FREQUENTLY ASKED QUESTIONS AND THE MYTHS OF TRACKLESS TRAMS

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By

Marie Verschuer

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PURPOSE

The following list of frequently asked questions have been compiled to assist those interested in Trackless Trams better understand the advantages and limitation of the technology and the areas where further research is needed. Information has been sourced from manufacturers, literature review and from study tours conducted in 2018 and 2019 to view and evaluate the emergent and latest technology suited to the provision of mid-tier prioritised public transit. This FAQ document is ancillary to the reports and case studies prepared as part of the SBNRC 1.62 Sustainable Centres for Tomorrow research project.

FREQUENTLY ASKED QUESTIONS

1. *What is a trackless tram (TT)?*

A trackless tram is a rubber tyred, high capacity vehicle suited to a corridor transit system equivalent to light rail. The vehicle in its design and internal layout is more closely aligned to a tram or light rail vehicle than to a bus as it has six innovations from High Speed Rail that have been transferred across. It travels in a dedicated corridor and should have signal priority to ensure smooth running free of traffic congestion. It is a smooth ride quality as it has sensors that anticipate bumps in the road so the vehicle adjusts its rail-like bogeys. It is a quiet electric vehicle with batteries on the roof. It has wide doors typically 2 per carriage, one each side. Boarding is from all doors adjacent to the platform. It has a low floor and level boarding enabling easy access for prams and wheelchairs. It may have metro style limited seating that provides for the maximum number of passengers and wide aisles. The driver is in a cabin at the front of the vehicle and it could be driverless but this is unlikely in mixed traffic and can be useful in over-riding the guidance to go around blockages or to drive to the Depot at night. The vehicle has distinctive styling which is easily recognised. It has a known and simple route and regular and frequent running so that it is timetable free if used properly. Onboard, via apps and at stations there is electronic up to date route information provided. It is part of an integrated networked system and usually would be seen as a mid-tier prioritised transit service that connects across the city along main roads.

The TT technology is rapidly developing as shown below. The vehicle offering is diverse and there are currently several manufacturers developing products that will potentially meet the requirements of this emerging global market but with some having extra features. The technologies offered by the various suppliers will be required to meet interoperability and transparent procurement requirements, so ensuring that implementation would not result in becoming 'captive' to any one supplier. There has been emphasis in the research on the Chinese CRRC ART as this appears to have significant 'crossover innovations' and is considered at present the most light rail-like of the vehicles in service.

Trackless Tram Type Vehicles currently in operation

2. *What is a mid-tier prioritised transit system?*

A mid-tier transit system is one that provides direct and prioritized routes, primarily in dedicated lanes. Unlike buses the route is more direct being confined to priority transit corridors and not winding through local streets this provides a more efficient and legible service.

There is a wide variance in electric transit vehicles that could be considered for use in a BRT or TTS. Most of the available electric buses have the look and feel of a conventional bus. It was considered that although the electric operation provides a smoother and quieter ride the electric vehicles alone may not be perceived by patrons as different enough to induce increased ridership or support redevelopment. The above examples of TTS vehicles suggest that stylised electric buses that provides a more tram like service have a higher quality image and that this together with improved access could result in increased ridership and city development but the more tram-like the better.

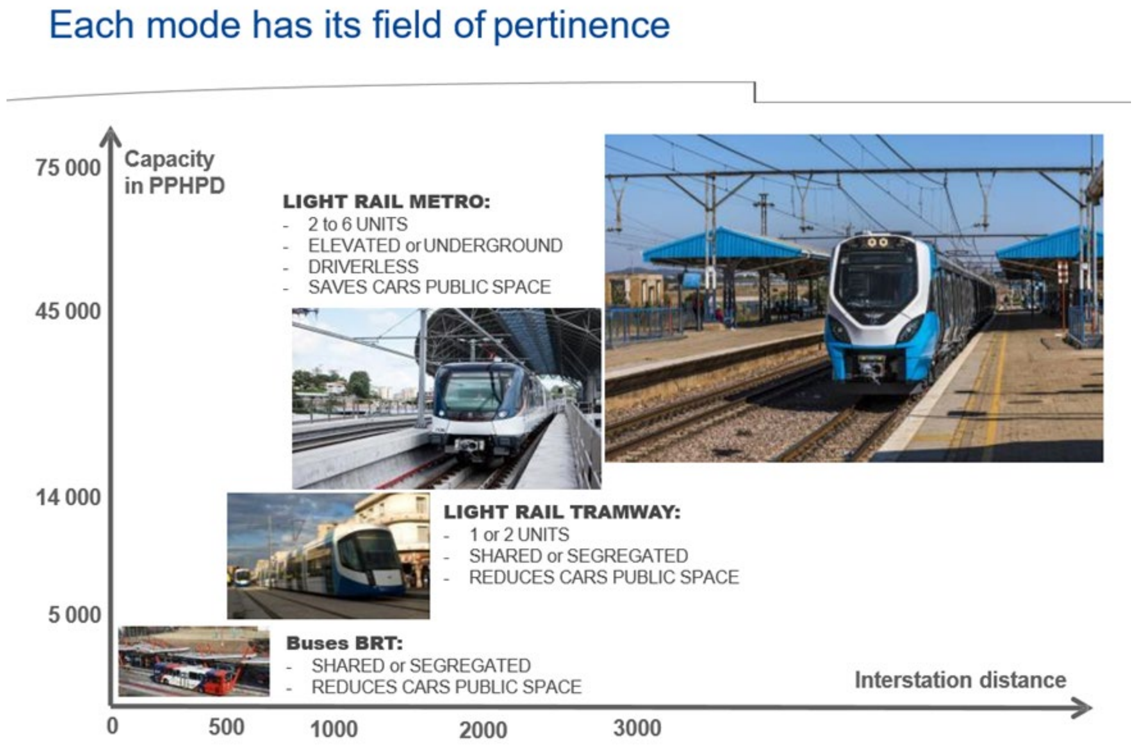
Other vehicle specific features that can help achieve this are:

