Trams Making Way for Light Rail Transit

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Introduction

In 1978, the city of Edmonton in Canada opened the world's first urban transport system based on the Light Rail Transit (LRT) concept discussed in this article. Over the next 25 years, LRT systems have been built in more than 70 cities worldwide. Of the approximately 350 tram systems now in operation, about 30% can be described as LRT systems, because they have been refurbished and modified to LRT standards.

Due to historical differences and different approaches taken when introducing light rail systems, the term 'LRT' means one thing in Japan and another in Europe and North America. This article examines tramways and LRT systems bearing in mind the different definitions and the differences in rolling stock, lines and operations.

Japanese Definitions of LRT

In Japan, there is renewed interest in the possibilities of tramways and the mass media use the term 'LRT' frequently. Moreover, different writers in different countries use the term LRT differently, making it hard for Japanese to understand exactly what kind of urban transit system LRT is.

The term LRT was first coined in the USA in the early 1970s as an attempt to revitalize the image of tramways, which were seen negatively as an out-of-date system not fulfilling the needs of modern urban transit. When tramcars share the right of way with motor vehicles, their transit potential is limited by traffic jams and competition for space. This fact indicated that LRT systems should basically have their own right of way to support faster operations.

The European and North American definition of LRT has tended to focus on medium-capacity, electric cars running on rails. The cars are about 2.65-m wide and operate on their own right of way over elevated track, underground, etc., permitting higher operating speeds. This type of definition could also include many suburban railways.

In Japan, LRT systems are typically viewed as sharing the road with motor vehicles, like the trams in Grenoble and Strasbourg. Although such systems are known as trams or streetcars in Europe and North America, it is often assumed that even low-floor trams are not LRT systems.

Many Japanese cities had tramways in the early 20th century but most abandoned them in the postwar period of rapid growth in private-vehicle ownership when trams were seen as out-of-date. However, the last 20 years have seen renewed interest as it becomes clear that many LRT systems in European and North American cities are helping to reduce automobile emissions and revitalize city centres. Moreover Japan's greying population is creating further demand for barrier-free urban transit using low-floor light rail vehicles. The Japanese are beginning to see trams as a way to reduce urban pollution and improve city life.

Even so, the old trams that managed to remain in operation in Japan when most cities were tearing up tram tracks are generally seen as vestiges of the past. Consequently, when LRT proponents talk about the advantages of LRT systems, they emphasize the differences from tram systems, stressing the modern rolling stock, track and operating systems. Despite this, LRT systems and trams look similar, making it difficult for most people to appreciate the differences.

New LRT systems in Europe and North America are following government guidelines to promote a modal shift from motor vehicles to a mix of pedestrian and public transit, creating environment-friendly and sustainable development. In these regions, LRT systems are seen as a key part of medium-capacity urban transit systems supplemented by links to cars, buses and other transportation modes through Transportation Demand Management (TDM) strategies.

LRT systems fulfil their role as medium-capacity urban transit systems by operating articulated cars that can be up to 40-m long and sometimes the entire train set can total 100 m.

Although some tram operators in Japan are modernizing by introducing low-floor light rail vehicles (LF-LRVs), trams are still not highly regarded as an urban transit mode because most rolling stock consists of 13-m or so bogie cars that are similar to buses. Consequently, we must explain the effective role LRT systems play in urban transit in many European and North American cities to create a consensus favouring upgrading of Japanese trams to LRT systems. Unfortunately, the conditions in Japan are still not right to reach this consensus.

Modernization of Light Rolling Stock

Trams in Japan came to be seen in a more favourable light in 1997 when Kumamoto City introduced models with lower floors about 350 mm over the rail head. Since tram platforms are generally between 200 and 300 mm higher than the road level, low-floor carriages almost eliminate the step when boarding and exiting, which provides nearly barrier-free access for everybody and permits faster schedule speeds. Passengers have always complained about high steps right from the first days of trams but the early 660-mm diameter wheels made low floors difficult to achieve until today.

