRT needs to be able to cater for not only peak-hour demands, but also for periods of lower demand such as the counter-peak, interpeak, evening and weekend demands, at any time service would be delivered.	• BRT offers more flexibility through running smaller vehicles, while allowing for capacity to be scaled up through increased frequency. • Very high peak frequencies greatly increase the peak vehicle requirement and operating costs. • BRT can have difficulties with design and operation for very high peak demands, as the number of buses can create congestion at stations and slow operations while requiring a larger footprint.	• LRT allows higher peak capacity to be scaled up the use of longer or coupled vehicles (if sufficiently long platforms are available), without the need for very high frequencies. • Designing stations with an envelope for longer platforms to be built at a later date can postpone some of the cost, and avoid construction of infrastructure that will not be immediately used. • However, such coupling/uncoupling operations should be performed in sidings or depots rather than on the mainline to avoid congestion. • LRT is more difficult to optimise for lower off peak demands due to higher unit costs combined with minimum frequency standards.
Demand growth	Consideration of projections of demand growth, must include resilience and adaptability to substantially higher or lower growth rates.	• Using existing and conventional buses, can cater for higher than predicted demand in the short term, especially off peak.	• LRT requires dedicated vehicles that must be ordered years in advance.
Response to changing demands	Both have the potential to increase or decrease service frequencies or introduce shorter or longer vehicles to meet demands.	• BRT is easier to start small and optimise service delivery for lower demands • May be easier to meet moderate all day demands with high service levels. • More efficient to scale between and high peak and low interpeak.	• LRT is easier to meet high demands and absorb increases in off-peak demand due the higher capacity vehicles. • Less ability to reduce off-peak service levels to optimise capacity due to lower frequencies and higher operating cost per vehicle.

4.4 Deciding on a network design and operating model

4.4.1 Difference between Open vs Closed

One of the first decisions when deciding to pursue a new BRT/LRT service is whether or not the proposed network will be made:

- **Open**, which is functionally compatible with existing transit routes, either for immediate or possible future through-routing of services, or
- **Closed**, using a dedicated right-of-way network exclusive of all other types and modes of transit (Proboste *et al.* 2020).

Often, this decision is impacted by whether the proposed BRT or LRT service is a completely new (greenfield) network or whether it is seeking to expand or enhance an existing transit service (brownfield).

If an 'Open' network is chosen for a brownfield project, technology choices are often limited to whatever the current system utilises, in order to ensure technological and practical interoperability. If an Open network is chosen for a greenfield project there are more options available to practitioners, including the opportunity to learn from other jurisdictions that have similar considerations as detailed in the ATAP BRT/LRT Options Initiation Checklist (refer to Appendix B).

All these factors add cost to the project, but that may be offset by benefits if legacy or existing services and networks are not compatible with the desired future service model.

If a 'Closed' network is chosen (for instance, most greenfield projects) then design standards, fleet maintenance facilities and operational procedures will need to be designed from scratch, and if the new route is later extended to an interchange with another route, passengers could be forced to interchange between different services with associated actual and perceived travel time penalties (Kühn 2002 p7; Hensher 2007 p1). However, it is acknowledged that an increased percentage of 'Closed' or exclusive networks correlate with improved land value uplift at the project completion (Stockenberga 2014, p.16).

Note that the use of Open and Closed in sections 4.4.2 and 4.4.3 are slightly different to what might be expected internationally; this is because the common usage only considers net service outcomes, while the sections below discuss infrastructure and vehicle issues as separate elements.

4.4.2 Open vs Closed: Infrastructure

Most new LRT systems will necessarily be closed, with railed vehicles unable to operate off the track network, and little or no provision for other vehicles to operate on the railed right-of-way. Nonetheless, there are examples of partially open LRT corridors shared with buses and other vehicles, as well as LRT lines that extend onto legacy (typically tram (streetcar)) networks. One such example would be the St Kilda Road corridor in Melbourne, where the segregated central spine branchs out to a range of mixed-traffic routes. Conversely, there are some entirely closed BRT systems, including the Sunway Busway in Malaysia and Transjakarta's Corridor 13.

'Open' BRT/LRT systems are often cheaper and faster to construct (Nikitas & Karlsson 2015, p.5) because much of the engineering work has already been completed before the project starts (or is easy to adapt), but the service quality will be reduced as frequency and reliability are impacted by mixed-traffic environments, and this will bleed over to reduced land value uplift post-project. Additionally, building new infrastructure to accommodate a fully open specification may present additional cost and complexity to the design, for example allowing for the additional height of double decker buses (which are sometimes used to incrlogin capacity at the expense of dwell time), as well as the additional platform length required by articulated vehicles, if either of these options are included in the scope. On the other hand, being able to run services into and out of the exclusive corridor is a significant benefit of 'Open' BRT systems (and potentially 'Open' LRT systems) because the arrangement permits services to share a common route where sufficient demand is present, then fan out to various destinations as required without forcing passengers to change vehicles. Table 8, below, considers the opportunities and constraints that arise from selection of an 'Open' system or a 'Closed' system.

Cities with smaller or less densely-packed populations, particularly those focused along a central spine, are best posited to make use of 'Open' systems. However, once a city's population grows above a certain threshold 'Closed' systems will be required because the sheer volume of passengers will demand customised solutions that provide higher frequency of services with reduced cross-compatibility. The exact point of inflection is likely between 500,000 and 1,000,000 residents (Proboste *et al.* 2020, p.205; Kühn 2002, p.7), depending on what metrics are being used to measure success of a system – for instance raw patronage, mode share, cost of service absolute or per-passenger, return on investment or any balance between these and other factors.

Table 8: Comparison of open system and closed network considerations:

Component	'Open' Network BRT/LRT	'Closed' Network BRT/LRT
Types of vehicles	Conventional buses are able to enter and leave the network via existing infrastructure.	Tram vehicles are only able to operate where tracks are provided. Similarly, custom technology like extra-long articulated buses, guided buses or unique power supply systems could experience technical implementation challenges. However, vehicles can have customised interiors, for example allowing for luggage, bikes or surfboards.
Station layout and dwell times	Stops must be built at a height allowing compatibility with all existing vehicles.	Level-boarding platforms can be provided, reducing dwell time both in passenger boarding and avoiding the need for vehicles to tilt down.
Boarding experience and access	Services can enter and exit the system as required, allowing trips with fewer interchanges needed, however service frequencies may be lower with longer wait times.	Passengers will need to change vehicles more often but will usually have less wait time for each.
Number of routes	Many different routes can use an Open system.	Fewer routes can use the line, and adding new routes after the fact will be more expensive.
Customer perception	Fewer interchanges provides an easier overall ride, but the routes may be vulnerable to vandalism or other issues outside of the new infrastructure, impacting passenger experience in the new section/s.	Likely to have a short-term perception improvement, lasting for perhaps 6 to 10 years (based on ATAP M1 Figure 1, p13; assume saturation approximately inverse to passenger experience). After that point the route is just another part of the overall transport network.
Customer experience	Large numbers of different route services constantly arriving, so it can be confusing for the customer to find the right platform or bay and vehicle. Note that if all routes converge to a common destination the problem only exists in the opposite direction .	With fewer routes operating, it is easy for customers to know which vehicle they want to take. Likely to have both fewer and shorter platforms, so stations will be easier to navigate. In a Closed network more passengers will need to make interchanges between services during their trips, adding to actual and percieved trip time and increasing the risk of unreliable services impacting the overall experience.
Station size	Potentially large stations because the large number of services using the new infrastructure requires more stopping bays/platforms (longer) as well as parallel platforms or passing lanes (wider). If island platforms are desired, reverse-running will be necessary (i.e. M2 Freeway in Sydney).	Smaller stations because lower frequency requires fewer bays/platforms (shorter) and stops can be inline, so no passing lanes are required (narrower). Smaller stations require less land acquisition and construction costs and provide for improved urban integration. Custom vehicles can also have doors on both sides, making island platforms easier to use.

Component	‘Open’ Network BRT/LRT	‘Closed’ Network BRT/LRT
Signal priority	High frequency of services and irregular headways at various locations makes it difficult to provide signal priority to any of those services.	Fewer services arriving more regularly (because of the inline stops, if applicable, and regular dwell times) make it easier to provide signal priority for the rapid transit services.
Fleet size and operating costs	As there are more services interacting, operations are less efficient and less reliable, so more resilience needs to be built into the schedules. On the other hand, being part of a wider network may make it easier to arrange spare vehicles or maintenance capacity at short notice.	Fewer services means operations can be more efficient and reliable, so a smaller fleet can deliver an equivalent service level to other operating conditions. This reduces the vehicle and driver costs. Also, savings in having a uniform fleet, both in spare parts (maintenance) and spare vehicles (rostering).
Reliability	With more buses joining and exiting the busway at various points, and lots of buses at the stations, there are more opportunities for delays and variability to be introduced. An open system is more likely to have reduced disruption during maintenance activites.	With just one or two services using the line for large distances, and inline stops, services are very reliable. A closed system will need to have parallel services established in the event of a planned or unplanned service disruption, and this can be harder to organise unless a catalogue of easy-to-deploy responses is developed in advance.

4.4.3 Open vs Closed: Vehicles

An ‘Open’ BRT/LRT vehicle is one that can run both on the exclusive right-of-way and beyond those limits, while a ‘Closed’ BRT/LRT vehicle is constrained to the exclusive right-of-way (Proboste *et al.* 2020, p.187).

‘Open’ vehicles are constrained by the need to conform to existing standards – for example, weight, length and turning circles – while ‘Closed’ vehicles can be custom designed for a particular route. Similarly, an ‘Open’ BRT/LRT route permits external vehicle access (transit vehicles, but also emergency vehicles), while a ‘Closed’ route does not.

In practice, the Adelaide O-Bahn is ‘Closed’ infrastructure with ‘Open’ vehicles because only buses fitted with guiding equipment are permitted on the route (Ferbrache 2019, p.15), but those buses are also capable of running on the rest of the road network. By comparison, the Brisbane Metro alterations to the existing busway system will have ‘Closed’ vehicles on a (mostly) ‘Open’ network, as the double-articulated Metro Buses will not be able to leave the system – but other vehicles will be allowed to enter and exit the network (‘Brisbane Metro vehicle’ n.d.; Jacobs 2018, p.41 & 54).

These experiences can be compared with the Melbourne tram network, which is largely streetcar (mixed-traffic) but most routes include at least a short length of light rail track; and at least in theory any vehicle can run on any route if required (depending on power supply availability and how many other vehicles are in the same electrical supply section). However, no tram vehicles are able to operate beyond the confines of the track system, and ballasted track sections, for example, are not available to buses.

4.5 Network integration and staging

The ability to integrate with existing transit systems can be a major factor in the performance and cost-effectiveness of a particular BRT or LRT route, especially where staged development of the route is proposed.

There are potential benefits from interlining with or extending from existing corridors, leveraging existing stations or infrastructure to extend service to new areas. However, this can also constrain new corridor to existing capacity and operational problems, and potentially obsolete design requirements. For example, a new LRT line may access a city centre on an existing streetcar or light rail corridor, but short platforms at stations may limit the length of the LRT vehicles and service frequencies may be limited by network capacity.

BRT has the advantage of being able to extend beyond a dedicated right-of-way as it can generally integrate with the road network, except where highly specialised buses are used. This can allow for the benefits of rapid transit to be realised without the need for infrastructure along the whole length of every route. Buses can continue through areas like suburban streets or the city centre, where building dedicated infrastructure would be disruptive, impractical or unnecessary. The section of dedicated busway can deliver enough time benefits to make the bus more attractive than driving. LRT being rail based does not have this advantage unless it connects to an existing line with spare capacity. Similarly, this means existing roads can be used to stage BRT infrastructure, through painted shoulder bus lanes, prior to a dedicated right-of-way being opened.

BRT can operate with sectorised trunk routes and connecting feeder services, or with through routes that perform both roles. Sectorised trunk routes (i.e. ‘Closed’ services) require transfers but tend to be more reliable as they are contained on the BRT infrastructure (therefore isolated from external impacts), and can create a more legible system for users as there is little confusion what bus they should take on the corridor.

Through routes allow for single-vehicle rides, and provides for higher frequencies through busier sections of the routes (while saving operational expense on less-patronised segments), but the number of services running through the core section of rapid transit becomes less legible for users at intermediate stations. Through routes can also suffer from unreliability and bunching, as the routes operating on the trunk are also subject to traffic congestion and other delays on roads and streets beyond the dedicated corridor.

Sectorised trunk routes are almost always the case with LRT, as connecting feeder services are usually provided by transfer from buses and other modes at interchange stations. However, a branching network consisting of an LRT trunk with tram-style operation on suburban branches would be subject to the same benefits and risks.

4.6 Service frequency and headway

Service frequency is the number of services per time period, usually per hour. It is the inverse of service headway, which measures the time between departures from a stop or passing any given node along the route. Both factors are critical components of measuring service levels, including net travel time and capacity. It determines the waiting time to access a BRT/LRT route in the first instance, and again in cases of transferring between routes. It is therefore a primary factor in both actual journey times and the perceived convenience of using the route or transferring between routes. More frequent services have shorter wait and transfer times, and more convenient connections. High frequency routes with short headways also offer resilience against delays and unreliability from the user perspective, as the impact of a missed or cancelled departure is limited to waiting for the next service following soon after.

A defining characteristic of intenational BRT/LRT systems is that they will often target a ‘Turn Up And Go’ (TUAG) or ‘timetable free’ approach, where relatively high frequencies are provided at least during daylight hours. Under this arrangement a user does not need to consult a timetable or plan their travel around a particular departure. They simply go to the stop and board the next service with only a short wait. While not explicitly defined, TUAG is usually marketed at the threshold of six or more evenly-spaced services per hour.

