Fit for Purpose?
The Design and Technology of Modern Light Rail Vehicles
Tony Prescott

The objective of this paper is to describe the major technology issues of modern light rail vehicles, not only for the layperson, but also for decision-makers who have to select light rail vehicles for city systems from an array of dazzling and usually superficial publicity for different brands and models. It is important to go behind the gloss to see a few facts more clearly.

To most people, modern light rail vehicles, also known as trams, are, on face value, pretty-much standard-design, low-floor articulated rail vehicles that epitomise the modern renaissance of trams in city streets. But behind the façade of the elegant designs and glossy publicity there is a technological scenario still being played out, accompanied by a lot of dubious claims, and all is not quite as simple and straightforward as it seems.

Development of the tram

Light rail vehicles have been around for a long time. By the end of the nineteenth century they were already electric-powered, making them the most advanced land-transport vehicles of their time. They were further developed in the twentieth century, including the development of a low-floor tram in the US as early as the 1910s, until, in the 1930s, the US PCC tram was a thoroughly modern vehicle that could out-accelerate any motor cars of the time and carry far greater numbers of people than any bus. They were able to operate in city streets very easily due to their ability to take tight corners and climb moderately steep hills, unlike a conventional railway, so the streets of many cities, such as Sydney, were often designed or adapted around their original tram systems.

In spite of their huge advantages, including quietness and lack of air pollution in otherwise noisy and polluted cities, trams were wiped from city streets around the world by the popularity of the motor car and the bus after the Second World War. Except in Europe where the tram largely remained the principal means of street transport in cities, it is no coincidence that these cities are regarded as some of the world’s most habitable and attractive. However, as is well known, tramways, light rail, to use a another popular description, are making a comeback as many cities seek to increase the capacity of their transportation, attract riders out of cars, encourage economic development and make cities more efficient and pleasant places to be.

By the 1940s, development of the tram came to a halt in the US and Britain, once two of the leaders in world tram systems. However, in Europe design improvements continued unabated, often using PCC technology, and a large tram industry thrived, particularly in Germany, the former Soviet Union and what is now the Czech Republic. Between 1945 and the 1990s, the Czechs produced some 23,000 trams, largely based on the former Soviet Union and some 8,000. Smaller numbers were developed and/or produced in some other countries such as Belgium, Switzerland, Sweden and Poland. By comparison, the few other world countries operating trams during this period, such as Australia and Canada, produced very small numbers using European-derived designs. Europe was the home of the tram and it was from Europe that the modern ‘light rail vehicle’ has evolved.

While the Czechs concentrated on producing sound, reliable trams for the demanding operating conditions of old European cities with their hills and narrow streets, the Germans, together with the Belgians, Swedes and Swiss, tended to innovate and experiment more, sometimes at some cost to operators! In the 1980s, as part of this approach and because of increased awareness of rights of equal access for the mobility-impaired, the Swiss, Germans and French, in particular, took to the notion of developing a fully-accessible tram, having a low floor that passengers could move in and out of easily at kerb level and also being accessible to wheelchairs. This was the genesis of the modern light rail vehicle.

Today there are estimated to be over 40,000 trams in the world, the vast majority in cities in Europe. Of these, several thousand are modern low-floor vehicles. New stand-alone light rail systems are a growing but still tiny proportion of operations compared to the many great so-called ‘legacy’ systems operating around the world. While the average new system carries less than 50 million passengers a year, often being only the recently-built launching pad for further growth, some of the legacy systems are huge movers of hundreds of millions a year. A summary of the patronage of the world’s largest systems is shown in the attached table. For the tram manufacturing industry new light rail is an important, growing market, but meeting the resupply needs of the legacy systems is core business for many. This means designing trams that meet the historical operating conditions of old European cities with their hills and narrow streets, the Germans, together with the Belgians, Swedes and Swiss, tended to innovate and experiment more, sometimes at some cost to operators! In the 1980s, as part of this approach and because of increased awareness of rights of equal access for the mobility-impaired, the Swiss, Germans and French, in particular, took to the notion of developing a fully-accessible tram, having a low floor that passengers could move in and out of easily at kerb level and also being accessible to wheelchairs.