New York began operating partial low-floor trams as early as 1912. They were called stepless or hobble skirt cars (because women in hobble skirts, which were very narrow below the knees, could board and disembark with ease). The mid-

Stuttgart LRT on own right of way (Author)


Strasbourg LRT sharing road with motor vehicles (Author)

section of the car had a door leading to a low floor with the bogies at the two ends. Similar tramcars ran in the Los Angeles suburbs and elsewhere in the USA, with 176 manufactured for New York. A non-motorized version was built in Europe in the 1920s and was pulled by the motorized cars in a number of German cities.

Today's LF-LRVs use modern motor technologies to cut floor heights to between 300 and 350 m. Switzerland was the first country with genuine low-floor cars in the mid-1980s. During the same time frame, LRT systems were beginning to contribute to urban renewal in the USA; Germany and elsewhere started segregating trams from road traffic and even moved some tracks underground. While these improvements helped boost the role of trams in urban transit it was the appearance of low-floor cars that greatly increased the appeal as people realized that the almost street-level access was very pedestrian friendly. Many cities that had torn up their tram tracks decades earlier began building LRT tracks as part of their urban renewal plans, and cities that still had old tramways began upgrading based on LRT concepts.

New technologies

Development of new LF-LRV technologies has focused on changing the location and configuration of bogies and under-floor equipment to achieve a low, flat floor.

Early developments moved under-floor equipment to the roof or inside the car. The next step was to develop stub axles for the trailing bogies and small-diameter wheels, allowing the low floor to cover about 70% of the carriage floor area (70% LF-LRV). Completely flat floors throughout the cars (100% LF-LRV) were finally achieved by developing independently powered bogie wheels located under the seats (Fig. 1).

Advances in semiconductor technology reduced the size of conventional under-floor control devices as well the need for regular maintenance, contributing to repositioning. Variable voltage variable frequency (VVVF) inverter control transformed the old heavy traction motor into a small, light, three-phase induction motor, eliminating the need for bogie mounting. Insulated gate bipolar mode transistors (IGBTs) also made inverters smaller and more efficient, permitting smaller control and other devices.

Resistors, batteries and other equipment used by regenerative braking as well as auxiliary power units have been unitized and mounted on the car roof. In addition, air brake equipment such as compressors was eliminated by use of electric command braking with a spring-activated hydraulic release mechanism.

Introduction of axle-less bogies opened up the space usually occupied by the long wheel axles to increase the low-floor area. In the early cars, only the non-motorized trailing bogies were axle-less but later 100% LF-LRV designs moved the traction motor to the bogie side. Modifying the drive made it possible to extend the low-floor space over the powered bogie with the wheels extending inside the car under the seats. Single-axle bogies were also developed to reduce the number of wheels, thereby opening up more low-floor space. To obtain a wide aisle over the bogie sections, the bogies are anchored to the articulated bodies so that they barely rotate on curved track.

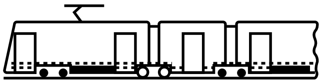
The 70% LF-LRV began operating about 15 years ago followed by the 100% LF-LRV a few years later. In 2003, there were more than 4000 low-floor tram sets in operation worldwide. Although this figure includes units with a low-floor area of no more than 10%, about one-third are 100% LF-LRVs (Table 1).

Due to structural limits, 70% LF-LRVs with conventional bogies must have interior steps, but small traction motors make it possible to lower the floor near the bogies to less than 600 mm. Thus, some 70% LF-LRVs have only one step that passengers can easily negotiate. Unlike in Japan, fare collection in Europe does not involve movement through the car between separate entrance and exit doors, so European tram operators do not necessarily require 100% LF-LRVs. Some operators prefer cars with conventional, highly reliable powered bogies and drive mechanisms, or cheaper vehicles, so these are still being manufactured.