Generally, the more frequent a route the better, due to minimised wait and transfer times. This suggests running smaller vehicles more often is optimal for any BRT/LRT system. However, there are several compound factors of high frequency service that should be considered concurrently:

- **Operating cost:** Service delivery costs are likely to increase proprtionally with service frequency if all other factors are equal. Higher frequency requires more vehicles and more drivers in service at any given time. Doubling frequency will, in most cases, proportionally increase the fleet and driver requirements for the given time period, though this relationship can depend on other operational factors. Accordingly, a smaller fleet of higher capacity vehicles operating less frequently and with a smaller driver pool could have reduced overall operating cost.
- **Operational impacts**: Bunching of vehicles is more prevalent with higher frequency, especially where inline stops and a lack of passing lanes or multiple tracks limits the ability to manage headways. This indicates that a route that requires very high frequencies may be more reliably delivered with a BRT configuration with offline stops and passing lanes. Conversely, signal priority and traffic light pre-emption systems become ineffective on routes where the headway is close to the signal cycle time, as the system does not have sufficient time to modify and recover signal phasing between successive transit arrivals at the intersection. This indicates that systems using signal pre-emption will have a relatively low maximum frequency and will therefore require high capacity LRT vehicles to provide sufficient system capacity. The same frequency limits apply to other systems that are constrained to a regular minimum cycle time, for example those which use barrier arms that raise and lower, or routes passing through urban centres requiring long and regular pedestrian crossing phases. There are also significant capacity and reliability penalties if vehicles do not match the available platform space. For LRT, this might happen if platform lengths do not account for longer or coupled vehicle sets; for BRT the problem could arise if platforms are designed with a specific ratio of articulated to single-unit buses, if the wrong ratio happens to occur – for example, a given-length platform could handle four standard buses or one plus two articulated buses, but not three articulated buses.
- **Reliability impacts:** At very high frequencies, stop congestion and operational can easily compound. This is particularly a problem where the headway of the line approaches, or is shorter than, the dwell time of each vehicle; and where the headway is close to or shorter than the minimum traffic signal cycle or block cycle time.
- **Infrastructure impacts:** Where frequencies are relatively low, vehicles can operate reliably in a linear fashion with inline stops and only one lane or track per direction. This has the advantage of minimising the corridor width and stop footprints, which can have very significant capital cost benefits on existing corridors in urban areas. Where frequencies are high and headways are shorter than dwell times, infrastructure such as passing lanes, multiple stop bays with independent access, and/or offline stations are required to avoid stop congestion and allow sufficient capacity. In practice this can make a BRT stop considerably wider and potentially longer than an LRT stop of equivalent capacity, which may limit the value of BRT on corridors that are both physically constrained and high demand. Conversely, LRT may present an excessive specification and capital cost on corridors where demands are moderate, or where space is readily available for wider stations and right-of-way.
- **Customer experience:** At very high frequencies, a user at a BRT/LRT station would experience multiple vehicles boarding and alighting simultaneously in each direction, for example multiple offline busway platforms or, to a lesser extent, multi-track LRT stations. This may be a significant disbenefit for the customer in terms of legibility and time spent boarding and alighting (particularly for occasional or newer users), as it can be confusing and stressful to navigate multiple arrivals and departures simultaneously, perhaps best described as "running up and down the platform trying to find the right bus". This can be ameliorated by allocating platforms or bays to specific services with clear wayfinding information, rather than allowing all vehicles to use any stopping point on a first-come-first-serve basis. However, this needs to be balanced against space requirements and the maximum number of vehicles likely to be at the station at any given time.

- **User benefits:** Above a certain frequency, there is a marginal additional benefit to users arising from more frequent departures. As the average wait time is always less than the total time between departures, there are diminishing returns for wait time improvements as frequency, and operating cost, increase. For example, moving from four-minute headways to two-minute headways requires increasing frequency from 15 vehicles per hour to 30 vehicles per hour (a 100% increase in operating resource), yet only reduces the average wait time by about a minute (roughly a 3% reduction on a thirty-minute journey). However, a more frequent service will clear platforms faster than a high-capacity but low-frequency service, giving a more comfortable overall journey; and is more likely to minimise interchange time between services.

This last point is demonstrated in Figure 1 below. The chart compares vehicles per hour, headway between those vehicles and the equivalent weighted minutes (per ATAP M1) that influence a potential passenger's decision process. It does not show the typical or average wait time; this requires further research. In short, potential passengers may either arrive randomly at a stop or plan their arrival to minimise waiting time; the latter is more likely if timetables are published, if the service is reliable and if the service runs at a low frequency – the point at which average passengers change their behaviour has not been determined at time of writing but appears to be around a service every 10 minutes (Ingvardson *et al.* 2018 p.293).

Figure 2 is adapted from Ingvardson *et al.* (2018 p.300) and shows various empirical data sets for typical passenger wait time, as a proportion of total passengers and the maximum wait time possible for given service headways in Copenhagen; it is possible that time of day, purpose of trip, method of arrival at the stop and other local socioeconomic and cultural factors could alter the shapes of these curves, as seen in Fan & Machemehl's 2002 study (p.5) of bus passengers in Austin, Texas.

Figure 1: Service delivery requirement, average wait time and perceived travel time contribution, as a function of headway.

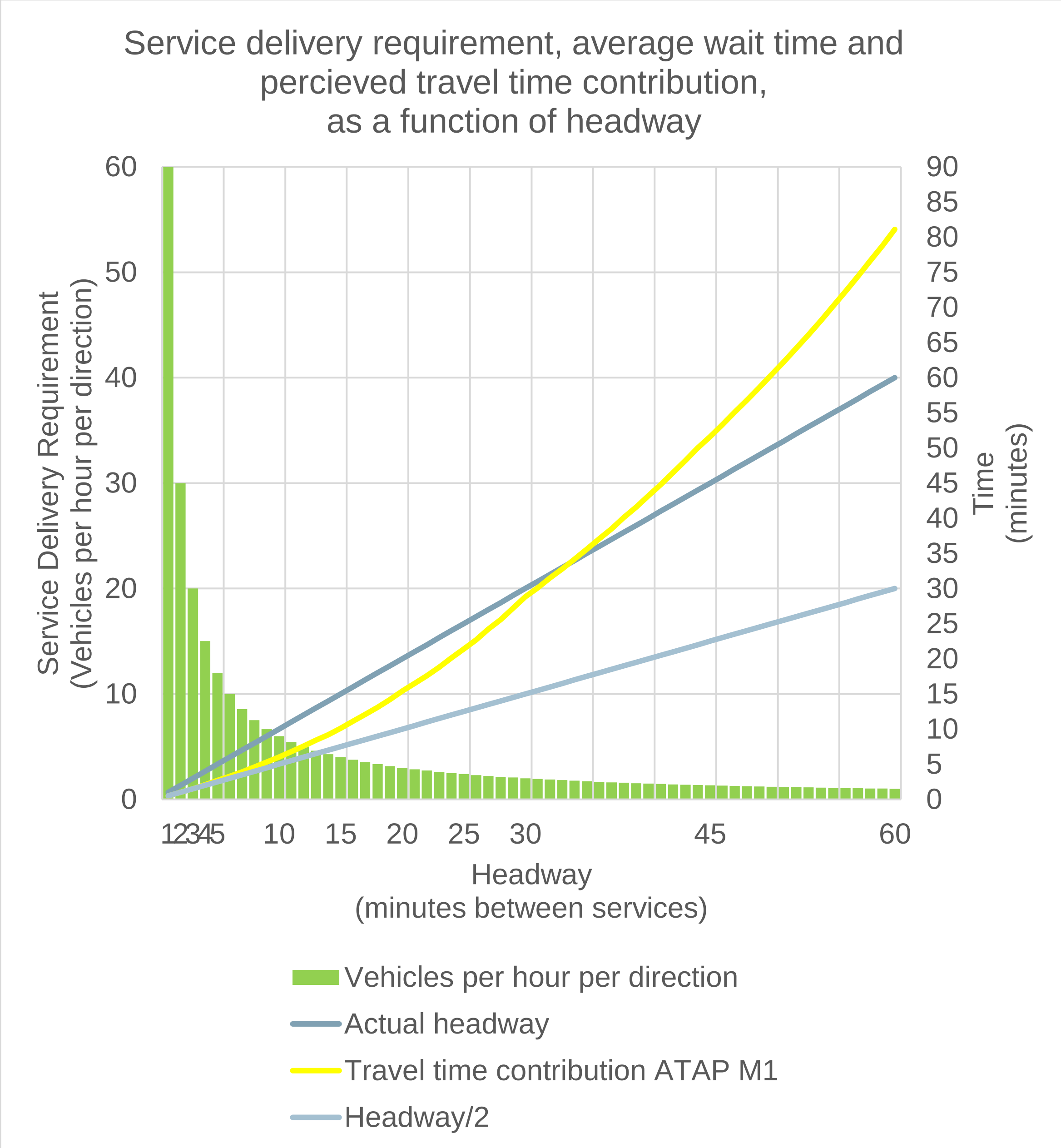


Figure 2: Typical passenger wait times at stops, proportions of total passengers against maximum wait time for various service frequencies.

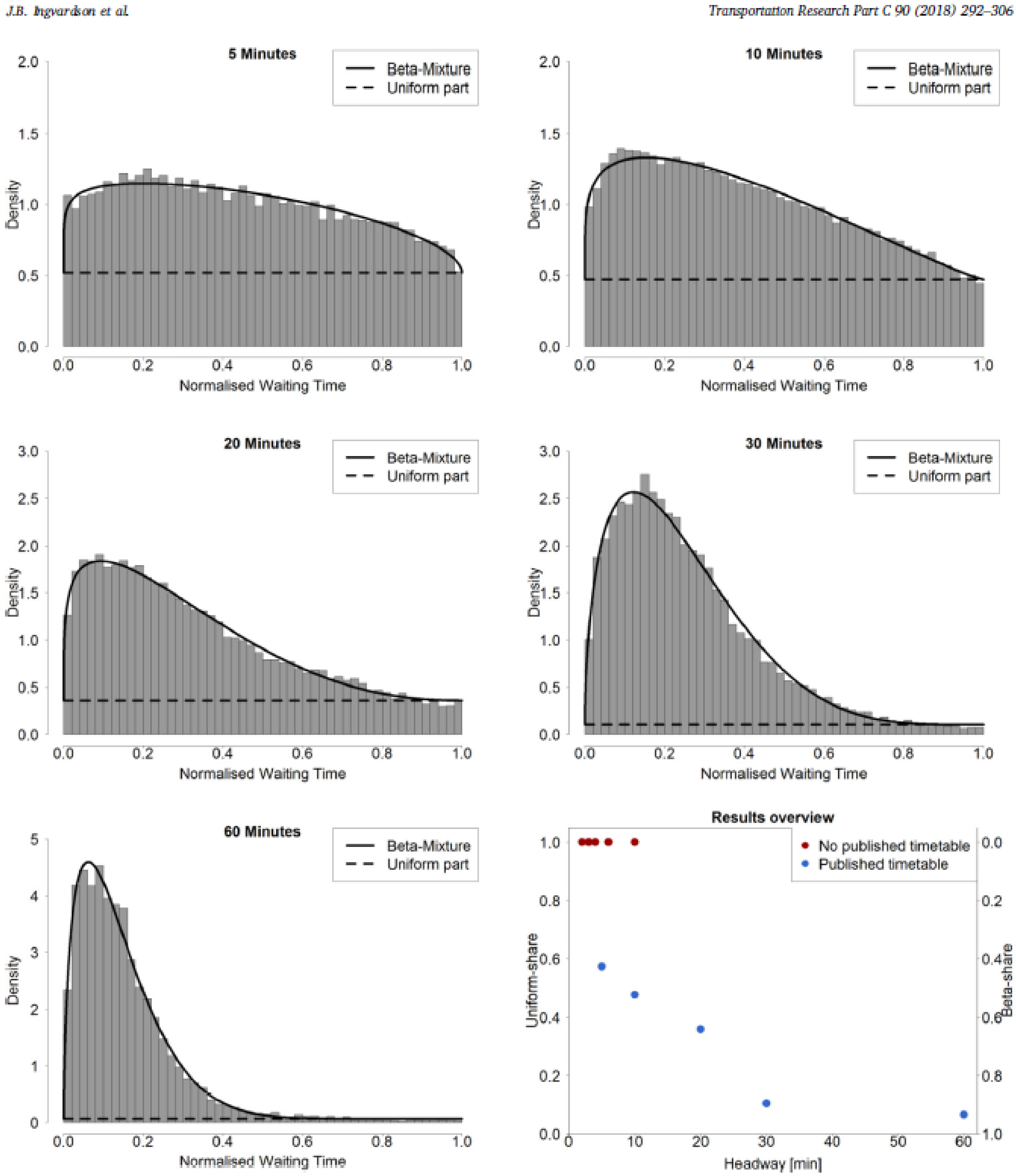


Table note: The bottom-right chart is a summary, with each dot representing one of the other charts. It indicates that as long as a timetable is provided, the majority of passengers time their arrival at stations/stops to minimise wait time.

Source: From Ingvardson et al. 2018, p.300.

4.7 Span of service and service model

A characteristic of BRT/LRT is a long span of service provision across both the hours of the day, and the days of the week – for instance, 5am to 1am, both weekdays and weekends. The span of service determines when the system is available to customers. In practice it may be useful to define at least two levels of span: firstly, the basic hours of operation when the mimimum level of service is available, and secondly the hours in which a higher-frequency service is available - for example during peak hour/s or for event traffic.

The span of service, and the service frequency operated at each hour of the day, is a significant driver of operating costs.The core service patterns of a BRT/LRT system typically operate at for at least 17 hours a day from early morning to late evening, seven days a week, to provide consistent availability to users.

The lower per-vehicle operating cost of buses indicates that a system with low to moderate demands at off-peak periods would be most efficiently served with BRT, particularly where the service model is aimed at maintaining high frequency service all-day, every day. Conversely LRT would have potentially prohibitive operating costs to provide a high frequency base timetable on a corridor where demand and revenue are low. However, on corridors with high demands across the day, or where service frequencies are limited due to physical or operational constraints, LRT may have efficient operating costs.