Typifying the high floor trams of the late twentieth century when over 17,500 of these Czech Tatra T3 PCC trams, and their T4 variant, were built between 1960 and 1990 to become the world’s most numerous tram model, is no.6102 of 1962 preserved at the Prague Transport Museum. These are practical and reliable cars with their only major problem today being that they are not low floor! Although many of the world’s high floor trams have been fitted with low floor sections, new low floor trams are gradually replacing them. Image provided from Wikipedia.
The US Hedley-Doyle low-floor tram of the 1910s which was an early attempt at a low-floor design and expresses perfectly the dilemma faced by designers eighty years later as they struggled to reconcile a low floor with bogies. The Perth Electric Tramway Society preserves an example of this tram. The photo was provided by the Oxley Library, State Library of Queensland and shows a Brisbane car.

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Before we go ‘beneath the skin’ to the real story, it is pertinent to point out the typical features of a modern light rail vehicle, common to almost all manufacturers internationally. Although there are variations on the theme, it can be said that the typical modern tram is an articulated vehicle about 30 metres long but is modular so that additional body modules can be added, or taken away, to make a longer or shorter tram according to customer needs. Vehicles can also usually be coupled together to make a train-like multiple unit for heavy traffic. The vehicles can be unidirectional, driver’s cab at one end only, with a small control panel at the rear for reversing, or bidirectional, full driver’s cab at both ends, and can have any number of doors, either on both sides or on one side only, again according to customer needs. The nose cones at the ends are also modular and some cities choose, at extra cost, to have a unique design for the ends of the vehicle. Within a 30 m bidirectional tram there are typically anything from about 40 to 80 seats according to the number of doors and the service requirements of the operator in different markets, as in more standees vs more seats. Unidirectional trams are used on most high-capacity, high-patronage systems and constitute the great majority of the world’s trams. They can fit up to about 90 seats per 30 m without sacrificing standee capacity. Overall, a 30 m tram can carry about 250 passengers in a crush load, but about 180-200 is regarded by many operators as a more typically comfortable.

The modern low-floor tram

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The most common type of 95/100% low-floor tram on the market is represented by this fixed-bogie Siemens Combino, shown here in Fitzroy Street, St Kilda in Melbourne. Designed for routes with few or large-radius bends, the body-modules crudely ‘steer’ the tram around corners, leading to stresses and wear to running gear, body and track on tighter curves. The original Combino model suffered structural failure as a result of the stresses on the body resulting from the use of fixed bogies on services with arduous track profiles and curves. This Bob Wilson photograph was taken on 20 June 2011.

This Bombardier Flexity Classic tram in North Terrace, Adelaide represents the earlier solution applied when the city has smaller radius curves, typically at street corners in city centres. The tram has rotating bogies under sections of high floor at each end and is only about 70% low floor with internal steps. The middle bogies on this model rotate slightly but in typical multi-articulated trams like the Combino that middle module is short so that their fixed bogie does not generate severe stresses on corners. Scott Mitchell took this photograph on 21 March.

The interior of an Adelaide Flexity Classic showing the step and part-high floor at the end over the rotating bogie. Note the “mind the step” sign and yellow markings! Photographed by Ian Hammond.

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‘full’ load in markets such as Australia where bidirectional trams with a higher seating ratio are preferred. Width of the tram is determined by the system design but a 2.65 m width is preferred in Australia as it enables 2+2 across seating with a generous 700 mm wide aisle which, combined with a generous seat pitch, is much more comfortable space than a bus offers. Performance characteristics are common across brands, with exceptional and smooth acceleration and braking, as well as regeneration of electricity into the power grid. If a city is particularly hilly all wheels will be powered, otherwise only some wheels need to be powered. These are the superficial basics.

However, designing a low-floor tram is a difficult challenge. A high floor tram is able to use normal railway-type bogies that rotate on a pivot point and steer the tram around the often tight curves of a street tramway system, while there is plenty of space underneath the tram for other equipment. In a 100% low-floor tram there is no room underneath and equipment has to go on the roof and in cabinets inside the tram. Solving the equipment-space issue is relatively easy compared to the issue of the running gear wheels and bogies.