Different models of 100% LF-LRVs have been developed as prototypes and some are being used in transit systems. Each

Figure 1 Low-floor LRV Vehicle Types

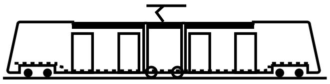
Partial low floor



- Ordinary articulated cars coupled to centre-body low-floor section

Partial low-floor car in Basel (Author)

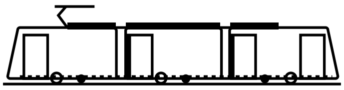
70% low floor



- Trailing bogies with axle-less independent wheels to permit low-floor structure
- Under-floor equipment relocated to roof

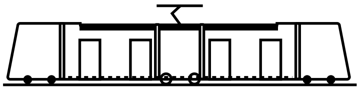
70% LF-LRV in Orléans (Author)

100% low floor



- Powered bogies with car-mounted motors to permit 100% low floor
- Under-floor equipment relocated to roof

100% LF-LRV in Kumamoto (Author)



- Like model on left: axle-mounted motors (hub or small geared motor)
- Under-floor equipment relocated to roof

100% LF-LRV in Hiroshima (Author)

(●: powered wheels; ○: trailing wheels)

model has technical advantages and disadvantages. Two obvious problems are difficult maintenance of the complex mechanical systems as well as the high cost per unit because there are no economies of mass production yet.

Mergers have forced some manufacturers to produce a variety of different designs but they are attempting to unify the various technologies and develop standard models and equipment, aiming for the day when they can begin low-cost mass production.

Standard 100% LF-LRV

Standard low-floor LRVs appeared between 2001 and 2003 and are promoted by their manufacturers, with various names like: *Combino* (built by Siemens and chosen by Hiroshima Electric Railway); *Citadis* (by Alstom); *Flexity Outlook* (by Bombardier and including technology from the former Adtranz); and *Sirio* (by Ansaldobreda). These so-called System Cars are based on many common design concepts and give an idea of the future of 100% LF-LRV designs.

Table 1 World Manufacturers of LF-LRVs in Early 2003

	Bombardier			Alstom			Former			
	Bombardier	Adtranz	Siemens	Alstom	Fiat	Ansaldobreda	Eastern bloc	China	Japan	Total
Partial (under 70%) LF-LRVs	105	102	210	61		32	43		5	558
70% LF-LRVs	446	42	742	301	58	140	157	30	78	1994
100% LF-LRVs	54	732	581	178	117	28			3	1693
Trailers	60			30						90
Total	665	876	1533	570	175	200	200	30	86	4335

Source: Data mainly from Stadtverkehr 2002/12, Metro Report 2002, and Tramways & Urban Transit
Note: Data for China and former Eastern bloc mainly verified but some estimates

Citadis in Lyon (Author)

In some configurations, floating bogieless articulated cars are coupled to short cabs running on bogies. The cabs are spring-mounted on the bogies either directly or in a way that permits slight rotation, ensuring little carriage overhang on curves and a smooth ride. The small rotation on curves, permits construction of fairly wide aisles between the left and right bogie wheels. For example, the *Combino* has an aisle width of between 800 and 830 mm. Different track gauges are supported by changing the position of the beam on the bogie frame inside or outside the wheels.

The structure of the powered and trailing bogies is very similar. A beam links the left and right axle boxes to provide a cantilever supporting the short axles of the independent wheels and permitting more low-floor space. In most cases, the traction motor is mounted on the side beam of the bogie frame and the drive and brake assemblies are mounted as a unit on the powered bogie. The drive for the independent wheels depends on the manufacturer, but all are based on a conventional design that has proved successful in high-floor vehicles.

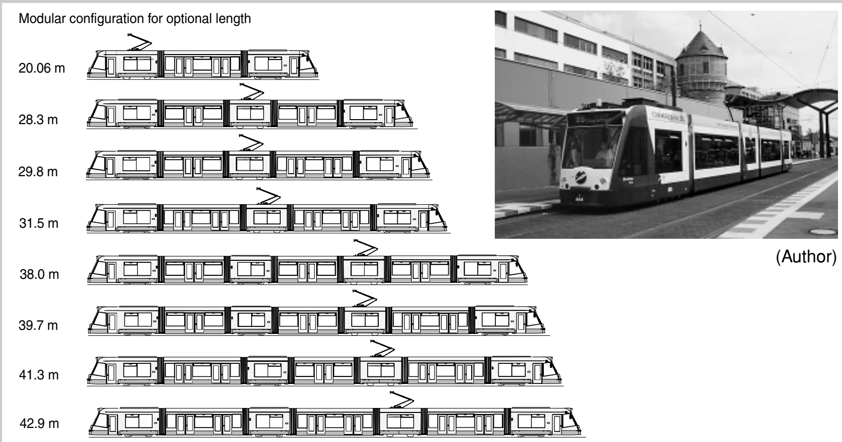
The *Flexity Outlook* sold by Bombardier to Linz (Austria) and Eskişehir (Turkey) has small-diameter 560-mm wheels with conventional axles driven by small electric motors mounted on the bogie frame. The low-floor section is 365 mm above the ground and slopes gradually up to a section that is over the bogies and 450 mm above the ground, making this carriage almost a 100% LF-LRV. The bogies are mounted directly on the car body, which can impact ride comfort depending on the track (especially with regard to vertical wheel/rail interaction). For this reason, Alstom's *Citadis* offers a choice of three bogie types, each suitable for a specific track condition.