Under a demand-optimisation approach the base span of service may be at limited frequency, with high frequency operation targeted at increasing capacity during commuter peaks only, and lower interpeak and evening frequencies aimed at minimising operating costs during times of lower demand. Furthermore, additional peak-only or express services may also use the same infrastructure, which effectively increases peak capacity. This approach is common where per-unit or per-passenger operating costs are high and transport strategy is primarily aimed at relieving peak traffic congestion, with the main benefit being optimised operating costs and service delivery. The primary downsides of this approach are the requirement to size the fleet and infrastructure to accommodate an intense but short peak period, and relatively poor service quality outside of peak times which may limit all-day patronage and total revenue.

Under a service-led approach, the base span of service is maintained at high frequency at all times, except very late at night or very early in the morning. This is combined with additional frequency at peak times if required to meet peak demands. The benefit of this approach is a better ability to attract and serve customers across the day and evening, even outside of peak times when traffic congestion is minimal, leading to increased overall patronage and fare revenue. It may also benefit from reduced peak fleet and infrastructure requirements and induce peak spreading of demand. The primary downside is the potential for higher operating costs across the interpeak and evening periods, combined with the perception of operating 'empty' vehicles across periods of low demand. This approach is more effective where per-vehicle operating costs are low, or where all-day demands are high, and where transport strategy is focussed on increasing mobility and accessibility rather than relieving traffic congestion.

The BRT Standard (ITDP 2016 p.44) specifies that high-ranking services should operate until at least midnight and on both Saturday and Sunday as well as normal weekday services; in addition, all routes operating on the combined corridor should provide at least 4vph (15min headways) off-peak and at least 8 vph (7.5 min headways) in peak (p.70). These numbers assume multiple routes using the corridor for a higher total service and reduced waiting times; therefore, for a closed LRT system, the minimum service threshold per route to grant sufficiently short waiting times is probably closer to 8-12vph offpeak / 16-24vph peak.

4.8 Service capacity, vehicle size and throughput

Service capacity is determined by two principal factors, the passenger capacity per vehicle multiplied by the throughput of vehicles per hour.

The passenger capacity per vehicle is influenced by several factors, primarily the length of the vehicle, which in turn can be limited by operational practicalities and regulations as well as constrained by city block and platform lengths; and the interior configuration of seats and standing areas, which is limited by vehicle design constraints, service standards and acceptable crowding levels.

BRT vehicles are limited in size by design standards that enable the safe operation of driver-steered buses on road. BRT vehicles tend to have slightly lower passenger capacity per metre of vehicle length than LRT, due to slightly narrower body width and more interior space occupied by wheel wells for larger diameter steerable tyres. Conventional rigid body buses have capacities in the range of 70 to 80 passengers per bus, while double decker and articulated buses can accommodate over 100 passengers per vehicle. The largest BRT vehicles available on the international market (as of 2020) are double-articulated buses of 24m length and 2.55m width, with multiple door level boarding and a ‘metro’ style interior configuration with a high standing ratio. At four standing passengers per quare metre of floor space, these have a capacity of around 120 people. Some experimental double-articulated vehicles are capable of conveying over 200 passengers.

LRT vehicles can be much larger, due to the guidance and weight distribution properties of rails allowing very long multi sectional articulated bodies. At time of writing, the largest individual LRT vehicles are 55m in length and have a capacity of 344 passengers per unit, as seen in Dublin’s Luas network in Ireland. In addtion, some models of individual LRT units can be coupled into multiple-unit consists (sort of like short trains) under the control of a single driver, a configuration that is most common in North America. For example, Sydney operates double units for 67m length and crush capacity 540 passengers in total, while Seattle, Dallas and Salt Lake City operate triple- or quadruple-unit consists of up to 120m in length with crush capacity (absolute maximum, i.e. event traffic) of approximately 1,000 passengers. About two-thirds that number could be carried comfortably under normal conditions.

In both cases of BRT and LRT, larger vehicles tend to increase capacity but decrease the ability of those vehicles to run beyond the confines of the central corridor. For buses, a longer vehicle may not be able to safely negotiate local roads; for LRVs, a longer vehicle or coupled sets might require longer platforms or double-stopping, both of which impact travel time and would need to be accommodated in traffic light cycles; the latter could also lead to reliability penalties.

Table 9 and Figure 3 show typical capacity for an “Open” system with inline stops and different vehicle types, while Table 10 and Figure 4 show typical capacity for a “Closed” system, using inline stops for tram types and offline stops for bus types.

The maximum throughput of vehicles per hour is largely determined by limitations of the running way infrastructure and stations. Intersections or junctions are the primary constraints on a running way, as access is controlled by some combination of give way rules, merges, traffic lights, signals or barrier arms. Furthermore, station throughput is constrained by platform space and the availability of passing lanes, combined with service frequencies and boarding and dwell times.

In theory, a grade separated busway can accommodate over 1,000 buses per hour per lane (i.e. one vehicle per 3.6 seconds) in free flow conditions, and junctions and stations could be built arbitrarily large to accommodate as many vehicles as required. However, in practice even highly expansive station and junction designs will limit the feasible throughput to less than a third of that figure. Likewise, an LRT track could theoretically operate with vehicles separated by only tens of seconds under line of sight operation, however in practice passenger activity at stations, plus the track-switching time in advance of vehicles approaching junctions, limits the practical maximum to around 60-100 vehicles per hour, while signal priority systems may only function acceptably for traffic and pedestrians at less than 12 to 15 vehicles per hour.

In both cases there is an inverse relationship between service frequency and service speed, as the safe distance between vehicles increases at higher operating speeds. This is more significant for LRT than BRT if traditional trackwork, junction and signalling systems are employed, as these require a minimum time to release, change and detect the new track setting between the previous vehicle clearing the section, and the next vehicle being authorised to approach at any speed; conversely, buses are able to split across multiple parallel bays relatively easily with a zipper-type approach.

Tables 9 and 10, and Figures 3 and 4 below give approximate capacity ranges for various vehicle classes and operating methods. These tables and figures were generated using typical manufacturers' specifications for vehicle sizes where available, or ATAP M1 Table 9 Column 4 if such data was unavailable. An assumption was also made of up to 30vph in an Open system (to avoid bunching), or use of M1 Table 9 Column 5 numbers to guide maximum vph for a Closed system, allowing for traffic light cycles and adjusted for longer vehicles (e.g. 5-section LRVs). These figures and tables are an approximate guide only; later stages of the options analysis should use data for specific vehicle classes and service frequencies.

These are samples of the most likely scenarios, not absolute limits. For instance, they do not account for light rail vehicles longer than 7 cars, because beyond that length theoretical operation in mixed traffic is less practical (i.e. more likely to require a Category A ROW). It is also worth pointing out that the values provided assume a single corridor alignment for all vehicles. This model is applicable in most but not all cases; for example in Sydney a plethora of routes use the Sydney Harbour Bridge corridor, but then spread out to multiple pathways running through the CBD. In this case each sub-corridor is constrained by the number of vehicles that the individual stop arrangements can cope with, but the bridge itself, with no stops, can handle far more vehicles. In this case the key constraint is traffic light cycles at the south end of the bus lane (the intersection of York and Grosvenor Streets), rather than the north end of the bridge bus lane (slip lanes from Mount Street) which at least in theory allows various routes to merge at speed.

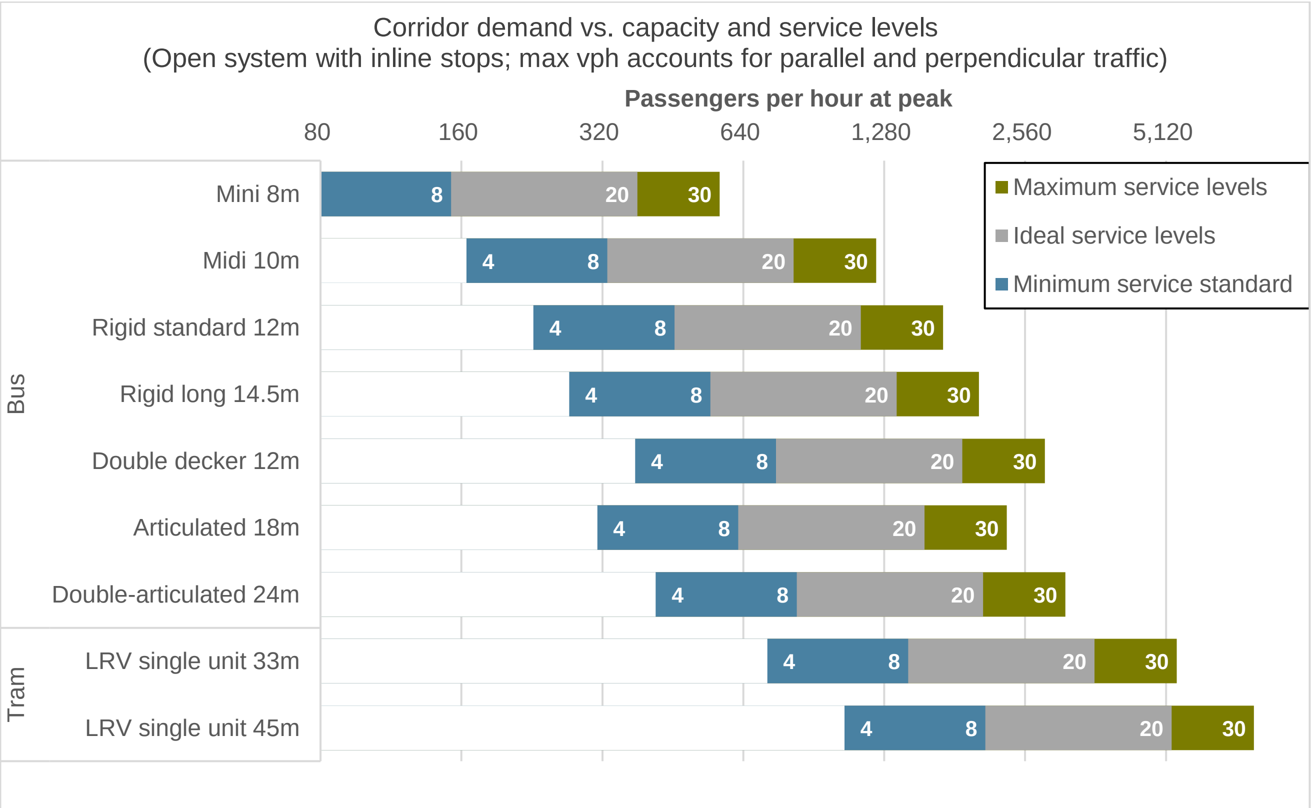
Within those constraints, and comparing like-for-like, in most cases the maximum passenger capacity of a route is determined by the width of the corridor, the design of junctions and intersections, and the feasible size of stations, far more than by the mode. Nonetheless, systems that have limited corridor and station width requiring inline stops, and those that rely on signal priority for speed and reliability (i.e. those retrofitted to an urban street environment), will have a practical capacity limit with BRT, and high peak demands could require LRT to enable longer vehicles and achieve the minimum capacity required in the busiest periods.

Table 9: Vehicle and corridor capacity by mode (open system, compatible with mixed traffic operations)

Mode	Description	Length (m)	Seats	Seats plus maximum standees	Practical peak hour capacity per vehicle	Capacity range at 8 to 20 vehicles per hour	Vehicles per hour for 1,000 passengers
Standard bus	Mini	8	19	19	19	152 to 380	52.6
	Midi	10	30	48	41	328 to 820	24.4
	Rigid standard	12	43	65	57	456 to 1,140	17.5
	Rigid long	14.5	51	78	68	544 to 1,360	14.7
High capacity bus	Double decker	12	85	100	94	752 to 1,880	10.6
	Articulated	18	57	90	78	624 to 1,560	12.8
	Double-articulated	24	76	120	104	832 to 2,080	9.6
Light Rail	LRV single unit	33.5	64	218	180	1,440 to 3,600	5.6
	LRV single unit	43.5	80	309	263	2,104 to 5,260	3.8

Capacity range refers to efficient operation of a single line system; multiple lines sharing a route would divide the stated capacity among them. Adapted from ATAP M1 Table 9. Assume typical vehicles, not longer classes. Threshold of 20VPH allows for cross-traffic at intersections including other transit routes; 30-40VPH may be practical in limited cases.

Figure 3: Corridor demand vs. mode capacity and service levels (open system, per Table 9)



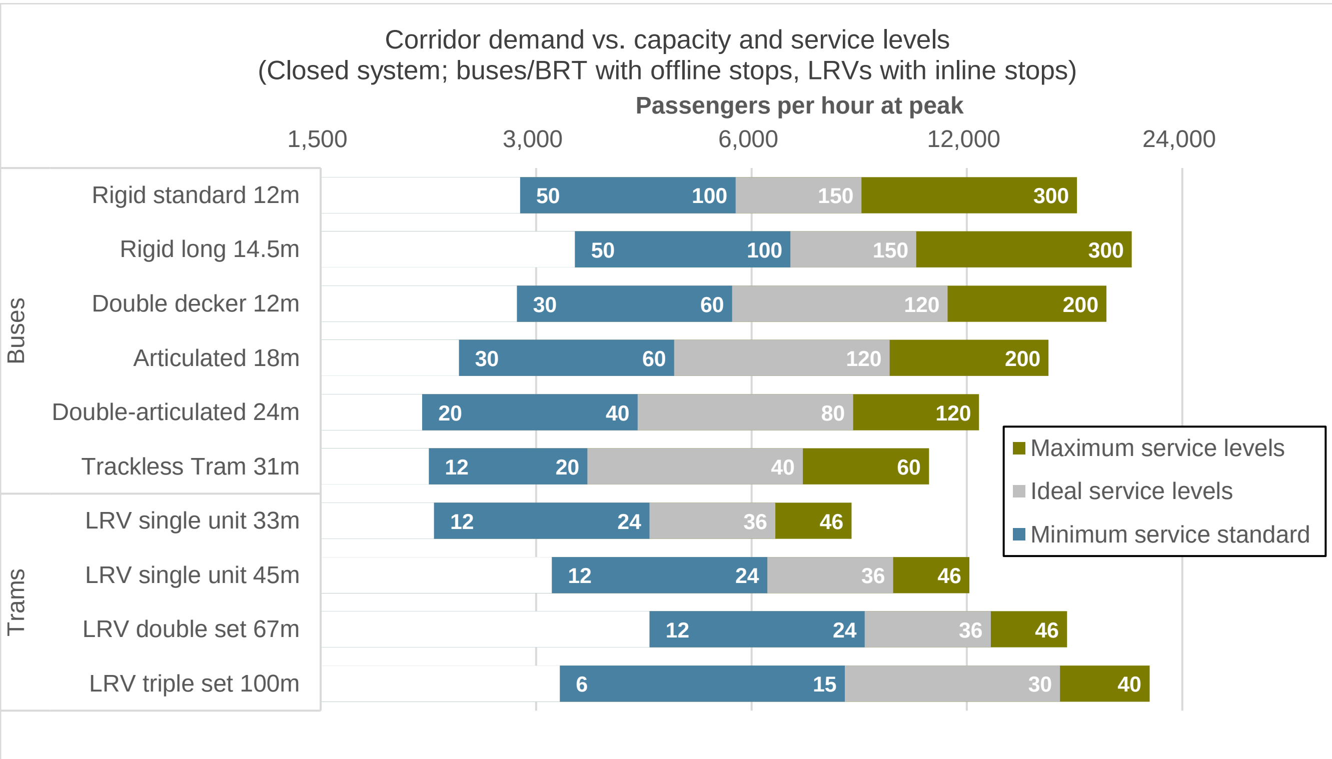
Note: scale is logarithmic. Refers to a single line closed system with inline stops. Adapted from ATAP M1 Table 9.