To go around a bend or corner a rail vehicle of any practical length has to have wheels that turn, like the steering on a road motor vehicle, usually in the form of wheels mounted on a rotating bogie, otherwise there is excessive wear to the wheels and track, strain on the vehicle structures and the possibility of derailment. Of course with a low floor in the tram there is, in principle, no space under the floor for the bogie to turn so, after a lot of early experimentation with other costly, complex methods such as steerable wheels, the now commonly used solution is to divide the tram into short articulated body modules and fix the bogies rigidly under each module so that in a corner the whole body module turns.

Fine though this concept may be in theory, in reality it is a rough solution and practical only on curves of larger radius, generally of 25 m and above and with transition curves, and, even then, the ride is far from perfect, exhibiting the yawing, side-to-side hunting characteristics of the old four-wheel single-truck trams. Manufacturers invest much effort in damping mechanisms to subdue this characteristic effect. However, many cities have narrow streets and it is not possible to lay tracks around a corner at such a radius without cutting into the footpath or, even worse, shaving back
ABOVE:
The Škoda solution, inside view 1, as seen inside a true stepless tram. The rear-facing seats in the foreground in this Riga 15T are mounted on bogie housings, but the floor is true 100% low throughout the entire passenger area of the tram at 350 mm above the rails, with a 100 mm ramp-over at the bogies, visible in the foreground, located under the articulations and at the rear end in this unidirectional model. The aisle width is a generous 700 mm in spite of the rotating bogies. John Smatlak supplied this photograph.

OPPOSITE PAGE:

TOP:
This interior mock-up of the new Melbourne E class trams by Bombardier demonstrates a tidier example of a ‘95%’ 100% low-floor interior. These trams are based on the Flexity Classic, with rotating bogies, but the high floors have been suppressed, resulting in a ramped floor and narrow aisle to accommodate bogie rotation, evident in this image. As a result of this lower floor there is now a step-up to the bogie seats. The yellow lines delineating the edges of these steps represent an acknowledgment of a safety issue but would not help much in a crush load. Photo supplied by DOT Victoria.

BOTTOM:
The Škoda solution is represented by this Prague 15T, being tested in Plzen in the Czech Republic and shows the rotating bogies placed in such a way that they do not intrude on the passenger spaces. They rotate down to a minimum 18 m turning radius, or 15 m in a depot, the tightest radius of any 100% low floor rotating bogie tram. Four bogies significantly reduce the axle-load of the tram compared to the typical three-bogie 30 m low-floor tram. Photograph supplied by Škoda Transportation.
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buildings. Some long-established tram systems have track radii as low as 11 m, although 16-20 m radius is more common. So the fixed-truck bogie concept has only been satisfactorily workable on new or existing light rail systems where the routes are designed to ensure that the track does not have to take any tight turns. In many existing systems in cities with narrow streets and tight corners, such as Helsinki and Prague, and Sydney for that matter, the fixed-bogie tram becomes a problem, being very hard on both track and tram components, particularly on a busy system where trams may be passing over a curve at the rate of one every minute or two. Many new light rail systems accept the damage of fixed-bogie trams because traffic is modest and a curve may only have a tram passing over it every ten or fifteen minutes, thus somewhat deferring the need for maintenance. In some trams, such as the Škoda 14T, the bogie turns a few degrees and thereby electronically detects the entry into a curve and slows the tram to a crawl to go around the curve. In others, such as the Siemens Combino Supra/Avenio, the bogies turn a few degrees and are positioned in the centre of every body module in such a way as to reduce impact on the curve. 1,2

In Helsinki, where fixed-bogie 100% low floor Adtranz Variotrams, the same model as the Sydney MLR trams, were ordered, it was quickly found under testing that the trams developed excessive wheel wear and severe structural problems from the stresses generated by the tram bogies, while at the same time track-wear increased. The original Siemens Combino was another tram that developed stress-related structural problems. Similarly in Prague and other cities it has been found that fixed-bogie trams increase track wear on corners and have to corner very slowly so as to reduce wear and not derail, thus incrementally slowing journey time if there are many corners to traverse. Another problem from fixed bogies is excessive wheel-squeal noise on corners, very undesirable in an urban environment. 3

So the solution adopted to date in cities where this is an issue is to compromise on the ideal of a 100% low-floor tram and to have only part-low floor trams. In such trams there are conventional rotating bogies at each end and often a fixed bogie in the middle, thus at least partly mitigating the stress-impact of entering curves. There is therefore a conventional high floor over these end bogies, such trams generally having only about 50-70% of their length low-floor.