Some vehicles are designed as modules that can be coupled together to configure the required length, door positions, and other features. The modules include cabs with powered bogies, trailer cars with trailer bogies, and articulations floating between wheeled units. Modular design cuts costs for manufacturers and increases configuration options for operators. For example, the *Combino* offers 9 possible configurations (Fig. 2), ranging from a three-car articulated vehicle measuring 19 m in length (running in Nordhausen, Germany and Melbourne, Australia), to a seven-car articulated vehicle 43 m in length long (running in Basel, Switzerland and Freiburg, Germany). Operator compartments, windows and other modular units are assembled on the body frame fabricated from aluminium structural parts or welded steel. This simplifies manufacturing and results in a lighter body. The plug doors create a smooth, stylish exterior.

In addition to technical standardization, stiff competition between European manufacturers sometimes results in mergers and takeovers. The above four manufacturers are gradually dominating the market for 100% LF-LRVs, leading to the assumption that standard bodies will become even more prevalent. Bombardier presently makes a number of different drive systems, because of commitments made during mergers, but it intends to standardize on the axle bogies used for the *Flexity Outlook*.

Equipment standardization and modular body designs are driving mass production, which cuts both manufacturing prices and delivery times for 100% LF-LRVs. For example, Amsterdam placed a simultaneous order for 155 cars and took delivery of more than 100 just 1 year later.

Figure 2 Modular Design of *Combino* Trams



ULF tram in Vienna (Author)

Little Dancer A3 in Kagoshima (Author)

Other 100% and 70% LF-LRVs

Some cities are independently developing and running their own 100% LF-LRVs. Vienna has a growing fleet of ultra low floor (ULF) LRVs. Vertically mounted traction motors have lowered the floor to a surprising 205 mm above the ground, and there are plans to put 150 of these units into service soon. Zürich has developed its own low-floor *Cobra* tram with an electric traction motor mounted on the car and a special drive system for the single-axle steering bogie. Six vehicles have been completed.

However, many operators prefer 70% LR-LRVs, because they are cheaper and dependable. Bombardier's recently released 70% low-floor *Flexity Classic* is operating in Dessau and other German cities. Frankfurt and Halle are already operating 100% LF-LRVs and have decided to augment their fleets with the *Flexity Classic*. Alstom's 70% low-floor *Citadis* has been chosen by new transit systems in Montpellier, Orléans and Valenciennes in France, and in Dublin in Ireland. New 70% LF-LRVs are also being developed and manufactured in the Czech Republic, Poland, Spain, and China. Some models have attracted US buyers, partly because of low prices. For example, Portland in Oregon has bought the *Astra* manufactured by Škoda.

LF-LRV manufacturers in Japan

In Japan, many people think that the country's first LF-LRVs were the two articulated vehicles purchased in 1997 by Kumamoto City from the Adtranz/Niigata Engineering joint venture. However, Japan's first low-floor trams date back to 1955 when Class *Deha* 200 cars were manufactured by Tokyu Corp. for Tokyu's Tamagawa Line (today's Den'en Toshi Line) in Tokyo. They had small-diameter (510 mm) wheels on single-axle articulated bogies, permitting part of the floor to be at a surprisingly low (for that time) 590 mm above the ground. The unusual non-standard design led to the model's withdrawal from service in 1969 but if it was still in the public eye today, it would be seen as a pioneer pointing to today's developments.