- Level boarding
- Contactless ticketing
- Completely flat floor throughout the vehicle
- Generous width
- Floor to ceiling windows
- Opening doors on both sides
- Opening door at very rear of vehicle
- Study/ teen spaces (eg. at back of bus)
- USB chargers/wifi
- Inviting lighting and use of quality interior and exterior finishes eg wood laminates
- Incorporating curated locally-relevant art-work
- Four-wheel steering
- Driver assistance tools to enable “close to kerb” parking.

The Irizar i.e.-tram and the Van Hool Exqui.City are two leading examples of vehicles that were experienced in operation and these meets most of the above attributes. Studies undertaken by transport agencies of services in Metz, Malmo and Belfast have found that the vehicles are well regarded by patrons and have resulted in increased patronage by approximately 30% in the early days of demonstration.

Other vehicles such as the Alstom Aptis a 12metre smaller vehicle are also proving to provide an enhanced passenger experience and have attracted industry support with orders for the vehicle exceeding the capacity to supply. The Scania NXT and the Mercedes e-Citatro concept are examples of concept buses that are not yet commercially available but take the passenger experience further.

The Alstom model of the ***field of pertinence***, presented below is helpful for understanding the different roles of bus, trackless tram, and light rail vehicles. Mid-tier transit is denoted by BRT and light rail tramway in this example.



'Field of Pertinence' Alstom 2019

3. Why is this mid-tier transit mode required?

Mid-tier prioritised transit is required to generate connections across the city and support tier-one transit, as well as support growth and development of cities through its ability to enhance urban regeneration. It is often a missing link that can provide significant social, economic and environmental benefits and is usually extremely popular with the communities it services. It will provide equitable and efficient mobility, support urban development, reduce pollution and carbon emission, reduce the space needed for roads, support active and personal mobility modes that improves health and liveability. It is a more efficient and cost-effective way to move people and goods within a city environment than buses and can provide a genuine option to entice people out of cars.

4. *What are the comparative specification data for the different Trackless Tram systems?*

Table 1: Comparative Vehicle Specifications

Vehicle specifications	ART CRRC	LRT vehicle Based on Urbos 3 CAF	Translohr Alstom	ExquiCity 24 Van Hool	Hess electric25 (Brisbane metro)	IE Tram Irizar	Diesel Electric hybrid Bus Crealis Iveco	Aptis Alstom
Length	31m	18-43m	25m-46m	24m	25m	18.7m	18.4m	12m
Width	2.65m	2.65m	2.2m/2.46m /2.65m	2.55m	2.5m/2.55 m	2.55m	2.55	2.55
Height	3.4m			3.3m	3.3	3.4m	3.56m	3.4m
Boarding height	330mm	356mm	350mm	330mm	330m	330m	330mm	330mm
Low floor	100%	100%	100%	100% +slope	100%	100%	100%	100%
Doors	6 double 2 single	8-20 suit to length			4- 3double 1 single	5	3	3 double
Articulated sections	3	2-7	2-6	3 bi-artic	3 bi-artic	2	2	no
Overall weight	48t - 3 car set	34.8t - 3 car set	23t - 44t	24t			30t	
Axle weights	Drive 9t Non driven 8.5t		9t		11ton	Drive 11.5 t Steer 10.5t	Drive13t Steer 11.5t	
Passeng er Capacity	307	129-327	178-358	178	190 Hess/150 BM	155	150	95
Passengers per m2	6	4	6	3.4	3	3	3	4
Max Speed	70kph	70kph	70kph	70kph	90kph	70kph	70kph	70kph
Max Gradient	13%		13%		15%	18%		
Axle number	6	3 bogies		4	3	3	3	2
Suspension	Bogies	Fixed bogies					hydraulic	4 steerable wheels
Running way	Line guided	rails	Centre guide rail	none	none	none	none	none
Turning circle	15m	25m	10.5m	12.2m	11m	23m	12m	8m
Range	65km @100%	1.4km	1.4km	70km	40km min	70km	na	200k up to 6 hours
Power supply		750vdc			600kva		Electric trolley	