Table 10: Practical vehicle and corridor capacity by mode (closed system, buses with offline stops, trams inline stops)

Mode	Description	Length (m)	Seats	Seats plus practical standees	Practical peak hour capacity per vehicle	Maximum capacity: Ideal service	Maximum capacity: Maximum service	Vehicles p/hr for 1,000 pax
Standard bus	Rigid standard	12	43	65	57	8,550	17,100	17.5
	Rigid long	14.5	51	78	68	10,200	20,400	14.7
High capacity bus	Double decker	12	85	100	94	14,100	28,200	10.6
	Articulated	18	57	90	78	11,700	23,400	12.8
	Double-articulated	24	76	120	104	15,600	31,200	9.6
	Trackless Tram	31	34	208	177	26,550	53,100	5.6
LRVs	LRV single unit	33.5	64	218	180	6,480	8,280	5.6
	LRV single unit	43.5	80	309	263	9,468	12,098	3.8
	LRV double	67	128	436	360	12,960	16,560	2.8
	LRV triple	100.5	192	654	540	19,440	24,840	1.9

Capacity refers to efficient operation of a single-lane-each-way system; multiple lines sharing a route would divide the stated capacity among them. Adapted from ATAP M1 Table 9. Maximum-service corridors could impose congestion penalties on perpendicular traffic flows. M1 advises a maximum of 300vph per lane for a BRT system (Table 9), but the Sydney Harbour Bridge bus lane operates at nearly 400 vph.

Figure 4: Corridor demand vs. mode capacity and service levels (Closed system, per Table 10)



Note: Scale is logarithmic. Refers to a single line closed system. Adapted from ATAP M1 Table 9.

4.9 Alignment constraints

Yarra Trams in Melbourne specifies a maximum gradient of 1:15 (6.7%) for all new track, and the absolute limit of adhesion for steel wheels on steel rails is normally about 1:11 (9.1%). Most steeper routes require rack railway or cable-haul technologies, which come with additional maintenance costs and speed constraints (Choo 2020, p.20; Odhams 1948, p.21; Stretch, E.K. 1979). Otherwise, alignment costs unique to LRT technology generally depend on the type of track chosen, i.e. concrete slabs with rail mounting or fully ballasted track.

By contrast, buses can manage gradients far steeper than that. A gradient of 1:16.6 (6%) is recommended as the steepest for main roads, but in Brisbane limits of 1:12.5-1:10 (8-10%) are usually deemed acceptable (Brisbane City Council 2014). In Vancouver, the limit is 12%, and in San Francisco bus route 67 climbs a slope greater than 23% (BC Transit 2010, p.48; SFMTA 2020). However, these sorts of gradients are not recommended except in extreme cases, where the transit need is critical and no alternative route is available; and it is quite likely that alternative road surface treatments would be required to increase the coefficient of friction.

Another factor to consider is the turning radius of the vehicle. AustRoads standards specify a minimum turning radius for buses (whether single or articulated) of 12.5 metres at 5 km/h, up to 30 metres at 20 to 30 km/h. This is much tighter than limits for LRVs of 25 metres at 15 km/h, plus Euler spiral transitions either end (Austroads 2013, p.15; Choo 2020, pp.19-22).

4.10 Spatial footprint

As noted in the previous sections, the spatial footprint of the running way and stations can vary considerably depending upon the mode (BRT or LRT), network model (‘Open’ or ‘Closed’ system, passing lanes, offline stations) and the required vehicle frequency and passenger capacity.

The spatial footprint has implications for the capital cost of construction, as well as the function and amenity of the corridor.

In densely developed urban centres it can be prohibitively expensive to widen road corridors or acquire and demolish properties to clear a new corridor, and doing so may reduce catchment, create new barriers to pedestrian access, and result in an undesirable urban environment. In these cases the available corridor width can constrain the maximum spatial footprint, and accordingly limit the mode options that can deliver the required capacity and performance.

In corridors where sufficient space is available, for example alongside freeways or in greenfield development areas, BRT systems can achieve very high capacity using by utlising double running lanes and large offline stations with multiple stopping bays. However, this large footprint application of BRT will tend to create barriers to pedestrian access due to longer walking and crossing distances, as well as creating visual and noise pollution problems that discourage walk-up use. Furthermore, corridors with large amounts of space available for BRT development tend to be located away from centres of demand and activity, often relying on through connections and feeder services over direct access.

In existing corridors where space is constrained, smaller footprint options may be the only practical option. This will tend toward the use of a closed system with inline stations and no passing lanes at stops. This configuration can deliver moderate capacity with either BRT or LRT, however LRT will be required for higher capacity.

Where space is very constrained, signalised single lane or single track sections can be used, however these can create capacity constraints and reliability issue, and limit options for future scenarios when higher frequencies are needed.

4.11 Speed and reliability

There are no major differences in reliability or service speed between LRT and BRT technology packages, and therefore no intrinsic differences between hypothetical LRT or BRT systems. However, a 'Closed' system is guaranteed to have higher reliability than an 'Open' system because there are fewer variables that make an impact, and they can be more tightly controlled. This may be part of why LRT (traditionally 'Closed') is perceived as presenting higher reliability than BRT (traditionally 'Open').

4.12 Feasible configurations of corridor elements

A BRT alignment can be grade separated, physically separated by a kerb or similar, or run in a dedicated and segregated lane within the roadway alignment, although this last option leads to poorer reliability (ITDP 2016). LRT can also operate as grade separated or physically separated. Both run faster and more efficiently when separated but this comes at a higher capital cost. Running in mixed traffic for very short sections only can be useful where there are space constraints on the corridor. Where this occurs, adding priority by holding traffic back at the start of the mixed running section can reduce delays and runtimes.

At intersections there are three options which can apply to both BRT and LRT: grade separated, at grade with priority/level crossing, or at grade without priority. Grade separated allows for less disruption of general traffic but comes at a higher capital cost. Priority at grade intersections can deliver the same time benefits as grade separated but disrupt other traffic and pedestrians and places an upper limit on service frequencies. At grade, without priority slows rapid transit and can lead to bunching and a poor level of service for users.

Stops/stations (inline or offline). At BRT stops or stations, buses can stop inline or offline. Stopping inline allows buses to easily align with the platform and have faster approaches and exits to the stops. Stopping offline requires the buses to slow down and 'swing' into the stop, increasing overall runtime and making it harder to align with the platform, but this also allows other services to overtake or otherwise run express. Aligning with the platform creates a better customer experience, reduces dwell time and is more likely to automatically comply with disability accessibility legislation. However, stopping offline allows buses to easily pass if they are not stopping or if one bus has a longer dwell time. LRT almost always uses inline stops; while offline is hypothetically possible it requires more complicated trackwork, introducing maintenance, headway and safety constraints.

4.13 Perception of customer experience and quality

Perception of customer experience and quality is an important factor when designing and assessing BRT and LRT. While there are some measurements such as customer satisfaction rankings there are also external influences which often lead to unconscious bias of preferring one mode over another.

4.13.1 External influences

A bias against BRT and favouring LRT (the 'rail factor') has been noted amongst the general public and sometimes extends to transport planners and policymakers. This is summarised as "the assumption that trains are sexy, and buses are boring" by Hensher (2016).

Aspects typically associated with LRT services such as reliability, fast travel times, and comfort account for some of the apparent preference for LRT over BRT (Neelagama 2014). However, even when these factors are equalised, there can still be a preference for LRT:

> *A psychological rail factor (i.e., a preference for using rail assuming equal service conditions) of 63 per cent for regional train and 75 per cent for trams when compared with bus services. The rail factor is highly loaded with emotional and social attributions. They account for 20–50 per cent of the share in the different schemata for bus, rail, and tram. (Neelagama 2014)*

Preference of one vehicle type over another may be based on real customer experience (use of network) or influence by external factors (including past experience and media bias) in terms of perception of which mode is ‘better’. Work by Hensher and others has noted that when explicit trade-offs are included in preference surveys people can be drawn to the positives of BRT, especially when cheaper capital costs are translated to improved service coverage. Hensher also notes that familiarity of a system impacts willingness to accept it; those with direct experience with a high-quality BRT system are more willing to prefer BRT (Balbontina et al. 2017).

A national 2015 study found that people in people in Sydney had a 2:1 preference for tram solutions over buses, against 2.5:1 in Melbourne, Adelaide, Brisbane and the national average, and 3.5:1 in Perth and Canberra (Hensher & Mulley 2015, p.13). This can be attributed to direct and media experience of each mode although in all cases there was a strong preference for modern light rail over traditional buses; modern-styled buses against traditional light rail were about even except in Canberra (Hensher & Mulley 2015), though the authors acknowledge that the survey was undertaken at the same time that the Canberra Light Rail project was first being publicised. By extension, LRT systems are easier to advocate for and often BRT is forgotten and abandoned or explicitly excluded from the scope of potential service options (i.e. Shyr et al. 2017).

Conversely, a Melbourne-based study in 2018 found that buses as vehicles rated roughly the same as trains in most categories, and significantly better than older trams but worse than modern trams across the board, per Figure 5 below. Note that the category of ‘Smart Bus’ includes both the orbital routes that essentially operate as chained local/feeder routes, and the express routes from Doncaster to the city and Rowville to Caulfield; the former application is not in any way BRT, while the latter could theoretically qualify as very-low-end BRT (per The BRT Standard v7.75, ITDP, 2016) with relatively minor improvements. Similarly, some parts of the Melbourne tram network could qualify as LRT, though more than half of the total route length and the majority of routes overall operate in mixed traffic and therefore are categorised as Streetcars providing the Local or Feeder tiers of service, within the confines of the definitions provided in Appendix A.

A key challenge of comparing customer perception and experience side by side is that there are few cities in the world where both LRT and BRT systems exist. In Nantes, France there is a small new BRT system and a more extensive older LRT system. A survey conducted of the users of both systems found that BRT rated higher for comfort, safety and cleanliness, while LRT rated higher for capacity, frequency and interchanges (Gleave 2015).

Practitioners should ensure that biases towards a particular mode are not influencing how they perform project assessment. Practitioners need to also be careful not to overcorrect against these biases.

Figure 5: Vehicle attribute scores

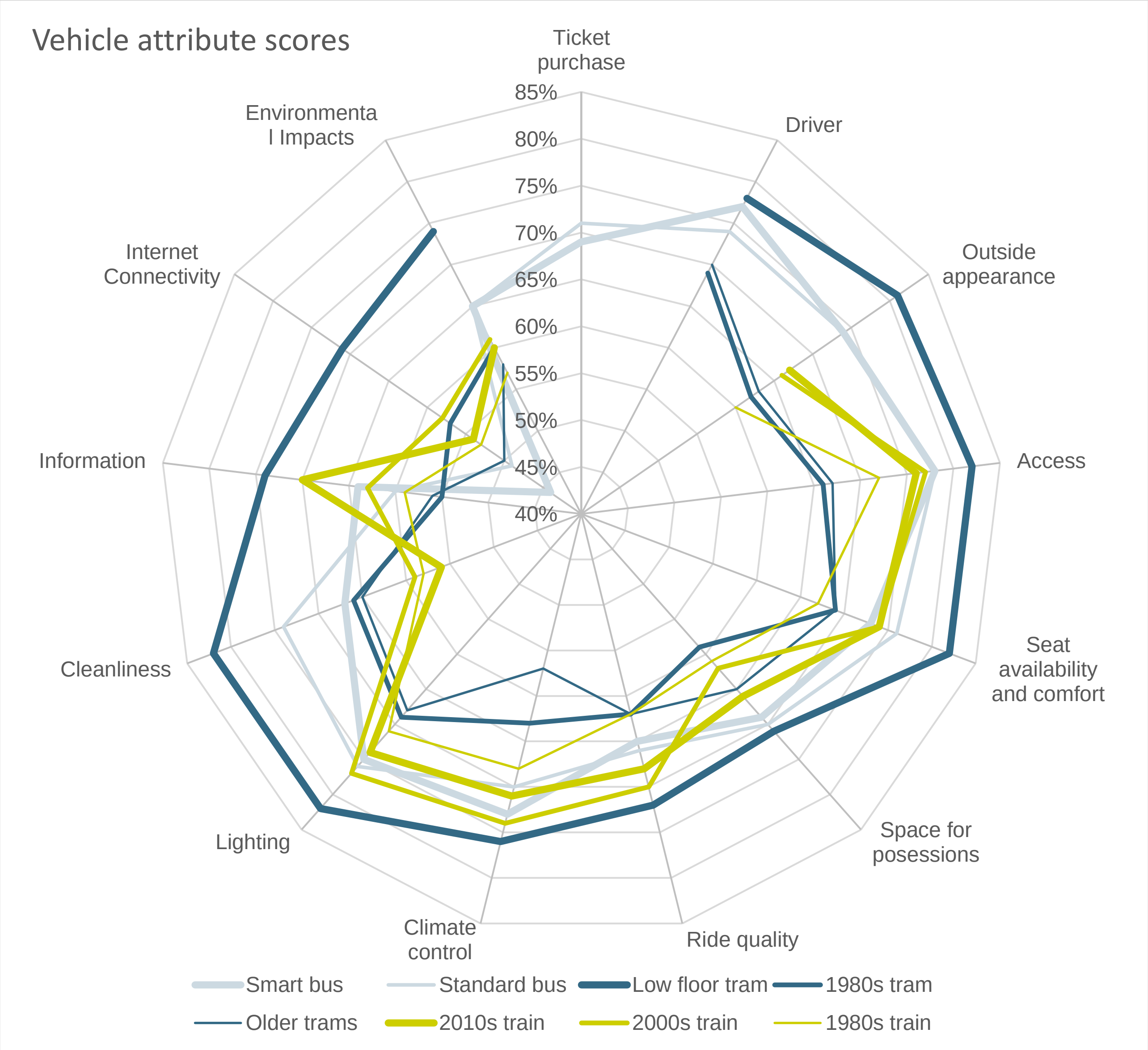


Table note: Line thickness is an approximation of mode modernity. Note that the Victorian "Smart Bus" does not map well to the concept of "BRT"; it primarily reflects availability of information relating to the next service arriving at a stop, and service frequency overall.