Most tramway networks in Japan were abandoned after the 1960s, pushed aside by growth in motor vehicle traffic. With no new domestic demand for trams, technical development tapered off until trams were once again viewed positively overseas. In the 1980s, Japanese companies began developing and manufacturing LRVs, but most were exported rather than used to modernize the small domestic fleet. Since the start of these efforts, Japanese manufacturers have built more than 800 LRV sets, but more than 600 were exported to the USA (some being assembled there). These Japanese-built units helped the rebirth of trams in the USA, a fact that is not generally known (Table 2).

But Japanese development of LF-LRVs was delayed by several factors: overseas manufacturers held patents on many of the basic technologies; low domestic demand increased development risks; and Japanese passengers enter by one door and exit by another, paying the fare before exiting—a system that would be inconvenient in a 70% LF-LRV with internal steps. Because of this delay in development, manufacturers imported most major parts for the low-floor vehicles built in Japan. Since 1997, Niigata Engineering has manufactured 100% LF-LRVs for the Japanese domestic market using Adtranz drive units—five went to Kumamoto City, and one each to the cities of Okayama and Takaoka.

This poor development environment changed in November 2000 when the Barrier-Free Transportation Law was passed. This law requires that operators respect accessibility standards when introducing new rolling stock and provides subsidies as tax relief and tax exemptions to compensate for the price difference between conventional cars and the more expensive barrier-free designs. These changes suggest that more low-floor vehicles should be manufactured in Japan. (Domestically built LF-LRVs would make maintenance easier too.) The new regulations and incentives have created expectations that 30% of all rolling stock in Japan will be barrier-free by 2010.

Nippon Sharyo. was the first company to take advantage of the new standards by manufacturing the Class *Mo* 800 LRV for the Minomachi Line belonging to Nagoya Railroad (Meitetsu). The central low-floor between the bogies slopes up to the two ends and wheels of different diameters are used, making the design quite unusual.

Table 2 Japanese LRVs Sold or Exported

Country	Purchaser	Class	Delivered (year)	No. of carriages	Manufacturer
USA	Philadelphia	9000	1980–82	112	Kawasaki Heavy Industries
		100	1980–82	29	
	Buffalo	100	1983	27	Tokyu Corp.
	Boston	3600	1986	50	Kinki Sharyo
		3600	1988	50	
	Los Angeles	100	1988	54	Nippon Sharyo
		100	1994	15	Nippon Sharyo
	Dallas	100	1995	40	Kinki Sharyo
			1999	55	
	Boston	3600	1996	20	Kinki Sharyo
	New Jersey	100, 2000	1999	45	Kinki Sharyo
	San Jose	900	2001	30	Kinki Sharyo
			2003	70	
China	Hong Kong	1000, 1200	1992	30	Kawasaki Heavy Industries
Total				627	