5. *Why should Australia adopt new technology like a Trackless Tram?*

Australia like most countries is investing significantly in transport infrastructure to address increasing urbanisation, rapid population growth and environmental sustainability. It is particularly needing to address how zero carbon transport can be implemented. The transport sector is evolving with advances in vehicle, infrastructure, data and communications technology and Australia needs to be part of this evolution. Australia's mining industry is leading in innovation in vehicle automation for large trucks and is moving towards electric and solar-based systems in their remote locations. By working on similar solar-electro-mobility in cities the two arms of innovation can enable us to be part of this emerging future. The transition to electro-mobility will not only result in more efficient public transport and other innovative electric vehicles, but will create new jobs. If Australia can develop leadership in this research and innovation there will be possibilities of manufacturing the systems here as well as developing an electro-mobility services industry supporting growth of our knowledge economy exports.

6. How can Australia lead in this new technology of Trackless Trams?

There is an imperative to move quickly to progress these new and rapidly emerging technologies to the benefit of Australian cities and position Australia as a leader in this field through a Trackless Tram Trial and Demonstration Project.

In order to progress this initiative, the project is proposed to consist of 3 stages.

- Demonstration and Familiarization - To assess the attributes of available vehicles and to produce an evaluation framework that will assist in selecting vehicles suited to community need and the specific urban environment
- Vehicle and System Testing in Closed Environment - To develop and test a set of system and vehicle standards to ensure resilient, adaptive and compatible interoperable systems - this is most important as the enabling technologies are evolving very quickly and the system will need to be able to adapt to advances in technology As most projects are being implemented to support urban development and regeneration the system will need to be integrated with the existing network and scalable.
- Field Trials - To provide government, industry and community confidence and awareness of the opportunities presented by the technologies through engagement and collaboration that can enable full global certification of the Trackless Trams. Many cities are waiting for Australia to show this leadership.

7. What are the lessons from the ART vehicle operation in Zhuzhou?

- The rutting of part of the pavement resulting from 1 year of operation suggests the ART vehicle as currently configured could require a higher quality pavement constructed for heavy vehicle use. The rutting occurred in an area where a temporary road was built and hence may not be a good test. Other parts of the road did not have rutting. This needs more careful testing.

- The ART demonstration line was flat and straight, and the vehicle did not exceed a speed of 40 to 50kph. As such it was difficult to assess the performance of the technology at the time of visiting in 2018 and 2019. The Yibin service routes commenced operation in July 2019 and these are demonstrating a higher operating speed and have curves and moderate gradients; thus a visit to Yibin is planned in 2020 to assess impact of the first year of operation. It will provide a better indication of the ART's comfort in real-life conditions when going around corners and over cambered roadways
- The ART uses all systems to operate autonomously (LIDAR, radar, GPS and visual line guidance) and cannot achieve full autonomy without all systems available. This limits fully autonomous operations and requires the presence of a driver. The full autonomous capability of the vehicle was demonstrated, and it is possible that this function could be utilised within specific circumstances such as within the depot or station docking (similar to the Alstom LRT trials) where the necessary enabling infrastructure exists. This staged adoption would assist technology refinement and acceptance. It is noted that signalling and communications

infrastructure is required and the introduction of 5G will further support autonomous vehicle deployment.

- In 2018 the ART was able to dock in stations precisely due to the autonomous technology in its guidance system. By 2019, due to pavement damage at stations the vehicle did not autonomously dock at the station within a distance compliant with disability codes, this was achieved with driver intervention.
  Post tour consideration relating to pavement by Stantec and Arup is provided below:
    - Although the ART has a 4 ½ T wheel load, we assume that it will tread heavily due to a relatively high un-sprung mass – each wheel has a hub motor and steering equipment.
    - The ART wheels are an odd size and the single tyre is having a significant influence on the point loading, which is evidenced by the observed rutting of pavement.
    - Pavement construction may involve up to 1.0m deep granular pavement, and around 0.5m with Foam Bitumen Stabilisation (FBS), all with structural AC layers. The pavement itself will be somewhere between $1.2M-$1.9M per lane.km. This doesn't include establishment, QA, traffic management, line marking, etc.
    - There are other possible options, e.g. cement stabilisation, but that will require quite high percentages of cement, and there are other issues associated with this, however the cost will be similar.

Zhuzhou pavement deformation at ART station

Example of concrete pavement at station in Amiens France BRT Nemo service.

8. Will all buses and TTS in the future be electric?

There is a clear and rapid shift in the bus industry towards electric vehicles. The new buses in Brisbane are electric, and the ACT is committed to going electric in its bus fleet. Almost 95% of the vehicles displayed at the 2019 UITP conference were electric (battery/fuel cell). At a recent UN conference, the head of Volvo Bus said that if procurement included the lifecycle of the bus then EV buses were now cheaper than diesel buses. The maintenance costs of electric vehicles is 25% less than ICE equivalents and this will reduce further as the industry adapts with greater availability of skills and services.