Source: adapted from Douglas 2018 p.15.

4.13.2 Customer satisfaction rankings

Customer perception and experience of a mode is based on a number of factors that can be classified into ‘hard’ factors (e.g. mode, service frequency, right-of-way, operating hours, and fares) and ‘soft factors (Fearnley et al., 2015). Soft factors, commonly referred to as ‘customer amenities’, are a range of ancillary improvements to public transport that do not directly relate to quantitative operations or service, but improve the passenger experience quality (Currie et al., 2013). While there is commonality of hard and soft factors to rank and rate LRT and BRT services each ranking is different.

Additionally, historically rail-based services are more likely to provide a better passenger experience (through a combination of frequency, comfort, exclusive right-of-way and other factors), passengers are more likely to prefer tram technology (or at least light rail-shaped vehicles) over buses as a solution. This bias leads to an underinvestment in bus-based solutions, and so no new positive experiences can be generated (Mulley, Hensher & Rose 2014). Furthermore there is misconception that due to buses often being stuck in traffic a BRT system would suffer the same, while most light rail routes have at least some length of exclusive right-of-way (Hensher, Ho & Mulley 2015, p.39). These problems are further entrenched by services falsely marketed as BRT or Busways, but which in practice have few if any of the critical elements provided (Weinstock et al. 2011).

This feeds back into a perception that buses provide less comfortable trips than light rail, although in practice this is dependent on a range of factors that can apply to both modes: a modern, custom-designed BRT system may well provide a better ride quality than track directly embedded in concrete (Hensher, Ho & Mulley 2015, p.39; Ferbrache 2019, p.17; Dunn 2010, p.203). Again, however, there is little to no quantitative study of public transit ride comfort factors across modes; a method to definitively calculate ride quality would be a good opportunity for future research.

Additionally, people without recent experience of bus travel were more likely to prefer LRT solutions, while those who regularly used buses preferred the advantage of the single-vehicle trip, which could mean either a preference for not having to stand during their trip, or a higher weighting of interchange penalties as a higher disincentive to use public transit (Hensher & Mulley 2015, p.15). Also notable is that the cheaper provision of bus services permitting a wider area of coverage for a given budget does not impact public preference in favour of either mode over the other (Hensher, Ho & Mulley 2015, p.39).

With that said, different demographics will prioritise different elements of comfort for any given trip, and for this reason it is recommended that practicioners arrange access to some form of customised weighting system for the communities that the new service will cater to. The thirteen vehicle attribute scores in Figure 5 are a good starting point for this type of survey, coupled with an analysis of service frequency and waiting time based on ATAP M1 section 5.2.

4.14 Disability accessibility of the service

4.14.1 Low-floor vehicles leaning into kerbs

Wholly low-floor vehicles are generally easier to provide with tram systems than buses, as there is no need to include onboard power supplies which are generally stored under the chassis of a bus. In both cases, low-floor vehicles are possible at the cost of some seats where insets are required for the wheel or bogie wells (Bentley et al. 2016, p.20).

However, modern buses are often capable of leaning into the kerb, reducing the vertical gap that mobility devices and prams have to navigate when entering and exiting the vehicle (at the cost of increased dwell time); while this could theoretically be applied to LRVs, issues could arise with the pantograph to overhead contact wire connection, if that method of power supply is utilised. The same may apply to BRT systems using trolleybus technology packages.

Ultra-low-floor tram vehicles have a very limited application in Vienna and Romania, but these are an entirely redesigned vehicle without axles; even then the vehicle floor is 220 mm above road surface level (normal low-floor tram vehicles are usually between 300-350 mm), so a platform would still be required for Disability Discrimination Act compliance (Bernhardt 2020).

Additionally, buses on main roads typically run in the outermost lane, so the roadside gutter reduces the vertical gap. Trams typically run along roadway medians and do not have this advantage, requiring platform stops in order to have any sort of mobility device accessibility.

While this is not a direct impact on dedicated BRT/LRT corridors, it can affect the quality of service on routes that run beyond such boundaries. If a tram (streetcar) line were extended beyond the limits of an LRT route and ran curbside to minimise vertical gap this would likely cause challenges in designing the terminus, either relating to crossing multiple lanes, tight curve radii or both.

In Melbourne, deployable ramp units were considered in the development phase of the E Class trams (introduced from 2011), but this proposal was rejected on the grounds that car drivers attempting to illegally overtake a stopped tram would risk destroying the mechanism and disabling the vehicle. Additional concerns were raised relating to timekeeping and delayed vehicles causing uneven frequencies down the line. These concerns do not apply in a fully-segregated route, but in that secenario low-level platforms can be provided at all stations making the concept moot.

4.14.2 Low-floor vehicles and low-level platforms

The alternative is to build platforms at slightly higher than footpath level, so that vehicles do not have to lean into the stops. This requires a larger stop footprint to accommodate ramps from footpath level to platform level. Examples can be seen at Melbourne Airport’s shuttle bus platform stops as well as at some tram stops in Melbourne.

For a fully segregated alignment disability accessibility is less of a problem (though just as important) because such a route is better poised to include full station fittings, shelters and level platform boarding – this last feature is a critical element of reducing dwell time at stations in any case (ITDP 2016).

4.14.3 High-floor vehicles and platforms (Closed systems and vehicles)

Some MCT systems use exclusively high-floor vehicles and platforms, for example the BRT lines in Jakarta (Indonesia), Bogota (Columbia) and Curitiba (Brazil), and LRT networks in Hong Kong and some North American cities. The vehicles avoid sacrificing internal space for wheel wells as mentioned above, but all stops need to have high-level platforms for access and this includes provision of ramps (or possibly lifts) from ground level.

These systems are necessarily fully-Closed because neither the vehicles or stops are compatible with external stops or vehicles respectively. Bi-level platforms could be explored to partialy overcome this (i.e. high level connecting to low level at the same stop), but this could lead to one type of vehicle being trapped behind another while waiting for a suitable platform position, or a wider station footprint.

Historically, Melbourne's prototype light rail lines recycled railway corridors, using a pair of high-floor LRVs with retractable step units (Chandler 2004) which permitted access to both the high-level platforms at former railway stations, and low-level access to footpaths and on-street stops. The units were later removed and low-level stops were built adjacent to the former railway stations in lieu.

Another consideration is that exclusively high-floor vehicles have more complex emergency exit procedures in the event of a service disruption or collision; like with trains, it may be necessary for all vehicles to carry portable ladders.

4.15 Land use, public realm integration and development potential

Land use changes are primarily a function of the improved connectivity (links between locations), service quality, and amenity a new service brings which subsequently allows for a planning system change permitting increased densities. Therefore, the improvements in connectivity, service quality, and amenity enabled by a new service is the driver of land use change rather than the specific mode which enables this, whether that is BRT or LRT.

As a result, land use impacts need to be assessed on a project by project basis, and in terms of a project's impact on these typical determinants of land use changes, rather than the specific mode.

BITRE (2015) found the impact of transit modes on land use value as shown in Table 11 below. It shows the levels of land value uplift that various classes of transit projects can be expected to generate. It suggests that:

- BRT and LRT achieve higher land value uplift than heavy rail
- BRT and LRT each achieve about the same level of land value uplift.

At the same time, there had been relatively little development along the Gold Coast light rail, which had replaced existing bus services instead of providing a new route (Applied Economics 2016).

One of the main differences in studies appears to be the distance from stations or routes that are tested for value uplift. Residential buildings adjacent to bus stations tend to have lesser value (perhaps due to noise and pollution, although this has not been properly quantified), although this effect is more than compensated by the value increases of properties within walking distance (Stokenberga 2014).

Outside of the residential market, land value uplift is practically guaranteed in parallel with provision of a well-serviced BRT/LRT station, regardless of mode selected. The degree to which this effect occurs depends primarily on service frequency and reliability, both of which are drawn from the quality of infrastructure (i.e. exclusive right-of-way) provided (Stokenberga 2014).

Table 11: Average value uplift per transit mode.

Mode	Average value uplift (%)	Range (%)	No. of observations
Heavy Rail	6.9	-42 to +40	18
Light Rail	9.5	-19 to +30	32
Bus Rapid Transit	9.7	-5 to +32	14

Source: BITRE 2015, p.3

Neelagama (2014) reports land value uplifts similar to those in Table 11, with: LRT uplifts typically range from 5% to 30% for properties within close proximity of a station (for instance within 1km); and BRT uplifts for nearby properties typically range from 3% to 25%.

However, there is some contention around the impact of BRT on land value compared to LRTs or other rail-based modes. Lower values are sometimes attributed to BRT's perceived lack of permanence compared to rail-based infrastructure. For example, the ACT Light Rail Business Case states:

> *"A quantifiable increase in residential and commercial property values has been demonstrated in areas in close proximity to light rail alignments. The same increase in land value does not occur from new bus routes. This is partly because of the permanence of light rail systems versus the relative flexibility of changing bus routes…" (Capital Metro Authority 2014)*

There is unlikely to be much disagreement that LRT would be seen as more permanent that regular on-road street bus services in mixed traffic. On the other hand, a comparison with BRT in a dedicated right-of-way (rather than street bus services) is quite different. The perceived permanence (and subsequent land value impacts) of a BRT project is highly dependent on the specific project. Features influencing perceived permanence include track design (i.e. fixed guide way and separate rights-of-way), system branding, as well as substantial stations. These factors are design choices rather than something necessarily inherent to BRT. In principle, a BRT can be designed with most of the characteristics of LRT. Furthermore, a perception of impermanence can be dispelled over time, with higher land value uplifts found for new BRT projects within cities with already established BRT systems (Zhang 2019).

Railed modes such as LRT are generally seen as providing better land development outcomes than tyred BRT systems. Hypotheses as to why this is the case have included the perception of route permanency, aesthetic qualities and level of service provision, all of which can be applied at least somewhat to BRT systems but need to be quantified in further research (Hensher 2007). Other claimed elements might include pollution and noise, which make BRT stations less pleasant places to be at than LRT, but these may be resolved in the near future with technological advances and the application of electric buses.

Note that land value uplifts cannot normally be treated as benefits in CBAs of transport initiatives because to do so would double count user benefits capitalised into land values. ATAP Part O8 provides guidance on the land use benefits of transport initiatives. O8 explains which land use impacts of transport initiatives can be counted as benefits and the circumstances under which it is valid. The discussion in this section is commentary about the relativities between BRT and LRT in relation to land use impacts, not guidance for benefit estimation (see discussion in section 6.2.12).

4.16 Costs

4.16.1 Capital cost

A review of recent projects indicates BRT systems generally tend to cost less to deliver than LRT systems of a similar size (Martin 2014). However, BRT systems also tend to be smaller and less constrained, with lower capacity and lower demands. The apparent lower capital costs of BRT may simply reflect the fact that BRT tends to be selected for less demanding corridors while higher cost LRT is usually reserved for high demand corridors or highly constrained corridors. Douglas and Cockburn (op cit) assessed the capital costs of BRT and LRT using Australasian examples and found no major difference on a like for like basis.

In practice the capital costs of delivering short stages of BRT can be considerably lower than LRT, especially on smaller systems that lack economies of scale for fixed infrastructure costs and overheads. Any section of corridor on which LRT is to be run requires capital development for tracks and reticulated power supply, and often signalling or other control systems. In addition, LRT systems require more specialised depots and maintenance facilities, including a larger footprint to accommodate the larger turning circles at yard throats (where one track splits into multiples). On the other hand, LRT depots can include under-vehicle inspection pits with the vehicles supported on rails, allowing inspection and maintenance activites to occur

Hensher notes that typically BRT has a significantly lower cost compared to LRT (Hensher 2016b). He also observes that this allows additional features to be added to the BRT option, such as higher service frequency, better quality vehicles, stops and other infrastructure, etc. In the extreme, he even proposes a BRT option of the same total cost as LRT, allowing the provision of significantly superior BRT services for the same budget.

Nonetheless, BRT also requires capital expenditure on running way, usually including higher specification of pavement and new traffic signals and priority systems, and stabling and maintenance facilities are also necessary. However, as BRT is generally compatible with standard roadway design and conventional bus depot facilities, these can be considerably less expensive in practice, and BRT has a much greater ability to utilise sections of existing roads or infrastructure with little or no modification.

Major civil works to deliver running way and stations, such as retaining walls, bridges, tunnels, and viaducts, are similar between the two modes as they have generally similar design specifications. In the extreme case, a new fully grade separated transit corridor with purpose-built stations and structures will have minimal capital costs difference if delivered with tracks for LRT, or with engineered pavement for BRT.