Country	Operator	Class	Delivered (year)	No. of carriages	Manufacturer
Japan	Sapporo City Traffic Bureau	8500	1985	2	Kawasaki Heavy Industries
		8510	1987	2	
		8520	1988	2	
	Hakodate City Transportation Bureau	2000	1993–94	2	Alna Sharyo
		3000	1993–96	4	
	Tokyo Metropolitan Government	8500	1990–93	5	Alna Sharyo
	Tokyu Corp.	300	1999–2001	10	Tokyu Corp.
	Meitetsu	*Mo* 770	1987–88	4	Nippon Sharyo
		Mo 780	1997–98	7	
		Mo 800	2000	3	
		Mo 880	1980	5	
	Toyama Chiho Railroad	*De* 8000	1993	5	Nippon Sharyo
	Man'yo Line	1000	2003	1	Niigata Engineering
	Keihan Electric Railway	800	1997	32	Kawasaki Heavy Industries
	Keifuku Electric Railroad	*Mobo* 2001	2000–01	2	Mukogawa Sharyo
	Hankai Tramway	700	1987–95	11	Tokyu Corp.
	Okayama Electric Tramway	9200	2002	1	Niigata Engineering
	Hiroshima Electric Railway	700	1985	4	Alna Sharyo
		800	1983–97	14	Alna Sharyo
		3500	1980	1	Kawasaki Heavy Industries Alna Sharyo
		3700	1984–87	5	Alna Sharyo
		3800	1987–89	9	Alna Sharyo
		3900	1990–96	8	Alna Sharyo
		3950	1997–98	6	Alna Sharyo
	Iyo Railway	*Moha* 2100	2002–04	6	Alna Sharyo
	Tosa Electric Railway	100	2002	1	Alna Sharyo
	Nagasaki Electric Tramway	2000	1980	2	Kawasaki Heavy Industries Alna Sharyo
		3000	2003	1	Alna Sharyo
	Kumamoto City Traffic Bureau	8200	1982	2	Nippon Sharyo
		8800	1988–93	3	Alna Sharyo
		9200	1992–94	5	Alna Sharyo
		9700	1997–2001	5	Niigata Engineering
	Kagoshima City Transport Bureau	2100	1989	2	JR Kyushu
		2110	1991	3	JR Kyushu
		2120	1991	2	JR Kyushu
		2130	1992	2	JR Kyushu
		2140	1994	2	JR Kyushu
		9700	1998	2	Alna Sharyo
		1000	2002, 2004	6	Alna Sharyo
Total				189	

Note: An articulated tram set is counted as one car.

This design was followed by three low-floor types—known as the *Little Dancer* series—manufactured by Alna Koki (now Alna Sharyo Co., Ltd.). All have conventional axle bogies. The three types are:

- Single-unit *Little Dancer S* with bogies at extreme ends to permit central low-floor area
- Three-car *Little Dancer A3* with low-floor floating articulation and total of four axles for two cab units (registered as bogie car)
- Three-car *Little Dancer L* with short articulation with axle bogies and small-diameter wheels

Kagoshima City started operating three *A3* vehicles in January; Matsuyama City started operating two *S* cars in March 2002; and Kochi City started operating one *L* vehicle in April. Also in April, Hakodate City took delivery of a refurbished model with a low-floor area between the bogies and internal steps. Nagasaki City started running the three-unit articulated *Ultimate* model in March 2004; the design is an innovative version based on the *A3* and *L* types.

However, all these vehicle designs use existing technologies with a low-floor body placed on conventional axle bogies. Some vehicles do not offer enough low-floor space because of the limitations inherent in the body structure and the overall length. Even so, they have succeeded in the sense that the low-floor sections offer easy access and the vehicles themselves have about the same capacity as a bus, which is considered adequate for a tram in Japan. But these vehicles have not evolved toward the low-floor standards in other parts of the world, where articulated vehicles are common. Structural limitations and the fare collection system do not permit a major reduction in stop times, although boarding/exiting times have been reduced, and these problems remain to be tackled.

However, the future looks bright. Japan's public and private sectors have decided to join forces in developing a narrow-gauge bogie for extra-low-floor LRVs to permit construction of aisles at least 800-mm wide (required for wheelchair users who must move along the aisle to pay the fare when exiting) even when running on 1067-mm narrow-gauge track. The development programme will include work on LF-LRV elements such as ultra-small motors, control and braking devices, and bogie frames. Plans call for the prototyping of bogies that incorporate these elements with a view to launching domestic manufacture of 100% LF-LRVs.

With support from the government, in April 2001, major rolling stock manufacturers joined an association to promote research into bogie technology. The research is focused on development of one type of single-axle steering bogie, and two types of double-axle bogies (one with a hub motor, the other with a beam motor mounted on the side of the bogie frame). There are plans to use the new developments in low-floor articulated vehicles for Hiroshima Electric Railway with a prototype to be built during FY2004. If manufacturing costs are cut, development of 100% LF-LRVs in Japan will encourage more domestic operators to purchase them. Okayama has already taken delivery of Niigata Engineering's 100% low-floor Class 9200, nicknamed *Momo* (peach). So much attention was given to the design of this vehicle that it has a fun-to-ride reputation and shows how cities can use LF-LRVs to improve urban living.