Implementing electric bus technology carries potential operational risk as with all new technology, and a critical role of government will be to work with operators to manage this risk and ensure high quality service delivery for customers. A Trackless Tram program can be part of a city regenerating its whole vehicle fleet to be electric and with this may come some other challenges and potential benefits in the recharge system.

9. How will the vehicles be recharged and what could this mean for the grid?

The charging of electric transit vehicles can occur through either: (1) Opportunity charging –"refilled" with electricity while on service (normally at each end of the route for approximately 20 minutes); (2) Flash charging where super-capacitors enable a 40 second top up; and (3) Slow charging – "refilled" over the course of a number of hours at the depot (e.g. overnight). Battery configurations and density are evolving, and it is important to factor in changes when considering the need and place for on route charging.

Recharge Hubs can be provided at stations or at particular precincts where it is considered the electricity grid can handle recharge from a range of electric vehicles. Recharge Hubs should be fast recharge facilities linked to community batteries. These could be used to recharge Trackless Trams, electric shuttles, electric taxis, electric bikes and any other electric vehicles that need to bring people to a station precinct. The Recharge Hub can be a major contributor to the grid and provide storage and use for household solar in an affordable and efficient way. This would benefit both the community through more affordable living and the State through more efficient service delivery. This will require research and demonstration as part of the transition to a zero carbon city.

The modernisation and electrification of on road public transit and the improved service efficiency achieved through corridor transit systems, along with high quality urban design and station infrastructure, are expected to help with urban regeneration that is attractive for people who would want to walk and use transit as the main part of their mobility; they can also help with those who want to use an electric car but also want to have a more balanced and less car-dependent lifestyle.

10. How can precincts be designed to enable TT Technology?

A detailed study by SBEnrc has elaborated seven principles for how to make station precincts attractive for the introduction of Trackless Trams. The seven principles are set out in Table 2 below.

Table 2: Practices informing the Framework for designing and implementing Centres of Tomorrow

Practices informing the principles	Key literature references	References and resources for good practice
1. Precinct safety and accessibility		
• Human centered design	(Gudowsky, Sotoudeh et al., 2017; Russo, Lanzilotti et al., 2018)	Design Kit (IDEO.org)
• Walkable urban design	(Forsyth, 2015; Badland, Mavoa et al., 2017; Litman, 2017)	Pedestrians First (ITDP.org)
• Place and movement design	(Carmona, 2014; Wunderlich, 2017)	Movement and Place Framework (Transport Victoria)
2. Carbon neutral - positive approach		
• Solar passive design	(Horvat and Dubois, 2012; Futcher, Mills et al., 2017)	A focus on Greening our Precincts (Aurecon)
• Solar active design	(Kanters, Wall et al., 2014; Mohajeri, Gudmundsson et al., 2019)	Solar Energy (International Energy Agency)
• Carbon neutral analysis	(Liu, Zhou et al., 2014; Tozer, Klenk et al., 2018)	Carbon Value Analysis Tool (World Resources Institute)
3. Local shared mobility		
• Local mobility design	(Hüging, Glensor et al., 2014; Lyons and Practice., 2018)	Pedestrian Access and Mobility Plan (NSW RTA)
• Feeder transport design	(Cole, Burke et al., 2010; Venter, Jennings et al., 2018)	Principles of Network Planning (Griffith University)
• Mobility as a service	(Hietanen 2014; Jittrapirom, Caiati et al., 2017)	Rise of Mobility as a Service (Deloitte)
4. Property diversity		
• Community engaged planning	(Bose, Horrigan et al., 2014; Konsti-Laakso and Rantala, 2018)	Resources (Internat. Assoc. for Public Participation)
• Agglomeration economy analysis	(Duranton and Kerr 2015; Jin; Gong et al., 2018; Thisse, 2019)	Spatiotemporal Analysis Framework (Jin et al 2018)
• Financial modelling	(Evans, Foord et al., 2007; Mulley, Ma et al., 2016)	Toolkit for rapid economic assessment of cities (ADB)
5. Property affordability		
• Social housing analysis	(Kraatz, Mitchell et al., 2015; Flanagan, Martin et al., 2019)	Conceptual Analysis (AHURI)
• Life cycle assessment	(Lee, Ellingwood et al., 2017; Petit-Boix, Llorach-Massana et al., 2017; Trigaux, Wijnants et al., 2017; Mirabella and Allacker, 2018)	Applied to Urban Fabric Planning (Gabbarell et al, 2015)
• Sustainability operational analysis	(Gunasekaran and Irani, 2014; Yigitcanlar and Kamruzzaman, 2015;	Sustainable affordable housing (Wiesel et al, 2012)