However, the ability for bus-based BRT to run on regular roads and streets gives much greater flexibility to operate the passenger service while staging delivery of a new corridor over several phases. Furthermore, it provides the potential to use existing roadways to avoid or defer the need for high-expenditure capital items such as bridges, tunnel crossings or central city terminals.

By comparison, it is usually impractical to deliver interim or temporary staging of LRT due to the high costs of dedicated infrastructure. Likewise, short LRT lines require the delivery of full track, depot, power and signalling systems before even a basic service pattern can be operated.

Nonetheless for high and very high demand corridors, LRT may have a lower capital cost where the BRT equivalent would need to accommodate very high bus volumes, require extensive infrastructure such as double running lanes and large footprint stations with multiple stop bays and passing lanes. This could be especially so in constrained urban environments with high land costs and existing buildings.

Accordingly, LRT typically only has competitive capital costs on more extensive networks of high demand corridors, or as extensions to existing LRT networks where existing infrastructure and systems can be utilised.

4.16.2 Operating cost

Operating costs for public transport are comprised primarily of various factors: drivers' wages which accrue by vehicle-hour; fuel or power supply and maintenance which accrue per vehicle-kilometre; the amortized cost of purchasing or leasing vehicles, which accrue per vehicle; control system running costs; and fixed infrastructure maintenance costs (track per route-km, pavements, stations and traction systems).

With this cost structure, large capacity vehicles cost more to purchase and operate and therefore cost more per vehicle. However, a large capacity vehicle can carry more passengers, so will cost less to operate per passenger where demand and occupancy rates are high.

Buses cost less to purchase, operate and run than LRVs of equivalent capacity. On the other hand, LRVs are available with capacities considerably higher than the largest individual bus, and furthermore some models can be operated consisting of two or more units coupled together under a single driver. One individual light rail service has the potential to replace two or three buses, with potentially lower total fleet costs on high demand routes. On very high demand routes, a single driver can operate multiple light rail units with equivalent capacity to six or more high capacity buses. However, smaller LRVs tend to be expensive per unit of passenger capacity than equivalent buses and may be several times more expensive on low or medium demand routes.

BRT will tend to have lower operating costs on low and medium demand routes, particularly where the service frequency is close to or higher than what is required to meet demand, i.e. due to required minimum service standard for headways. LRT will have higher operating costs on low and medium demand routes, especially where a minimum service standard requires operating considerably more services at a higher frequency than would otherwise be required for optimised utilisation of capacity. Conversely, on high demand corridors LRT can have lower overall operating costs, as the higher per-unit capacity means a smaller number of vehicles and drivers are required to accommodate a given patronage level.

5. Demand Forecasting

This chapter covers the process of estimating demand for future BRT/LRT services.

As a general comment, the established methods of forecasting demand for public transport projects are readily applicable to BRT/LRT projects. These methods are documented in ATAP guideline:

- M1: 2. Travel demand estimation
- T2: 4. Step 4: Make demand forecasts
- T1: 3.1 Modelling demand

T1 2.1 provides an overview of the hierarchy of transport modelling applications, in order of increasing geographic detail:

- Land use and transport interaction modelling
- Strategic modelling
- Scenario modelling
- Project modelling
- Operational design

As with other transport modes, a BRT/LRT project can be applied across this hierarchy of modelling applications. Land use and strategic modelling covers mode choice at a metropolitan-wide level as well as the interaction between modes at this level. Project modelling assesses the performance of a project along specific corridors, and operational design assesses the detailed operational performance of specific transport infrastructure projects.

The multi-modal metropolitan/regional ('four stage') models discussed in T1 are used to assess major transport initiatives, and would also generally be used for appraising major BRT/LRT projects. M1 also provides simpler demand forecasting methods specific to public transport and which are generally used for smaller and less complex initiatives, and which usually apply elasticity-based or related methods. The methods in M1 are reiterated here with emphasis on their applicability to BRT/LRT.

5.1.1 Elasticities and diversion rates

In forecasting the travel demand impact of public transport projects, ATAP suggests using elasticity and diversion rate estimation methods. These methods require an estimation of how new and modified BRT/LRT services would impact travel demand as inputs to the modelling.

Estimations of propensities to take a particular mode need to be informed by the characteristics of the proposed mode. If comparator BRT and LRT projects both provide equivalent levels of connectivity and service quality, then they should be treated as having equivalent impacts on demand. As BRT typically provides a heightened level of service compared to a traditional bus service, it is generally not appropriate to assume a new BRT service would have the same demand impacts as a traditional bus service.

Component direct elasticities of demand

M1 2.2.3 Component direct elasticities of demand, notes elasticities for fares, service levels and in-vehicle time: "These elasticities may be used for all urban public transport modes — there is insufficient evidence of any intrinsic differences in elasticities between modes" (ATAP 2018).

Given BRT/LRT's typical position between a traditional bus service and a heavy rail service (along with many parameters) if the same elasticities are applied across urban public transport modes (from bus to train), then these are also appropriate for BRT/LRT. BRT/LRT does not represent something beyond the parameters of a typical urban public transport service.

Short run elasticities relate to the period of 12 months from implementation of the initiative. M1 2.2.3 notes that long-run elasticities, relating to the period of up to 10 years after implementation, are typically twice that of short run elasticities for major infrastructure initiatives, as most BRT/LRT projects would be.

M1 2.2.3 Table 2 provides a summary of how elasticities may be impacted by various project aspects. Regarding fare elasticities, it is noted that bus elasticities are generally greater than rail. It is also noted that in-vehicle time elasticity for bus is typically lower than rail. Both of these findings are related to the typically shorter trip lengths for traditional bus services. Therefore, these findings are not relevant to BRT which differs substantially from a traditional bus service. Given the similarities in service between BRT and LRT, all things equal, we recommend using equivalent fare, service level, and in-vehicle time elasticities for BRT and LRT in demand calculations.

Diversion rate

The 'diversion rate' is the proportion of the 'new' public transport passengers who did not previously use public transport for their trip.

Diversion rates from car to new public transport services historically appear to be higher for bus services compared to rail services. However, this is likely due to the nature of bus services provided rather than something inherent to bus technology. M1 2.2.4 notes:

> *For public transport initiatives particularly oriented to attracting motorists, use of the higher car driver diversion rates is appropriate. These include initiatives such as park & ride facilities and express bus services, each with diversion rates from car drivers of over 50% and in some cases as high as 70% to 80%. (ATAP 2018)*

M1 Table 3 provides diversion rates for a range of completed projects, including BRT and LRT (ATAP 2018). These diversion rates can inform estimated diversion rates for new BRT/LRT projects. However, when comparing BRT and LRT options for the same route, an equal diversion rate should be used if the service provided under each mode option is broadly similar.

Neelagama (2014, p.92) writes:

> *…the drivers of patronage on Rapid Transit, regardless of modal consideration are more related to the frequency, coverage, quality and reliability of services than the time travel benefits or speed of travel in areas of operation.*
>
> *Research indicates that both Light Rail and Bus Rapid Transit can have similar modal shift impacts.*

Caution must be taken in applying historical diversion rates to new BRT/LRT projects. There may be typical features of historical BRT-like investments which impact observed diversion rates but are not inherently related to the mode choice of BRT. For instance, if BRT like investments involve significant sections of shared traffic (due to a policy decision, rather than an engineering/technical limitation) then the attractiveness of the service would be less compared to LRT projects which may, historically, have been more likely to have right-of-way.

Diversion rates from non-car modes including active transport and other public transport modes are also important to understand. Douglas 2019 notes that diversion rates from walking are a relevant consideration for BRT/LRT projects. This is due to the nature of some BRT/LRT projects which have stops relatively close together along corridors with high pedestrian counts.

The key point regarding diversion rates for BRT/LRT is to base diversion rates on the characteristics of the project options at hand, ensuring that if historical diversion rates are used that these historical projects have similar characteristics.

5.1.2 Patronage ramp up, annualisation factors, and risk and uncertainty

Existing ATAP guidance on ramp-up periods of M1 2.3 is readily applicable to BRT/LRT. Guidance stating that bigger projects will likely have longer ramp-up periods also applies to BRT/LRT projects.

Some guidance refers to shorter ramp-up periods for bus projects. This is related to the typical smaller scale of bus projects rather than necessarily related to the bus mode, or BRT projects.

Methods for annualisation provided in M1 2.4 ‘Public transport demand annualisation factors’ are readily applicable to BRT/LRT. This annualisation method does not split out mode differences.

M1 2.5 ‘Risks and uncertainty in demand estimation’, provides suggestions to combat uncertainty in demand estimation for public transport. These also readily apply to BRT/LRT projects, however the ability to study historical data to help understand risk and uncertainty specific to BRT/LRT projects is hampered by these modes being novel in some Australian cities. Relevant case studies from where BRT/LRT has been implemented in other Australian cities or internationally should be reviewed in this case.

Like other transport projects, planning for BRT/LRT is susceptible to optimism bias and this should be considered in the assessment process. There is no clear indication that BRT/LRT projects are necessarily more prone to optimism bias than other transport projects. In terms of patronage forecasts, Australian experience has shown some over and some under forecasting (Currie 2006).

6. CBA costs and benefits

6.1 Costs and benefits identification

Table 12 below identifies typical costs and benefits to include in a Cost Benefit Analysis (CBA) for BRT/LRT projects. These costs and benefits align with those identified in M1 and T2. Further discussion on how the costs and benefits would apply to BRT/LRT projects is provided in section 6.2.

Table 12: Costs and benefits related to LRT and BRT

Impact	Type	Description
Investment costs – capital costs	Investment cost	Capital costs include planning, land acquisition, construction, and equipment costs, and system testing costs. These costs are essential for the delivery of the project and typically incurred upfront.
Investment costs – construction externalities	Disbenefit	Externalities arising during the construction phase of a project include air and noise pollution, and disruption to the transport network.
Operating costs	Operating cost	Operating costs are incurred throughout the project lifetime from the first year of operation. These costs include maintenance costs and can be split into time-related and usage-related costs.
Consumer surplus gains to users	Benefit/ Disbenefit	Consumer surplus covers the net welfare gained by users of the new service. This covers consumer surplus for people who use public transport under the base and project case ('existing trips') as well as consumer surplus by new users of public transport under the project case ('generated trips' and 'diverted trips').
Fare revenue (Producer surplus gain is the change in revenue less the change in operating costs)	Benefit/ Disbenefit	This benefit accounts for the additional fare revenue generated from a new transport project.
Car driver impacts	Benefit/ Disbenefit	This covers the benefit (or disbenefit) for motorists who remain on the road system following delivery of the investment.
Other benefits – mode shift from driving / active transport	Benefit/ Disbenefit	This covers the unperceived benefits/disbenefits from mode shifts following the development of new public transport services. This includes shifts from cars (both drivers and passengers) and active modes (walking and cycling) to public transport.
Car parking	Benefit/ Disbenefit	This benefit captures the reduced resource requirements for car parking due to higher public transport use net of revenue forgone for car park operators.

Impact	Type	Description
Safety	Benefit/ Disbenefit	This impact captures the net changes to safety. This covers lower road crashes from reduced car use as motorists switch to public transport as well as the increase in crashes and incidents from new public transport services.
Environment externalities	Benefit/ Disbenefit	This captures the impact of air pollution, noise pollution, water pollution, greenhouse gas emissions, impact on nature and landscape, and urban separation.
Urban amenity and livability	Benefit/ Disbenefit	This impact captures changes in the livability and amenity of an area following the delivery of a transport project.
Option and non-use value	Benefit/ Disbenefit	This benefit captures the willingness-to-pay for the existence of a public transport service which an individual is not currently using, which is not normally quantified in conventional CBA.
Land use benefits	Benefit/ Disbenefit	The land use benefits of transport initiatives consists of several elements, as outlined in ATAP Part O8 and listed here in section 6.2.12
Wider economic benefits	Benefit/ Disbenefit	WEBs are a class of transport project benefits which capture improvements in economic welfare, as outlined in ATAP Part T4. These benefits include: agglomeration economies from clustering, tax benefits from labour market changes, and output changes in imperfectly competitive markets.

6.2 Costs and benefits application to BRT/LRT

Expanding on Table 12, this section provides further detail on the identified costs and benefits and their application to BRT/LRT. Costs and benefits are described, existing ATAP guidance is cross-referenced, and its applicability to BRT/LRT projects is discussed along with commentary on possible quantification methods.

These guidelines recognises BRT/LRT as a single public transport mode class: MCT. Therefore, in general, equivalent treatment of costs, benefits and parameter values would apply across both BRT and LRT assessment.

6.2.1 Capital investment costs

Capital costs include planning, land acquisition, construction, equipment costs, and system testing costs. These costs are essential for the delivery of the project and typically incurred upfront.

Existing ATAP guidance on investment costs readily applies to BRT/LRT projects:

- T2 ‘3. Step 3: Estimate investment costs’
- M1 ‘7.1 Fixed infrastructure capital costs’
- O1 Cost estimation

There are recent examples of Australian LRT projects experiencing significant overruns in capital costs. However, cost overruns are not necessarily inherent to the mode choice of LRT (or BRT). Cost overruns are widespread across infrastructure projects for all modes.

Characteristics of a project tend to influence whether cost overruns are more likely, including project complexity and project novelty (Terrill 2016). To the extent that BRT/LRT projects are complex or novel, the likelihood of cost overruns can be minimised by implementing Australian Government best practice cost estimation guidelines (see ATAP Part O1).

M1 Table 34 provides indicative default capital costs for BRT ('Dedicated bus lanes – dual track') and LRT ('Light rail – surface dual track'). Note these cost ranges are general and should only be used only in a very indicative manner.

6.2.2 Operating costs

Operating costs are incurred throughout the project lifetime from the first year of operation. These costs include maintenance costs and can be split into time-related and usage-related costs.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 '7.1 Fixed infrastructure capital costs'
- T2 '5. Step 5: Estimate infrastructure operating costs'

Indicative default operating costs for bus and tram projects are provided in M1 at Table 32 and Table 33. M1 Table 33 covers bus types of higher capacity such as double deck or articulated which are common for BRT projects. These default operating costs can be applied to BRT and LRT projects as indicative costs for early stage project assessment. At a more advanced project assessment stage, operating costs should be based on more detailed design for the local system and settings.