Rubber-tyre trams

A rubber-tyre tram is a type of hybrid between an LRV and a trolley bus with a guide wheel that guides the tram along a central rail embedded in the right of way. It is being developed in France and takes advantage of the LRT concept while providing a more flexible transit system at lower cost. Power is collected using a pantograph and the controls are automatic. Along some parts of the route, the tram leaves the central guide rail and operates under its own power using a diesel engine to generate electricity. With its modular design and low floor, the tram looks very much like a 100% LF-LRV and has about the same capacity, but the rubber-tyre tram is bimodal and can either follow a central rail or run freely on roads. The extra adhesion provided by the rubber tyres enables it to negotiate urban streets with gradients of more than 10% (100 per mill). France has had considerable experience with rubber-tyre transit systems, notable examples being the subways in Paris and Lyon and the new driverless VAL system. As a consequence, it is well placed to carry on the tradition with rubber-tyre trams. There are three systems using different current collection and guidance methods. The TVR (Transport sur Voie Reservée) system developed by Bombardier has begun operations in Nancy, Caen and Rouen (see pp. 17–20).

Freiburg Transit Mall (Author)

LRT Track Modernization

Compared to heavy rail, LRT offers more options when considering where to lay track in urban areas. Indeed, LRT track can be built along almost any city street, and if the streets are too narrow or crowded, etc., the track can be elevated or put underground. Due to this flexibility, LRT track can serve pedestrian districts as a so-called 'transit mall' and many cities worldwide are reporting that transit malls are revitalizing their downtown cores.

LRT has another advantage not enjoyed by similar-capacity automatic guided transport (AGT) systems or monorails—it can be connected to existing railway track to offer through services. This advantage is now being exploited by connecting light rail networks to existing heavy rail lines in order to share the track system by running LRVs on track used previously by suburban and freight trains and by using abandoned rail rights of way.

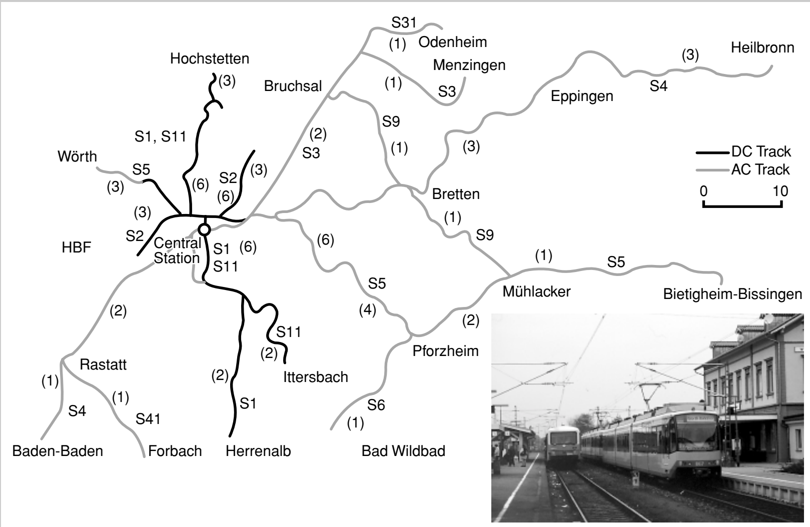
Transit malls to revitalize city centres

Many European and North American cities are revitalizing their centres by constructing pedestrian malls that use nearby city streets as transit routes. Car traffic is prohibited in the pedestrian malls but pedestrians, trams, buses, bicycles, etc., can use them. Americans generally describe these areas as transit malls while Europeans call them pedestrian zones. The problem with the latter term is that it does not distinguish between malls that are served by a public transit system and those that are not.

Transit malls are people-friendly areas for strolling and other urban activities. They are often constructed in city centres that fell on hard times when over-dependence on cars caused road congestion and forced urban functions and businesses into the suburbs. The provision of urban transit into the centre raises the profile and revitalizes it. The transit mall movement began in the 1960s with two successes—Munich Mall (opened in 1970) in Germany and Nicollet Mall (1967) opened in Minneapolis.