	Nesticò, Sica et al., 2017; Nijkamp and Perrels, 2018)	
6. Nature-loving and biodiverse spaces		
• Biophilic design	(Cabanek, Newman et al., 2017; el-Baghdadi, Desha et al., 2017)	Biophilic Design Initiative (Living-Future.org)
• Water sensitive design	(Seminal: Wong, 2006; Furlong, Dobbie et al., 2019)	Scenario Tool (CRC Water Sensitive Cities)
• Landscape oriented design	(Choi and Seo, 2018; Dennis, Barlow et al., 2018)	Foreground Forum (Inst. of Landscape Architects)
7. Inclusive, integrated, place-based planning		
• Joined up governance analysis	(Keast, 2011; van der Jagt, Elands et al., 2017; Rode, 2019)	A Joined Up Policy Guide (South Aust. Government)
• Partnership analysis	(McAllister, Taylor et al., 2015; Farhat, 2018)	Partnerships Analysis Tool (Vic Health)
• Procurement option analysis	(Grimsey and Lewis, 2017; Hueskes, Verhoest et al., 2017)	National Guideline (Australian Government)

There are relevant examples in using Trackless Trams strategically to improve the perception of public transport. In Strasbourg public art was used widely to overcome community reluctance to the re-introduction of tram technology. Similarly, in Amiens the new BRT uses cartoon images of Jules Verne curated from local artists to identify their buses. Note that advice from TfL is that a quality art strategy requires direct Government oversight (it can't be left to the consultant or builder to deliver).

11. How mature is the TT Technology?

The maturity of the technologies are sufficient that the systems viewed are viable for wider adoption and provide benefits of improved service delivery and customer comfort, economic and environmental sustainability. The vehicles are being deployed with a driver and are not yet fully autonomous.

There was a general view by manufacturers that conceptual fully autonomous vehicles will be ready for deployment within 5 years commencing within the public transport sector where dedicated right of way can be provided. This short time frame and the rapid evolution of these technologies in communications and energy storage require urgent consideration in transition planning of infrastructure or system investment.

The future transport ecosystem will rely on communications and energy to enable autonomy, sharing, connectivity and e-commerce and there needs to be integrated vision of how to equip the infrastructure of the future.

12. How do trackless trams differ from buses?

Trackless trams are more aligned to rail than bus. The suspension systems, electronic control, positioning and stability systems and dedicated running way provide a smoother and faster ride more like a rail system. Autonomous guidance and being fully electric result in less vibrations and noise and smooth acceleration and stopping. TTs have station stops and off-board or contactless ticketing. Passengers' board and exit through multiple doors making this quick and efficient. They have a distinct brand and style. TTs have fewer and more direct routes, these can provide increased frequency of service, reduction in travel times and legibility. TTs carry more passengers. TTs have different seating configurations and wider aisles making them more accommodating of prams, wheelchairs and bicycles. TTs may require interchange to complete the trip, these interchange points are preferably multi modal and offer nodal development opportunities.

13. Are there examples of trackless trams currently in operation?

There are many examples of Trackless Tram type vehicles that have had various levels of success and failure over the past 20 years or more. As vehicle technology advances and battery efficiency and storage improves so does the reliability and success of TTs. Relevant examples are the Van Hool Equixcity vehicles operating since 2015 and now in several cities in the UK and Europe, the Translohr operating as part of the light rail network line t5 in Paris and the Irizar ieTram that has won several awards in 2018 and is running in Amiens, San Sebastian and Barcelona. The ART vehicle operating in Zhuzhou China is the most tram like vehicle and technologically innovative having adapted many attributes from high speed rail and providing full autonomy.

14. Are all trackless trams electric? What different propulsion systems do trackless trams use?

No currently not all vehicles are fully electric with some hybrids and some with hydrogen fuel cell vehicles addressing issues with range. However, the most recent vehicles are fully electric such as the ART and Irizar ie Tram. As battery technology advances more TT's are becoming fully electric so there is predicted to be many more fully electric vehicles in 2020.

15. Why is there a need for a guidance system?

These elements provide improved safety and a more comfortable ride, the vehicle docks accurately at the platform and smoothly accelerates and stops.

16. Some previous guided transit has had limited success - why is this different?

Early guided vehicles such as the Translohr, Adelaide's bus way, Civis Iris bus had issues with first generation guidance technologies. The guidance system proposed is a modern system based much more on digital guidance systems that use sensors rather than mechanical controls. Reasons for failures relate to the maturity and type of the technology.

17. What is the range of an electric trackless tram?

The ART has a range of 70km on a full charge and tops up for 10 minutes at station ends to provide an additional 25km. Dependent on battery capacity some electric buses such as the Proterra have a range of 400km on a single charge.

18. Are the TT vehicles Australian Design Rule (ADR) compliant?

Currently ART or the Van Hool and other European manufactured vehicles are not totally compliant however as with all vehicle developments ADR are reviewed and devised to accommodate new technologies to enable adoption of new technology. A recent example is the modification that has allowed the Van Hool coach bus to operate in Australia previously not allowed as it was slightly wider and made to European and US specifications. ADR issues are related to vehicle width and absence of wing mirrors. Vehicles are compliant on axle loadings. Autonomy will also necessitate compliance review.