However, in a growing number of cities operators and passengers have an overwhelming preference for 100% low floor. Not only does the stepless interior facilitate moving around for less mobile people but it is also an important safety feature as it is found that passengers can trip or fall up and down steps during a journey. This is especially significant in a tram because of their capacity, like metro trains, to hold crush loads to the extent that passengers cannot even see where they are putting their feet! For buses, by comparison, this is not such an issue as buses are not intended to hold huge numbers of passengers. In Europe, buses have been developed that are 100% low-floor along the aisle but the wheel-arches and consequent steps up to elevated seats can never be overcome.

So in many cities the nominally ‘low-floor’ tram has become a compromised concept full of big and little steps, both along the aisle and onto little raised platforms with high-mounted seats over the bogies. In a metro train, which is the transport vehicle with the closest functional relationship to a tram, this would be regarded as a design disaster, but it has hitherto come to be accepted as a necessary evil in low-floor street trams. One of the less desirable outcomes has been that some cities that want 100% low-floor have been forced to rebuild parts of their systems to accommodate the fixed-bogie trams that have been the only ones to come with a 100% low floor. The technology that once fitted so comfortably into city streets has had to be shoehorned into a fit.

The Škoda solution, inside view 2, shows the rear end of the unidirectional Prague 15T showing some of the rear seats mounted on the housing for the end-bogie but still retaining a low floor with no platform. The space in the foreground would be occupied by a driver’s cab in the bidirectional version. The uncluttered interior space allows two evenly-distributed double doors per module, or six in a 30 m vehicle, speeding up loading and unloading by allowing 12 people simultaneously to pass through doorways, similar, per length, to a metro train. Trams with the restriction of bogie housings in the passenger compartments can typically provide only three to four double-leaf doors, and perhaps a couple of single leaf doors per 30 m, rarely evenly-distributed and enabling only six to 10 simultaneous movements. A typical Australian bus is capable of only three to six simultaneous movements if all doors are used, although European buses are capable of up to eight. This is another Škoda Transportation photograph.
The Alstom solution is seen in this modified Citadis 301, X04-derived, in Istanbul, showing clearly the extended housings for the rotating bogies at the ends. The bogies rotate down to a minimum 20 m turning radius, or 18 m in a depot. Photo supplied by Kirkor Gullabyan.

The Alstom solution on the inside is shown in this Istanbul Citadis where the ramped floor and raised seat platforms over the bogies in the passenger saloons can be seen. This is another ‘95%’ solution but an achievement nonetheless. Aisle width between the seats appears better than that of the Melbourne Bombardier but the step-up to the seats is higher. Photograph supplied by Kirkor Gullabyan.
Current developments

Fortunately some in the industry have not rested on their laurels and a lot of experimentation, and sometimes rather dubious, complex and expensive solutions, have been pursued. There has been a tendency to try to ‘reinvent the wheel’, so to speak, and the industry has often lost sight of the essential simplicity of the tram and tramway as a concept. So, more recently, the lack of a satisfactory outcome to this process has led to a growing conclusion in much of the manufacturing industry that a return to the traditional rotating bogie is the best way to go for systems with track profile and quality issues.

Much of the independent research on this subject has been undertaken by the Czech international rail research and testing centre, VUKV, which commenced a major study in 1999. Ten years later, Miloš Zelingr, Technical Director of VUKV, and Tomáš Heptner published a paper summarising the outcome of a decade of investigations. Two major manufacturers have already responded to this challenge of building a 100% low-floor tram with rotating bogies for systems with tighter curves and track quality issues: Škoda and Alstom. Škoda has developed a 100% low-floor tram, the 15T, Forcity, with three body sections per 30 m, instead of the usual five, and two articulations per 30 m, instead of the usual four. The body sections no longer have to be located under the two articulation joints, longer. It has four low-profile rotating bogies, two at the ends and two, known in rail parlance as Jacobs bogies, under the two articulation joints, thus enabling the whole passenger floor to be 100% low and having no need for passengers to climb onto internal platforms to access seats over the bogies, indeed the whole of the passenger spaces are clear of such obstructions and there is thus unlimited choice of interior layout. Also because of this, doors can be located anywhere the operator chooses, unlike other low-floor trams where door locations are limited by the location of the bogies within the cabins. This tram is in production and entering service in Riga and Prague.