6.2.3 Consumer surplus gains to BRT/LRT users

Consumer surplus covers the net welfare gained by users of the service improvement. This covers consumer surplus for:

- Existing trips: Undertaken in the base and project case
- New trips: In the project case — 'generated trips' and 'diverted trips' from other transport modes. This component is generally calculated using the 'rule-of-a-half' and is based on the costs perceived by users

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 4.2 Estimating changes in consumer surplus
- T2 6. Step 6: Estimate user benefits

The methods for calculating consumer surplus are discussed in ATAP T2 Chapter 6 and appendices B and C, and for public transport projects in M1 4.1 and Appendix B. The methods are all relevant to the assessment of BRT/LRT. These methods are the simple rule of half, rule of half using multi-modal demand, numerical integration modified rule of half, and logsum method.

For the assessment of many projects, practitioners will be able to use the rule-of-a-half method. The logsum method is more complex, but is the most accurate method of deriving consumer surplus. Application of the logsum method requires use of a logit (discrete) choice travel demand model.

M1 5. 'User benefit parameter values' provides default parameter values for in-vehicle time, travel convenience, and vehicle and station quality (which vary by level of quality). Parameter values are typically split by modes of Rail, Tram, Bus, and Ferry.

For consumer surplus assessments of BRT/LRT projects, it is generally appropriate to use the tram parameter values from M1 for both BRT and LRT projects. BRT, when delivered adequately, provides an emulation of the LRT user experience including in terms of onboard and station comfort (Neelagama 2014, p.31). Given this, it is not typically appropriate to use Bus parameter values for BRT projects for user benefit calculations, as Bus values are more reflective of street buses.

If a project is branded as BRT (or LRT) but does not meet the minimum infrastructure and service standards assumed for BRT/LRT then differing parameter values for consumer surplus inputs should be used.

6.2.4 Fare revenue

This benefit accounts for the additional fare revenue generated from a new transport project. Combining this with the change in operating costs indicates the change in producer surplus,

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 '4.4 Accounting for public transport fare revenue'

As noted in M1 4.4, the fare and GST paid by new public transport users is a transfer between users and the service provider. The inclusion of the change in fare revenue reflects this by offsetting the negative impact of fares and GST on the additional public transport users when measuring consumer surplus (as part of the travel time savings benefit for new users).

Both methods of quantifying this impact, 'Change in producer surplus' and 'Resource correction', can be applied to BRT/LRT projects.

6.2.5 Car driver impacts (decongestion and increased congestion)

This covers the benefit (or disbenefit) for motorists who remain on the road system following delivery of the investment. If a BRT/LRT investment results in former motorists using the new public transport project, this could improve travel time for the remaining motorists. Adjustments for the second-order effect of induced car traffic also need to be accounted for as part of this calculation.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 '4.8 Benefits to motorists who remain on the road system'

A key consideration for BRT/LRT projects is that in addition to mode shift impacts of a project, a BRT/LRT project could also impact the performance of the road network directly. For example, BRT/LRT vehicles could be mixed with car traffic for some of the route, or an existing car lane could be dedicated to BRT/LRT (and thus lost from car traffic). This could result in increased congestion for car drivers Therefore, the net impacts on motorists which remain in the system must be included for quantification, not just the benefits from lower mode share for cars. We note that this consideration is not necessarily unique to BRT/LRT projects but may be more of an issue for BRT/LRT projects as they sometimes use alignments based on existing road networks.

The method to calculate the disbenefits to motorists is the same as that to calculate benefits for motorists as set out in M1 4.8.

6.2.6 Other benefits of mode shift to/from driving/active transport

The BRT/LRT options will attract trips from other modes (cars, active travel). For these diverted trips, Section 6.2.3 requires calculation of consumer surplus gain based on perceived costs using the rule-of-a-half. A further benefit involves the reduction in unperceived or misperceived travel costs associated with mode shifts, requiring resource corrections. This covers unperceived differences in reduced operating costs, reduced crash costs, health and environmental benefits, reduced car use, reduced road maintenance costs, reduced car parking, and reduced car ownership when switching to public transport. These are discussed in ATAP M1 section 4.7.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 4.7 Other benefits for people shifting to/from public transport

ATAP default parameter values are provided for unperceived differences in reduced car parking and reduced car ownership when switching from cars to all public transport.

While mode shifts will differ between various public transport modes, the valuation of these benefits will not differ between public transport modes. Therefore, the valuation methods outlined in M1 4.7 can be applied to BRT/LRT projects.

6.2.7 Car parking

This benefit captures the reduced resource requirements for car parking due to higher public transport use, net of revenue foregone for car park operators.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 ‘4.7.4 Car Drivers, Reduced car parking’

6.2.8 Safety

This impact captures the net changes to safety. This covers lower road crashes from reduced car use as motorists switch to public transport as well as the increase in crashes and incidents from new BRT/LRT services.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 ‘4.5 Safety improvements’
- T2 ‘8. Step 8: Estimate safety benefits’

The general method of calculating safety impacts using crash rates and unit costs applies to BRT/LRT projects. Unit costs could use a willingness-to-pay or human capital (or hybrid) approaches to do this.

It is important to note that crashes still occur with public transport modes, including BRT/LRT. For example, there is, on average, around 80 instances of serious unintentional injury involving LRT each year in Australia. These commonly involve injury to passengers boarding or alighting, or falling while being an occupant (AIHW 2017).

Aside from interactions between BRT/LRT vehicles and private vehicles or pedestrians, another aspect that must be considered is interactions between these services and cyclists. For example, cyclists' wheels can get caught in the channel of the grooved LRT track. However, as outlined in 3.4 the BRT/LRT alignment should generally exclude other traffic including cyclists, and for that reason the risk is managed because cycling traffic may generally be crossing LRT tracks at a wide angle. Therefore, this issue should be mostly constrained to intersection design.

The costs of incidences must be reflected in the estimates, preferably under the cost of travel perceived by public transport users (as is usually the case) or otherwise under the estimates of public transport operating costs. As recommended in M1, data on crash and incident costs can be obtained from public transport agencies using actual data on crash and incident rates and costs that they incur.

6.2.9 Environment externalities

This captures the impact of air pollution, noise pollution, water pollution, greenhouse gas emissions, impact on nature and landscape, and urban separation. Impacts can be benefits arising from the reduction in externalities from reduced car use but need to be balanced against disbenefits associated with increased public transport use.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 '4.6 Environmental effects'
- T2 '9. Step 9: Estimate externally benefits and costs'
- PV3 '2.9 Externality benefits and costs'
- PV5 Appendix C Default externality values

ATAP default externality parameter values are provided at PV5 Appendix C Default externality values for passenger vehicles and freight vehicles. These are used to capture the externality impact that a new public transport service has due to changes to private users of the road network. Default parameter values are also provided for public transport (urban bus and rail). These default parameter values can be applied to BRT and LRT projects at the initial assessment stage. Where externalities are expected to be significant, these should be estimated specific to the project using the methods identified in PV5 Environmental parameter values.

There are possible differences in the environment externalities for BRT and LRT projects. These include differences between noise and air pollution impacts between BRT and LRT which can be related to the mode technology (i.e. rubber wheels on-road versus steel on rail).

Compared to a BRT powered by internal combustion engine (ICE), generally, LRT produces less noise (though noise for travelling around sharp curves can be loud) and less vibration and no local air pollution (Vuchic et al. 2012). For both BRT and LRT projects engineering and design measures can be taken to substantially mitigate noise impacts (U.S. Department of Transportation Federal Transit Administration 2016). Therefore, the precise design of a BRT/LRT project will determine the extent of these externality impacts.

BRT and LRT projects can differ in their greenhouse gas emissions. LRT is typically assessed as creating substantially fewer carbon emissions per passenger kilometre than a traditional bus (Puchalsky 2005). However, this performance is dependent on a range of factors including the mix of energy sources powering LRT and choice of bus engine technology.

The above discussion illustrates that externalities of BRT and LRT can differ but are highly sensitive to the context and how a project is designed and implemented. Accordingly, while default parameter values can provide indicative values for externalities, the particulars of a BRT/LRT project need to be considered in fully assessing environmental externalities.

6.2.10 Urban amenity and liveability

This impact captures changes in the liveability and amenity of an area following the delivery of a transport project. This includes a wide range of aspects such as quality of a place, aesthetics, the physical and urban design, how the place is used, and the extent to which a place supports quality of life, health and the general well-being of residents.

Existing ATAP guidance broadly applies to BRT/LRT projects:

- O3 ‘Urban Amenity and Liveability’

O3 notes that while urban amenity and liveability can be profoundly impacted by transport projects, impacts can be difficult to monetise. Therefore, noting these impacts in an Appraisal Summary Table (AST) which includes non-monetised impacts is important.

BRT/LRT, as a significant transport project, can have a large impact on amenity and liveability. However, as methods to monetise these impacts are not well established, they may need to be treated qualitatively in an AST.

6.2.11 Option values and non-resource benefit

This benefit captures the willingness-to-pay for the existence of a public transport service which an individual is not currently using, but may use in the future (option value) or may never intend to use it in the future (non-use value). This benefit typically applies to public transport networks in regional areas, with either low or no current levels of service. It is important to ensure these benefits do not double count other benefits in the conventional CBA.

Existing ATAP guidance readily applies to BRT/LRT projects:

- M1 ‘4.9 Option values and non-use values’
- M1 ‘Appendix D Option values and non-use values’

ATAP default unit benefit values (dollars per annum, per household) are provided for the combined option and non-use benefits using an ordinal high-medium-low scale dependent on the characteristics of the area and the service under consideration.

Given the substantial nature of most BRT/LRT as a class of projects, it could be expected that they would typically fall into the medium or high category, with the corresponding parameter values appropriate to use for BRT/LRT projects.

6.2.12 Land use benefits

ATAP Part O8 provides guidance on the land use benefits of transport initiatives. O8 explains which land use impacts of transport initiatives can be counted as benefits of transport initiaitves, and their reflection in land value uplifts. The discussion below is complementary, focusing on the relativities between BRT and LRT.

The types of land use benefits discussed in O8 are:

- Higher value land use — the transport initiative enables land to be used more intensively and there is a market imperfection present from zoning restrictions
- Second round tranport impacts — more intensive land use generates additional demand for transport which affects user benefits and transport externalities. Note that mixed traffic operation does not generate nearly as much benefit as segregated running (as reflected in section 3.5), due to reliability, speed and frequency limitations.
- Savings in public infrastructure costs provided at below marginal social costs — public infrastructure costs can be lower for infill locations compared with greenfield locations, and there is the market imperfection of under-recovery of costs of public infrastructure by governments from the beneficiaries
- Sustainability benefits — changes in built form can reduce carbon emissions
- Public health cost changes — denser pattern of urban development can increase active travel trips with benefits to health system above the health benefits to individuals.

6.2.13 Wider economic benefits (WEBs)

WEBs are a class of transport project benefits which capture improvements in economic welfare. These benefits include: agglomeration economies from clustering, tax benefits from labour market changes, and output changes in imperfectly competitive markets.

Existing ATAP guidance readily applies to BRT/LRT projects:

- T3 'Wider economic benefits'

To the extent that BRT/LRT projects improve connectivity and allow for more agglomerated cities, this is a relevant benefit to include in a CBA.

6.2.14 Construction externalities disbenefit

Externalities arising during the construction phase of a project include air and noise pollution, as well as disruption to the transport network that result in travel delays. As BRT/LRT projects are usually substantial, typically within dense urban environments, construction externalities are relevant. It is not common for these costs to be explicitly quantified in a transport CBA, but where they are expected be significant, they should be considered. If used in a CBA, these costs are included in a BCR as a disbenefit (Australian Transport Council 2006b).

Existing ATAP guidance on the approach to externalities (in operation) also broadly applies to BRT/LRT projects in the construction phase:

- T2 '9. Step 9: Estimate externally benefits and costs'

The method to quantify disruption to transport networks during construction is conceptually the same as any other transport network impact (i.e. how disruptions impact travel times and reliability).

Quantifying the broader disruption costs during construction to individuals and businesses (not related to the transport network) is less well established in CBA practice. However, frameworks exist to quantify these costs, and these could be applied if these costs are expected to be substantial (Nelson 2011).

While there are recent Australian examples of LRT projects causing significant and prolonged disruption during construction (O'Sullivan 2018), this is not necessarily an impact which is inherently specific to BRT/LRT.

6.2.15 Asset lives and appraisal periods

Asset lives will differ according to the particular investment.

ATAP guidelines T2 2.4 provides general guidance around asset lives: “It is usual to assume a 30-year life for road initiatives (except bridges, which have significantly longer lives) and a 50-year life for rail initiatives”. This is likely to be a reasonable generalisation for BRT and LRT appraisals. LRT assets typically have a longer operating life than BRT (Neelagama 2014, p.34).

Where infrastructure assets have an economic life that extends beyond the last year of the appraisal period, any residual value of the assets should be recorded in the assessment. As discussed in Part T2 Section 3.3, the Guidelines recommends that:

- Residual value be included in the assessment as a benefit in the last year of the appraisal period
- In calculating residual values, depreciation of fixed infrastructure assets can be calculated on a straight-line basis over the asset life.