19. Trams attract higher ridership is there evidence to suggest that trackless trams will have community appeal?

Level of community acceptance/appeal has been demonstrated by the increased patronage and mode shift that has occurred. For example, the ExquiCity Trambus operating in Mettis reported a 33% increase in patronage in the 1st year when introduced in 2013. The ART is very popular in China and the Intellibus is South Perth was fully booked by people interested in the new technology. It would be expected that considerable community interest would follow the introduction of a Trackless Tram. An Australian study by Currie and Sarvi in 2012 reported that high quality corridor transit achieves a mode shift from private vehicle of 24% to 56%.

20. What is the carrying capacity of a trackless tram?

This is dependent on the vehicle size and internal configuration. Up to 200 persons could fit on a 24 m vehicle like the Equixcity; a 30m ART vehicle can carry 300 persons, this is a maximum loading and would be likely not considered comfortable in Australia with a maximum capacity being more comfortably 240 persons at 4 persons per square metre.

21. How does a trackless tram compare to the patronage of Light rail and streetcars**[1] **in Australia?

These two systems are comparable and to answer this requires consideration with optimal patronage best achieved through a balance of capacity and frequency.

On average each tram route in Australia carries some 6.2M passengers annually or 736,000 riders per route km and 8 boardings per vehicle km. In ridership effectiveness terms, Melbourne routes perform better than those in both Sydney and Adelaide. Per route, Melbourne trams achieve 6.4M boardings annually compared to 3.89M in Sydney and 2.9M in Adelaide. Per vehicle km Melbourne is also highest (8.1) similar to Sydney (7.9) but Adelaide performs poorly (at 3.3 boardings/vkm). Overall average route length of a tram service in Australia is 9.3 kms. In Europe and the UK, the patronage has increased more than 33% from the bus service and is now comparable to light rail patronage.

22. How does the operating cost of a trackless tram compare to a bus service?

These will be comparable when at scale but generally a trackless tram will be two to three times the capacity of a bus service with similar costs as the major operational cost is for a driver.

A good answer should be based on an evaluation of the real driving cycles, the conditions of operation. We do not have information as yet for the ART vehicle but as an indication the ExquiCity 24m diesel-hybrid costs between 0.44 and 0.56 EUR per kilometre - excluding tyres and unforeseen events such as vandalism. This is made up of 0.12Eur/km for preventive maintenance and between 0.32 and 0.44 Eur/km for curative maintenance. Based on information sourced from The Lord Mayor's Taskforce Brisbane Mass Transit Investigation: Options for Consideration (September 2007) and the Infrastructure Australia Report Rapid Transit Investing in Australia Future (2014) the maintenance and operational cost estimate for a fully electric vehicle is $4.50 per kilometre approximately, half that of

[1] Light Rail Transit (LRT) is usually used to describe modern low floor trams operating in a right of way separate from other vehicle traffic. Trams are generally considered to be older vehicles often with steps to access the cab. These tend to operate in on-street or "streetcar" contexts but can have some degree of segregated right of way. "Streetcar" operations have an on-street right of way track shared with private car and freight vehicle traffic.

a standard diesel bus. Additional to this are the saving on operational costs if vehicles operate at capacity as 1 TT has the carrying capacity of 3 standard buses.

For a limited trial the maintenance and implementation costs can be higher.

23. What depot infrastructure does a trackless tram require?

The trackless tram if electric needs charging infrastructure at the depot as a minimum depending on vehicle range. The cost and sophistication of this element is fast improving. The estimated cost given for 8 pantograph 250kv chargers and 30 night-time totem chargers for a 30 Equixcity vehicle system was $7.16 m in 2016. A cost estimate for charging infrastructure and depot of $16 for an ART 12 vehicle system was provided by CRRC in 2018 this included the command centre standard facilities, special repair and maintenance equipment and comprehensive monitoring system. Pantograph chargers for stations were approximately $700,000 each (these were 600kv).

24. Can a trackless tram be accommodated in existing bus depots?

Yes. TT vehicles have a turning circle and similar dimensions, width and height, to buses. The Austroads turning path guide allows for long rigid bus (14.5 m) or an articulated bus (19 m) to have a 12.5 m radius at 5 km/h up to a 30 m radius at 20 to 30 km/h. Being bi-directional vehicles can be docked in less space as they will not need to turn around.

25. Does a trackless tram need to run in a dedicated roadway?

No. Similar to a tram in Melbourne, vehicles can run in shared roadways but it is not preferred for operational safety and route efficiency. However, the state-of-the-art guidance and crash avoidance technologies would mitigate against collisions. Shared running also does not convey a sense of vehicle priority.

26. What is the ideal spacing for trackless tram stops?

This varies dependent on built form and level of activity. Indicative spacing of 800m allows for a walk of 400m to stops but longer spacing will enable a faster trip down a corridor and a TT is best serving this mid-tier transit service which is much quicker than a bus that stops every few hundred meters.

27. How long does it take to build a trackless tramway?

Dependent on the running way and vehicle, once planning and procurement of vehicles is addressed the actual construction of route and station could be undertaken within a short period utilising the existing road asset rather than years as in some light rail projects. This is one of the system advantages.