More recently Alstom has developed a low-profile rotating tram bogie, the ‘Ixege’, to fit under the body modules of its existing Citadis tram and also, if desired, reducing the number of body modules to three per 30 m. Its first use is in the as-yet unreleased Citadis X04 tram, developed by Alstom’s Polish subsidiary Konstal. The first production examples, but with a fixed bogie in the centre have been built as a modified Citadis 301 model for Istanbul. This tram type has rotating bogies where fixed bogies are presently located in the Citadis range, still in the main passenger spaces, thus limiting choice of door locations. The floor in the X04 is level but uses ramps to replace the need for steps. It is ramped by about 120 mm over the bogies and there are still step-up platforms of about 180 mm to the bogie seats, so the tram has not quite fully achieved 100% low-floor and there are thus vertical undulations in the aisle in the passenger compartments, whereas Škoda has confined its 100 mm bogie ramp-ups to the articulations, where they are not noticeable, and to the non-driving end of the unidirectional model. Thus all of the Škoda’s seats are on the flat low level whereas a number of the Citadis’ seats are on step-up platforms. The X04’s solution is thus not as elegant as that of the Škoda, but it is a major step in the same direction using a different approach to bogie location.

Both the Škoda 15T and the Citadis X04 are also of interest for their use of synchronous motors rather than the asynchronious motors commonly used on low-floor trams. Synchronous motors are smaller and lighter which is a desirable quality on such a tram bogie. They can also be fitted directly to the wheel hub without a gearbox, which increases efficiency and reduces maintenance and weight; this is the arrangement in the Škoda but, curiously, the Citadis still uses gearboxes with the motors between the wheels.

A third manufacturer, the Finnish railway rolling stock builder Transtech, has recently been commissioned to produce a low-floor tram with rotating bogies for the unique requirements of the Helsinki system following the problems with the Variotrams. The Transtech tram is almost identical in concept to the Citadis X04; 100% low-floor but again compromised by bogies in the passenger spaces, with high-seat platforms over the bogies and an even more extreme floor ramp-up over the bogies than the X04 of about 160 mm. Helsinki does, however, have to design for a narrow 1,000 mm gauge, which limits the range of theCitadis’ seats are on step-up platforms. The X04’s solution is thus not as elegant as that of the Škoda, but it is a major step in the same direction using a different approach to bogie location.

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The original Adtranz Variotram, the model used in Sydney, had a completely flat floor even in the bogie area. The current Stadler model, still with fixed bogies, pictured here by John Smatlak, has a raised floor but ramped rather than stepped, still qualifying it as a true 100% low-floor stepless tram. The ramps do not create the ideal comfort situation for the seated passengers’ legs but at least are not likely to trip standees or passengers entering and leaving the seats.
the potential for the bogies to rotate in a low-floor tram, so it is not an easy project. As for other manufacturers, none has yet publicly gone down this path but it is likely that some will follow the Istanbul format so that they can avoid development costs by using their existing body designs rather than develop a completely new one as Škoda has. The other of the big manufacturers, Bombardier, is responding to the issue in its contracts for Toronto and Melbourne, both cities with traditional systems with smaller radius curves and, in Melbourne, is using the X04’s design approach on a Flexity Classic base but with low-floor ramp-ups over rotating bogies in the passenger cabins, again with step-up platforms to the seats over the bogies. On the other hand, a conventional multi-articulated type is proposed for Toronto and it will be interesting to see how this performs. It is obvious that the industry is entering a new phase in which aesthetics, passenger utility and running gear are finally to be melded into a satisfactory package. An operationally satisfactory, true 100% low floor tram is a very high design bar to set and it is not surprising that it has taken some 20 years, from the first designs in the 1980s to the start of Škoda’s project in 2005, to achieve some resolution of the conflicting issues. The intensely competitive industry will no doubt not be far behind Škoda’s flying start.