7. Gaps in knowledge, areas of contention and possible extensions

7.1 Wider areas of study:

This section lists areas of uncertainty and contention, which require further study:

- A detailed study of how various factors combine to generate the 'psychological rail factor' as recognised by experts (Scherer and Dziekan 2012), which manifests as community preference for rail-based solutions over bus-based solutions even when all other factors are equal. This bias can impact the treatment of BRT in the options generation and assessment process. Factors such as track, vehicle, and station design (impacting net trip comfort), as well as familiarity with BRT in the community, can reasonably influence the extent of this bias, while other factors such as service frequency and reliability need to be corrected for because they are not tied to any specific mode, but rather how each particular service operates.
- There are mixed results on the land use impacts of BRT versus LRT, after correcting for service frequency and reliability. The range of observed impacts on land value uplifts can be similar. However, the perceived permanence of a project can greatly influence impacts here. Community perceptions are subjective, making this a contentious issue.
- The energy and emissions performance of BRT versus LRT is contentious and a complex issue. While LRT is generally perceived as performing better than a traditional diesel-fueled bus on these aspects, the comparison depends on actual local power supply sources. In addition, different technologies and power sources can change the equation. New BRT systems powered by diesel-electric hybrid motors can have better lifecycle emissions performance than LRT under some circumstances (Neelagama 2014, p.111). Therefore, emissions performance is highly sensitive to the particulars of each project.
- Cross mode elasticities of demand for BRT/LRT projects are often informed by previous projects. However full BRT is relatively rare in some Australian cities, with some BRT-like bus-based projects not meeting full BRT standards. There is likely a gap in understanding the demand impacts of a relatively novel mode (in some cities) such as BRT or LRT.
- Costs and benefits specifically related to autonomus vehicle operation in the context of public transit applications, taking into account that shared roadway autonomus vehicle operation is still in its infancy relative to rail-based operation in fully sealed environments.
- Estimates of unit costs which could be used to undertake rapid appraisal (as per ATAP M1).

7.2 Related projects:

This section lists a number of potential investigations that would benefit the assessment of not only BRT-LRT options, but also other public transport modes:

- Construction externalities, including disruption to the transport network, users and businesses, and their trearment in CBA.
- Development of a method and metric for quantitatively measuring (and eventually predicting) ride quality and comfort for a given service, taking into account various in- and off-vehicle factors and what impacts they have, e.g. track or surface quality vs on-vehicle or in-seat suspension.

- Development of a formula or guideline for predicting the minimum service frequency at which passengers change behaviour from planned arrival at stops to random arrival, which could potentially be used in the definition of “turn up and go” services.
- Provision in ATAP M1 of an overview in of the different tiers of public transport (an extension of Table 1 and Appendix A here), including definitions of tier, mode, vehicle and service terminology to facilitate greater consistency in planning across Australia
- Development of guidance similar to this document for other tiers of transit (e.g. local and feeder transit, mass transit, commuter, regional, interstate and intercity transit).

Appendix A Glossary

Mode terms

Term	Definition
Medium Capacity Transit (MCT)	The tier of public transit provision between Local/Feeder and Metro services. Usually for trips no longer than 25-35 minutes door-to-door. May be either Semirapid or lower-end Rapid service.
Bus Rapid Transit (BRT) service	An MCT public transport service provided using buses within a dedicated right-of-way.
Light Rail Transit (LRT) service	An MCT public transport service provided using light rail vehicles (LRVs) with a dedicated right-of-way.
Rapid service	A transit service that runs in a largely exclusive alignment (Right-of-way Category A), which is either grade-separated or afforded absolute priority at all intersections in order to minimise random delays and unreliability (Vuchic 2007 p50-51).
Semirapid service	A transit service that runs in a protected alignment (Right-of-way Category B), such that the flow of vehicles is only interrupted by other traffic at intersections (Vuchic 2007 p50-51).
Street bus service	A bus service that runs almost exclusively on-road in mixed traffic (Category C Right-of-way).
Tram (streetcar) service	A public transport service provided using trams (streetcars) travelling on rails, primarily on-road in mixed traffic.

Vehicle terms

Term	Definition
Bus	A large vehicle used for providing transit services on a road surface.
LRV (Light Rail vehicle)	A large vehicle, or a set of articulated units, used for providing transit services along an LRT corridor. Distinct from "Train" mostly by dimensions, weight, and capacity
Trackless Tram	A type of articulated, driverless bus that can operate in both directions via a painted guideway instead of requiring tram tracks. Typically uses bogie technology similar to trams and other rail vehicles, instead of the fixed axles of a regular bus.
Translohr	A type of combined bus and tram vehicle, which uses rubber tyres for traction but overhead wires and a central ground-level conductor for the power supply.
Tram (streetcar)	A large vehicle, or a set of articulated units, used for providing transit railed services along a mixed-traffic corridor. Distinct from "Train" mostly by dimensions, weight, and capacity.
Train	A very large vehicle or a set (consist) thereof, used for providing transit services along a rail corridor. Distinct from "Tram" and “Light Rail” mostly by dimensions, weight, and capacity.

Alignment terms

Term	Definition
Right-of-Way (ROW)	Legal terminology for the legal right of a pedestrian, vehicle, or ship to proceed with precedence over others in a particular situation or place. In this guidance, it relates to the land reserved for exclusive transit use.
Category A ROW	From Vuchic (2007 p47), a transit alignment that is usually segregated longitudinally (parallel traffic), vertically (grade-separated) and horizontally (intersections) such that vehicle flow is unrestricted by conflicting movement.
Category B ROW	From Vuchic (2007 p47), a dedicated transit corridor which does not interact with other traffic except at intersections; and such intersections are generally designed to prioritise transit services above private traffic.
Category C ROW	From Vuchic (2007 p47), a transit service that operates on infrastructure shared with all other types of traffic, public and private, and as such is exposed to far more variables that can impact service frequency, reliabiltiy and speed.
BRT corridor	The right-of-way and fixed infrastructure required to operate a BRT service. Routes or segments operating entirely in Category A Right-of-way, may be called a Busway.
LRT corridor	The right-of-way and fixed infrastructure required to operate a LRT service.
Mixed Traffic	See Category C ROW.
Tramway	A set of tracks intended for the exclusive use of trams, excluding all other traffic. Historically also used for railways that couldn't use that term for legal reasons.
Railway	A set of tracks intended for the exclusive use of trains or similar vehicles, excluding all other traffic.

Technical terms

Term	Definition
At-grade crossings	An intersection where multiple routes cross at the same height, requiring one to wait for the other. In high-traffic environments, usually signalled for safety and to reduce delays. Includes all types of road and rail intersections, as well as cases where either intersects with a cycling alignment or footpath.
AM Peak	Services arriving at the city end of their trip between 0700-0929 on weekdays.
Axle Load	The maximum weight applied across any given axle of a vehicle, to the track or roadway below.
Bogie	A small box fitted below a vehicle, containing at least two axles and wheelsets. Capable of rotating in three axes to absorb impacts from an uneven surface or track alignment, and usually permits higher speed operation for a given level of comfort.
Bunching	Delays to a service causing following services to depart with very short intervals, resulting in long gaps in what would otherwise be a high-frequency service.
Closed	When applied to a vehicle, one that is only capable of running on certain alignments. When applied to a route, does not permit vehicles to enter/exit, so all passengers have to interchange.

Term	Definition
Consist	A coupled group of vehicles, which can be split if required.
Counterpeak	Services operating during peak hour (either AM or PM), but in the opposite-to-majority-demand direction.
Dwell time	The time a vehicle spends at a station, stop or platform for the purpose of unloading and loading of passengers, including time to open and close doors. Does not include extra time built into the schedule to allow for driver change-over or to allow for late-running.
Grade of Automation (GOA)	A measure between 0-4 of how many functions of a transit vehicle and system are automated, up to and including driverless operation.
Grade separated	Use of bridges or tunnels to segregate two or more routes that would otherwise intersect; helps to avoid delays and capacity constraints.
Headway	The minimum time between vehicles passing a specific point, after taking into account all safety measures based on braking distance from the maximum permitted speed, plus an allowance for overspeed and driver reaction time.
ICE	Internal Combustion Engine
Inline Stop	A stop or station platform adjacent to the main road or track, rather than offset so vehicles leave and then re-enter the main route.
Interlocking	The system that checks whether, for example, tracks are set correctly before providing a green signal to an oncoming vehicle. May include enforcement of emergency brakes if a vehicle passes a red signal.
Loading Gauge	The maximum height, length, width and overhang of a vehicle to be permitted on a given route.
Marchetti's Constant	The hypothesis that human societies generally have a commute time, averaged across the population, of around 30-35min each way per day. In practice there is a significant skew towards shorter trips, balanced by a small number of people who are comfortable with much longer trips (or who commute less often, giving the same average per week) (HILDA 2012; BITRE 2016).
MU	Multiple-unit control; allows a single driver to operate multiple coupled vehicles, even with intermediate trailers.
Offline Stop	Stops parallel to the main right of way. Vehicles have to exit the ROW to access the stop, then re-enter it afterwards, while express services remain on the ROW and skip the stop completely.
Open	When applied to a vehicle, one that is able to run beyond the boundaries of dedicated infrastructure. When applied to a route, allows vehicles to enter/exit, providing trips with fewer forced interchanges.
Overlap	Borrowed from heavy rail, the emergency stopping distance for a vehicle from a given speed, after allowing for driver reaction time and with a margin of error. Generally measured in metres for infrastructure purposes, or seconds that will have elapsed for service headway purposes.
Peak-of-peak	The busiest 15-minute window in the AM or PM peak, measured by patronage or number of vehicles.
PM Peak	Services departing from the city end of their trips between 1600-1829 on weekdays.

Term	Definition
PPHPD	Measure of capacity for passengers per hour, per direction, at any particular stop or node. For longer periods, may be expressed as, for example, PP2HPD.
Turn Up And Go (TUAG)	A service which runs often enough that passengers do not need a timetable; often defined as 6VPH or greater (evenly spaced), although passenger behaviour continues to change from planned to random arrivals well beyond that threshold, up to 12-20VPH.
Track Gauge	The distance between the tracks of a railway, measured between the points where the wheels make contact with the rails (i.e. the centre of the silver stripe on each railhead). Most, but not all, tram systems around the world use 4’8½” = 1,435mm. For instance, Japan and Hong Kong both have some systems built at 3’6” = 1067mm gauge.
Transit-Oriented Development (TOD)	Development within a certain radius (walking time) of, and because of, a new or upgraded transit station.
Turning circle	The minimum radius of curve permitted for a particular vehicle at a given speed, measured to the centreline of the curve and excluding transition curves either side.
VPH	Vehicles per hour; sometimes TPH for trains or trams; or BPH for buses. For longer periods, may be expressed as, for example, VP2H.

Cost-Benefit Analysis (CBA) terms

Term	Definition
Base Case	A CBA is always a comparison between two alternative states of the world–the Base Case and the Project Case. The Base Case is the state of the world without (i.e. in the absence of) the proposed initiative. The Project Case is the state of the world with the proposed initiative or option.
Cost-benefit analysis (CBA)	An economic analysis technique for assessing the economic merit of a proposed initiative by assessing the benefits, costs and net benefits to society of the initiative. Aims to value benefits and costs in monetary terms wherever possible and provide a summary indication of the net benefit.
Consumers' surplus	The surplus of consumers' willingness-to-pay over and above what they actually pay for a given quantity of a good or service. It is measured as the willingness-to-pay area under the demand curve above the price paid
Benefit–cost ratio (BCR)	Ratio of the present value of economic benefits to the present value of economic costs of a proposed initiative. Indicator of the economic merit of a proposed initiative presented at the completion of cost-benefit analysis. Commonly used to aid comparison of initiatives competing for limited funds.
Elasticity	A mathematical measure used in economics to describe the strength of a causal relationship between two variables. An elasticity value can be interpreted as the percentage change in the dependent variable in response to a one per cent change in the independent variable
Externality	An effect that one party has on another that is not transmitted through market transactions. An example is noise pollution from vehicles: those operating the vehicles disturb other parties such as nearby residents, but a market transaction between these parties is absent. It is generally assumed that the party generating the externality ignores it in their decision-making.
Generalised cost	The sum of money price and user cost. Synonymous with private generalised cost.

Term	Definition
Option value	The value that consumers place on being able to keep an option available, even though they may never in fact choose it. For instance, habitual air travellers may be willing to subsidise a competing train service in order to be in a position to use it if the need arises.
Project case	A CBA is always a comparison between two alternative states of the world–the Base Case and the Project Case. The Base Case is the state of the world without (i.e. in the absence of) the proposed initiative. The Project Case is the state of the world with the proposed initiative or option.
Producer surplus	Producer surplus is the difference between the price at which a producer is willing to supply a particular good or service and the price the producer actually receives.
Strategic Merit Test (SMT)	An assessment that provides a first-order determination of the ‘strategic merit or fit' of solving an identified problem, and/or the proposed initiative to solve the problem. Part of the process of early-stage filtering of options, identifies proposals that should proceed to the next stage of appraisal, proposals that require further scoping, and proposals that should be abandoned because they lack strategic fit. Also includes checks to ensure that the initiative has been properly formulated and is feasible.

Appendix B BRT/LRT options identification checklist

ATAP BRT/LRT Options Identification checklist

Project strategic context:

Identify the projects overall strategic context, this may be identified through government policy, commitments or XXX

Project problem definition:

Identify the problem that the project is trying to solve. There may be more than one problem in which case identify all that are known.

Is the project seeking to:	Yes/No	If Yes, provide metric
Improve accessibility? (Yes/No — if Yes, provide metric)		
Relieve congestion? (Yes/No — if Yes, provide metric)		
Improve travel times?		
Enable development?		
Other		

Project known constraints:

Identify the projects known constraints, these may be easily identified or may be more difficult to ascertain.

	Yes/No	If Yes, provide details
Budget		
Timing		
Topography / Terrain		
Integration with existing lines, vehicles or stations		
Integration with existing ticketing, information, IT systems		

Demand

Estimate the required peak and off-peak demand, as a sensitivity range for a future period.

	Lower Limit 10years	**Upper Limit 10 years**	**Upper Limit 30years**	**Upper Limit 30 years**
Expected peak demand				
Expected off-peak demand				

Minimum service standards:

Estimate the required service levels required, upon completion and in the future

	Upon completion	Future 10years	Future 30 years
Minimum frequency:			
Morning peak			
Interpeak			
Afternoon peak			
Evening			
Weekends			
Span of service:			
Hours per day weekdays			
Hours per day weekend			

Corridor characteristics:

Estimate the required service levels required, upon completion and in the future

	Upon completion	In future
Typical available width of corridor		
Width at pinch points or constraints		
Width at station locations		
Within street corridor or alongside street corridor?		
Level crossings or signalised intersections?		

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