28. Is there a need for a strengthened roadway to address troughing and rutting of the road pavement?

As outlined above, in some instances, this may be necessary as it would be for all heavy vehicles. In Australia the need to strengthen the pavement would be unlikely on roads that are not currently experiencing this wear from existing buses. The guidance system can be varied to ensure the vehicle is not always travelling on the same track; this was done successfully with the Irisbus in the early 2003-2013.

29. Can a trackless tram be driverless?

There are vehicles capable of driverless operation but this is dependent on the operating environment. There has been for some time driverless trains and the Heathrow and Schipol pods that run in dedicated lanes. The ART is fully automated but has a pilot that can take full control of the vehicle, as is the Nayva and Easymile shuttles being trialed in many cities, and the autonomous Volvo and Mercedes buses in trial operation in a Singapore university campus and Schipol airport respectively.

30. What is the required station infrastructure for a trackless tram?

With the standard kerb height of 300mm it could be as simple as a bus stop. The station infrastructure proposed however allows for integration with other modes of transport, conveys permanence and assists with value uplift.

31. What is the turning radius and hill-climbing ability of a trackless tram?

Hill-climbing ability is much better than trams which usually can only do 6% gradients but the Chinese TT can do 13% and other TT's can do up to 15% as set out in Table 1 Comparative Vehicle Specifications. The turning radius is dependent on the TT model; generally, the turning radius is between 10-15 metres at 5km/h which is similar to a single ridged bus.

32. What are the comparative widths of a trackless tram to a bus or standard tram?

The light rail vehicles used in Australia and the ART are both 2.65m being wider than a bus at 2.5m; the European TT models are 2.55m wide. The biggest difference however is in turns and curves. The TTs are much more flexible than light rail vehicles and can take shorter turns.

Comparison to light rail vehicles is difficult as there are some 540 light rail vehicles in Australia and 10 vehicle classes. All use standard gauge tracks but have a wide range of vehicle dimensions. Only 107 trams/light rail vehicles (LRV) or 20% of the fleet are low floor with no step access (from a platform stop). Door numbers range from 2 to 6 per tram/LRV. Interestingly the longest LRV's are in Adelaide (the 100 Flexity Class at 30M and Alstom Citadis 302's at 32m). The shortest vehicle is 14.17m operating in Melbourne it carries 148 passengers and has 2 steps up into the tram. Vehicle width also varies from 2.4m to 2.77m and the carrying capacity from 45+ to 217persons.

33. What is the corridor width required for a trackless tram?

For the ART a 3.6-metre-wide corridor is ideal being slightly wider than the 3.2m standard lane width. European vehicles are narrower and fit in the standard lane. This aspect needs further design investigation with preliminary studies suggesting that there is enough space to accommodate the wider ART vehicle on existing roadways.

34. Is there special driver training required for the operator of a trackless tram?

Yes. Drivers have very quickly adapted to new vehicles and a driver training program is provided by the suppliers of the currently available vehicles.

35. Are there special skills required to maintain a trackless tram?

Electric vehicles have special maintenance requirements from technicians who are familiar with electric vehicles and with the IT systems. As this is an emerging market the skills development is beneficial for the local workforce. Suppliers can provide training and support.

36. What is the maximum people per hour that can be carried on a trackless tram route?

This depends on vehicle size, speed and frequency indicatively 10,000- 30,000 pphpd. The required number of passengers for system viability is considered to be 1,500 per day.

37. Are there examples where trackless trams have demonstrated land value uplift?

A TT system is comparable to light rail and is above a high standard BRT due to its quiet and smoke-free electric system. The TT system would likely yield a higher return on investment due to lower implementation costs and yet similar attraction levels as an LRT. In general BRT has not been found to create much value increase but this depends on the design of station precincts. For example, the Cleveland Healthline BRT and Portland MAX Blue Line LRT leveraged investment of US$5.8b and US$6.6b respectively. The BRT provided approximately 30 times more return on investment due to lower cost. TT have a lower cost than traditional LRT

38. Could a trackless tram run in a green corridor?

A trackless tram could run on a green track. Although comparable in cost a green track is not popular with operators as it requires greater maintenance. It has the advantage of increased amenity, safety and reduced heat island impacts. If desired green tracks could be retrofitted incrementally and could be for selected lengths of track useful to indicate pedestrian areas.

39. What have been public response to the vehicles currently in operation?

Where these are in operation the passengers have a preference for vehicles due to the more tram like experience and space. There has been significant increase in ridership.

40. Some projects have had startup issues how can these be avoided?

It is important to have a trial. The trial will assist in training local staff and resolution of potential issues in design and operating compatibility. When implementing a good start-up and testing plan is required and this would include full manufacturer support during the start-up of the “Full system test” and the “’Go Live” with the appropriate local support team. The planning about the start-up will be organized in relation to the requirements of the project and the specific requirements of the customer.