Sorting the facts from the ‘facts’

There are some other detail issues that need to be considered when looking at tram technology and layout but getting a clear picture of those issues from manufacturers’ information is often a challenge. Perhaps foremost is the free and easy use of the term ‘low-floor’, an issue directly related to bogies. It is important to understand, as discussed above, that there are different degrees of low floor:

1. The totally flat, completely stepless passenger floor, perhaps slightly ramped in places, but by no more than about 100-150 mm in all areas that passengers tread, including between seats. This is pure 100% low floor and is represented mainly by the Variotram among fixed-bogie trams and exclusively by the Škoda 15T among rotating bogie trams. This is the best low-floor standard to aim for and most suited to potential crush loading.

2. The 100% low floor, excepting platforms over the bogies that passengers must access by a step to reach the seats, is perhaps better metaphorically described as ‘95% low-floor’! This is represented in many of the supposedly ‘100%’ low-floor trams such as those in Melbourne, where in fact there have been falls and injuries related to the bogie platforms. This tends to bring to attention the possibility of steps becoming a liability issue! The Citadis X04 concept and its derivatives, discussed above, are also in this category.

3. The part low-floor tram represented in many cities, the degree of low floor usually ranging from 50% to 70% and the high floor being at the ends, and sometimes in the middle as well. As stated, this type of tram is acquired for systems requiring rotating bogies but is also favoured by smaller cities with small budgets as in certain markets this type of tram can be much cheaper than a 100% low floor tram. Generally, however, this type is a dying breed as the preference for 100% low floor sweeps the market.

Manufacturers’ brochures often blithely gloss over these differences but the distinction can usually be made through model numbers and names. For example, the Citadis 301 and 401, represented in Dublin and Montpellier for example, is 70% low floor with rotating bogies, while the 302 and 402 are 100% low floor, excepting the platforms over the bogies, with fixed bogies, represented in many French cities and Adelaide, Madrid and Barcelona for example. The X04 is a development of the 301/401. Some Bombardier Flexity models, the Classic and Swift, represented in Adelaide and several German cities, are also part high-floor. Cities buying 100% low-floor trams with fixed bogies usually have generous track curvature in their new light rail systems, radii greater than 25 m because of wide streets, for example, in the case of Adelaide, and/or less frequent services, so they can get by with fixed bogies without a big maintenance cost.

The numerous smaller tram-manufacturers on the European scene have generally confined their product to 100% low floor multi-articulated trams with fixed bogies, the biggest market among new light rail systems and among the most economical to produce, but that 100% is invariably compromised by the step-up platforms for over-bogie seats, read ‘95%’. Some manufacturers’ examples have particularly poorly designed interiors, with bulky plastic mouldings around the bogies resulting in only one seat where there could be two and seats facing sideways towards the aisle. Few of the current manufacturers actually have an established history of tram manufacture and have recently expanded into the field from heavy rail and bus backgrounds, so it is legitimate to question technical issues and to pay attention to detail behind the glossy presentations.

The main inheritors of long traditions of tram design and manufacture are the Czech manufacturers such as Škoda and Inekon, which have inherited the century-long experience of Ringhofer/Tatra, and Bombardier which has inherited much of the German expertise. Alstom has been manufacturing trams since the 1980s and is now a well-established player along with its Polish subsidiary Konstal. Siemens, which inherited, but then closed, the German Düwag concern, suffered a setback with structural failures in its original Combino and has reverted to an earlier 1990s German double-articulated design that is kinder to the track than the multi-articulated fixed bogie trams. Siemens also produces the unique Austrian-designed Ultra Low Floor/ULF, which is designed for street systems without platforms higher than kerb height.