In general suppliers have 3 options to support a project:

- Send support personnel via short term assignments. This approach was taken for instance for the Exqui.City projects in Norway, Sweden and CRRC in Qatar.
- Locate personnel at the premises of the Customer (long term assignment). This approach was taken for the Exqui.City project in Martinique where one Van Hool employee was installed for 2 years.

- Organize support with trained personnel from the Companies for a local service partner. This approach was taken for the project in Metz.
- Navya in Australia sends staff from France at the time of commissioning and local support is also provided from the Perth team that has a high level of technical expertise. This is useful as assistance can be sourced quickly when required.

The final support planning can be a combination of the above-mentioned options.

A staff training program is very important. Training consists of 3 elements:

- Training of the drivers
- Training of the technicians and engineers
- Training liaison for track training progress. An assessment certification is needed to determine if the training requirement has reached its objective and what further training is required.

41. What is the pavement requirement to accommodate trackless trams?

The ART vehicle has an axle loading lighter than that of a bus or truck and Main Roads preliminary advice is that most of Perth's transit corridors have been designed and constructed to accommodate the weight of a TT. There may be sections that would require strengthening but this can be affordably achieved as outlined above. Some questions still need to be resolved on tyre pressure and suspension implications for pavement design and are best resolved during a trial.

42. What is the recharge time?

The top up recharge time for the ART vehicle is currently 10 minutes for 25km increased range. This is currently 600kw at 3C. As battery technology improves charging time will be shorter. A more frequent quicker charge is possible. Overnight deep charges top the batteries up to provide 70km range.

43. How many kilometres can the vehicle travel before it needs to recharge?

An ART can travel 70 kilometres but it is suggested that it uses only 50% of this range and utilises top up charges at station ends. European vehicles have a 100 kilometre range.

44. How suitable is the system in adverse weather conditions?

The vehicles are not adversely impacted by weather and are stable in high winds. They are designed to operate in temperatures from -25^{0}C to +45^{0}C. The vehicles are air-conditioned.

45. What is the height of the kerb or stop?

The kerb or platform height for the TT is similar to a bus or tram and is between 330-350mm. The ART is 330mm step height and the ieTram 350mm.

46. What is the rider experience?

The rider experience is better than light rail. It is smooth and quiet with no pitch, roll or yaw. Boarding is easy with multiple doors that are level with the platform. Large windows and a wide aisle of 1m and seating made the vehicle feel open and spacious. Onboard information provides trip advice. Phone charging and Wi-Fi enables connectivity.

47. How legible is the alignment?

The alignment is very legible due to the paint lines and the simple direct routes. Stations further reinforce route identity and permanence.

48. What is the minimum stopping time at stations?

Stopping time at stations is as quick as a metro due to the multiple wide doors.

49. What is the weight of the vehicle including the power supply/batteries?

Fully loaded 3 carriage ART is between 48-50 ton.

50. What is the maximum speed of the ART vehicles?

70kph is the design speed but it typically runs at 50kph.

51. Are the ART vehicles available in a range of widths and lengths?

The ART comes in a range of lengths from 2 carriages to 5 carriages and is modular like a train with these being added as needed. The width is not variable at this stage. Other vehicles available have differing widths the Translohr can be as narrow as 2.2m and have a turning radius of 10 meters.

52. Can batteries be exchanged as more advanced battery technologies become available?

With the batteries being arranged in packs on the roof there is ability to change them out easily and upgrade when possible or required.

53. Can the vehicles run in a light rail corridor without interfering with the charging infrastructure?

There will be no problems with electrical interference from a TT just as there is no problem with electric cars.

54. Can stations be used by various vehicles including LRT, bus and double deck bus?

Yes. Stations with a platform height of between 330m to 350mm will accommodate all vehicles as a 20mm tolerance is the accepted standard.

55. What is the availability of spare parts and ease of vehicle maintenance?

Many of the parts that are consumable are from rail or bus and are standard items making it easy to source parts.

56. ***What are the maintenance requirements for the alignment (e.g cleaning of alignment markings)?***

Normal road cleaning and line marking maintenance is needed as currently exists. The ART vehicles have redundant tracking systems and safety or operation would not be compromised by occlusion of line markings.

57. ***Where is the ART operating and how long has it been in service?***

The ART is currently running on a 3km track in Zhuzhou China and has been in operation in public since mid 2018. This 3km line has 4 stations and is to be increased by 9km being a total of 12km. The new city demonstrating the system is Yibin where an 18km system is in operation since 2019. In 2020 a new system will start in Qatar in preparation for the Soccer World Cup.

58. ***What is the service operation of the ART?***

The ART has an operational frequency of 1 every 30 minutes and an operating speed 50kph in Zhuzhou but when fully operating it could service a corridor with a 1 minute space as it is possible to maintain this kind of service with its rapid entry and exit for passengers through controlled doors on stations.

59. ***What is the composition of the ART batteries?***

The ART batteries are lithium ion phosphate batteries.

60. ***Is the ART robust enough to withstand side impact?***

Yes. The vehicle is based on rail carriage desi