Publicity from tram manufacturers is a bit like publicity from car manufacturers. The astute buyer needs to look past the glossy presentation and flamboyant claims and search out the technical facts. Again, as for cars, these are very hard to unearth from some manufacturers. Sometimes these claims go beyond reality and unfortunately it is not uncommon to read demonstrably wrong claims of ‘the first’ or ‘the largest’ etc. The best manufacturers’ websites contain itemised descriptions of the product range, detailed technical specifications and layout drawings. Unfortunately such detail is in the minority, perhaps understandable if trams were consumer goods, purchased on the basis of the glitzy promotion but later revealing some unfortunate technical shortcomings. However, trams are heavy engineering products with a 30-40 year life for an industry in which, regrettably, too many clients new to light rail are not adequately informed for the task and are constrained by inappropriate tendering processes that are not pitched towards finding the best product for the system, particularly when the tram comes with a ‘turnkey’ consortium package and the client has no input into tram selection. Some incautious authorities in charge of light rail systems are ‘taken for a ride’ by manufacturers and consortiums in more than a literal sense, others are victims of their own inadequate processes and lack of expertise.

Every system should thoroughly road test its proposed purchase before committing, no matter how widely used the model may be on other systems and no matter what computer modelling may predict. Every city is unique. This is fundamental.

Other details

Most other details can be left to properly qualified, experienced and informed technical specialists, who are, generally speaking, from Europe, or at least from Melbourne in the Australian case, working to a set of clearly-defined standards. The loss of institutional knowledge in Sydney was well-illustrated by the under specification of Sydney’s Variotrams in the 1990s that left them unable to climb the ramps at Central in certain wet conditions, resulting in belated fitting of sanding equipment. Sydney’s hills and grades will require trams to have all wheels powered and sanders fitted, a detail easy to overlook when institutional technical knowledge has been lost. A US paper well-demonstrates the need for specialised knowledge and that a heavy rail background is not what is needed for light rail design. It is also interesting to note the US definition of minimum curve radius for ‘light rail’, 25 m, below which a system is considered to be streetcar or tram. Note also that some of the trams listed as ‘low-floor’ are not 100% low-floor, the generalisation discussed above.5

Another example of loss of knowledge and lack of understanding of the essential simplicity of light rail is the fitting of railway signalling systems to tramways when drivers’ “line-of-sight” is the perfectly adequate traditional safeworking methodology. Ironically, not only does railway signalling increase the cost of a tram system, but also it decreases its efficiency and increases the chances of something going wrong. Provision of an adequate power supply is another unglamorous background detail that is sometimes inadequately addressed by those without experience, or trying to save money! On that subject, one issue that does attract the interest of the layperson and decision-maker is the running of trams without overhead wires,
The compromised passenger space in the interior of a Combino Supra/Avenio, the successor to the original Combino, in Almada, Portugal, showing how interior space is commonly wasted in low-floor trams by huge bogie housings in the middle of the passenger spaces. Suspension components intruding into passenger space have cost a potential two additional seats here, or 16 potential seats through the length of this tram. To cap it off, there are step-up platforms to some of the seats as seen in this Mal Rowe photograph.

MODERN LIGHT RAIL VEHICLES

which are considered by some to be aesthetically detrimental. A point to be made first-off is that modern overhead wiring systems have no visual similarity to their predecessors in old tram systems. Today, lighter and tensioned wire is used that is almost invisible to the eye against the typical urban background. The only issue is, not the wires, but stanchions where these are necessary to anchor the supporting wires. In Europe there are many attractive approaches to stanchion design, including sharing use of street-lighting stanchions. In the typical Australian streetscape with its poles and multiple strands of aerial service cables, tram wires are not an issue.

Wireless technology for trams has been around for a long time but has generally proven unreliable and very expensive, being vulnerable to flooding and grime and basically tripling the construction cost of the track. Some new systems are proving more reliable but are generally proprietary and come with only one manufacturer’s tram, something to be avoided. Many manufacturers are now using ultracapacitor, or stored energy technology which is able to move a tram a kilometre or more without wires, usually more than enough to clear any area where aesthetic sensitivity might be an issue. This technology is on the vehicle so involves no expensive infrastructure work on the ground.

Finally, there is inevitably the all-too-common political/financial expedient that up-front costs are given undue weight compared to whole-of-life costs. This syndrome is overwhelmingly evident in Australian governments, which choose up-front cheaper, long-term expensive, buses for mass transit rather than light rail. The same issue applies with tram purchases and their effect on both system and vehicle maintenance costs; cheapest up-front is not always cheapest long-term.

Conclusion

This paper summarises some of the key issues involved in acquiring light rail vehicles and assessing their suitability for systems and indicates that there are plenty of traps for the unwary. It can be concluded from this analysis that cities with easy track profiles and modest patronage can often continue to get by with fixed-bogie and/or part-high-floor trams even though, technologically, both concepts have been recently superseded and usually have little price advantage in any case. Even with new systems, however, maintenance issues will present themselves in the long term. Those big cities with major patronage, with potential for occasional, or frequent, crush loadings and with demanding track profiles because of factors such as narrow streets, tight turns and winding track, such as Sydney used to have, need to look closely at the new developments that synthesise true 100% low floor with appropriate running gear as rotating bogies. At the same time, manufacturers also should be reviewing the ‘95%’ compromise in their nominally ‘100%’ low-floors and eliminating the nasty little trip hazards and step-ups that still abound. These are not buses; light rail is a high capacity mode like a metro and passengers should not have to be watching their feet as they surge around in a crowd.

Most importantly, in making such decisions, there is no substitute for being armed with the right knowledge, the right professional advice and a good set of standards. It is emphasised that direction and management must come from those qualified and skilled in trams and tramways and it is not a field for those with other transport backgrounds such as heavy rail or bus and certainly not a case for political favour or insufficient weighting given to technical standards in the tender process. For vehicles, the appropriate minimum technical standard must be a mandatory component of the selection process; otherwise the wrong decision will have a long legacy.
Low floor trams have most of the floor 350 mm above the rail, that is, 1.8 to 3m (even more), carrying the bodywork in such a matter that it can return to traditional concepts. The wheels are driven individually by a synchronous motor without a longitudinal motor with a bevel gear, a transverse motor with straight gear or a hub motor with planetary gear. The concept of the bogie is related to the system of drive, for example a longitudinal motor with a bevel gear, a transverse motor with straight gear or a hub motor with planetary gear.

### 3.2. Fixed bogies

The low floor trams with fixed bogies have problems with the peaks of leading forces when entering a turn because of the small base area that initiates the rotation of the trams into the turn. In spite of the economic success of the fixed bogie tram, the retreat to older concepts and new innovations has occurred. Underneath the high floor segments are, again, rotating bogies with standard sized wheels (e.g. Bombardier). On articulated trams with [bogies] under the first and last [high-floor] segment, where the leading forces are a major problem, rotating bogies with small wheels are used again (e.g. Alstom, Siemens).

Nowadays there are two concepts of driven rotating bogies for [100%] low floor trams that differ in concept. The Citadis class X[04] has two rotating bogies under the first and last segment and two bogies under the middle segment. The bogies have two synchronous motors; each drives one wheel set on an axle through a bevel gear. The Škoda 15T has a rotating bogie with off-centre bearing underneath the rail. The Škoda 14T. Trams with these bogies form now the largest number of trams made in the last 20 years. It is clear that the use of 600 mm wheels on a rotating bogie would limit the space for passengers very much. Also the use of an axle 300 mm above the rail was not possible. The best solution found was the replacement of a wheel set on an axle with two independent wheels on a welded girder or on a pivoting beam.

This configuration was used on fixed bogies under the short segment in the middle of a three part articulated tram under each of the three segments, or under odd segments of an articulated tram with odd bogie segments and even floating segments. The bogies of this concept are on Siemens bogie with welded girders and Bombardier bogie with pivoted beams. The concept of the bogie is related to the system of drive, for example a longitudinal motor with a bevel gear, a transverse motor with straight gear or a hub motor with planetary gear.

### 3.3. Other solutions

There are other concepts like portal two wheel bogie on the Austrian Siemens ULF tram, or pivoted four wheel bogies with steered wheels on the Bombardier Cobra. They have not come into wider use.

#### 4. Comeback of the rotating bogie

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Both of these trams have a floor height 350 mm above the rail, elevated [by about 100 mm] above the bogies with ramps connecting the two parts.

#### 5. Conclusion

From the trends in low floor tram design it is clear that ways are sought to return to traditional concepts.

The rotating bogie is a key component of classic trams and it seems it will be used in low floor tram design even more.

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**References**


6. Translation of Zelingr and Heptner paper

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**Table**

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**Sources:** annual reports of operating authorities.