Unlike an ordinary shopping mall, a transit

Figure 3 KarlsruheTransit Network



(Author)

Note: Numbers in parentheses ( ) show service frequency per hour

mall is developed in tandem with the transit system that will serve it. Development revitalizes not only the city centre but the overall transit system too. Elevators bring customers to the various levels of tall department stores, while the transit system shuttles people horizontally from one end of the mall to the other, creating the atmosphere of a large, unified zone. The transit system provides convenient access to the city centre, reducing the need for parking lots and helping people enjoy city life without worrying about parking fees. The downtown mall distinguishes itself in a way a suburban shopping centre cannot. Transit vehicles are useful not only for transportation but also add atmosphere to the urban landscape.

In Europe and the US, LRT systems are often chosen as the most suitable transportation for pedestrian transit malls; the consensus is that LF-LRVs are easily accessible to everyone, they promote development of pedestrian-oriented urban infrastructure, and they have shown that they can improve urban living. The worldwide LRT trend has caught the Japanese imagination because it suggests how they can regenerate their own city centres; Fukui City is holding public trials with a view to building its own transit mall.

LRT sharing track with heavy rail

The transit system in Karlsruhe, Germany, has become a test case, proving that a tram network can be linked successfully to an existing railway network to provide through services. Development (since 1992) of rolling stock that can run on both AC and DC power made it possible to run through services between the tram network and the Deutsche Bahn AG (DB AG) heavy rail network. One result was a dramatic increase in ridership. The longest line stretches 124 km from Heilbronn through Karlsruhe to Forbach. Japan has also had success running through services between heavy rail and tram networks and the cities of Gifu, Fukui, Kyoto and Hiroshima currently operate such systems. However, Karlsruhe is the world benchmark, because the tram network expanded its service area and offered through services to the city centre at more frequent intervals with fewer changes from one line to another by taking over the DB AG suburban operations. This flexible approach provided vastly improved services at a relatively low cost and became a model for all cities on how to revitalize rail services. Some 7000 trackside Park & Ride encourage residents to use public transport and enjoy the advantages of both road and rail modes. Another result is that the city centres have remained economically healthy, with less pollution and motor vehicles.

Some problems needed to be resolved before launching the through services. First, the DB AG catenary uses 15 kVac at 16.66 Hz, while the urban tram system uses 750 Vdc. Second, the government regulates the two networks differently, enforcing EBO standards for construction and operation of railways, and BOStrab standards for tramways, resulting in different car structures, signalling equipment, and performance criteria. Third, it was technically difficult to reduce the size of transformers for low-frequency AC power transmission. Operations became possible after development of dual-voltage vehicles with small, light AC/DC transformers satisfying space and weight restrictions on trams (Fig. 3).

The January 1996 German railway reforms transferred jurisdiction from the federal to the state level for granting licences to operate short-distance urban passenger services, and for provision of subsidies. This made it easier to apply the Karlsruhe model elsewhere in Germany, starting with Saarbrücken in 1997 and Chemnitz in 2002. Kassel and a number of other cities are planning similar projects.

In France, Strasbourg and Mulhouse plan to introduce a so-called *Tram Train* based on the Karlsruhe model. Other shared-track projects will offer through services linking electrified LRT networks with non-electrified railway tracks, using light diesel railcars travelling into city centres, or hybrid rolling stock with a diesel generator. As a first step, the Siemens' *Combino Duo* with a 180-kW diesel engine is scheduled to start through services at Nordhausen in Germany using the tracks of Harz Railways (HSB), which is famed for its steam operations.

Grassy right of way in Hiroshima (Author)

Blending in with urban landscape

Strasbourg in France decided to run uniquely designed LRVs that would become a symbol for the city and the strategy has successfully improved the city's image. Today's transit systems are expected to blend in with the surrounding cityscape and add to its aesthetic appeal. Cities planning LRT systems sometimes face opposition from residents who fear that the catenary will be an eyesore.

There are various ways to configure the catenary and supporting poles so that they blend in with the urban landscape. Use of centre poles reduces the number of poles, which can also be erected among trees. On narrow streets, the catenary can be strung from buildings and insulated wire eliminates ceramic insulators.

Going one step further, the catenary can be eliminated by using a ground-based collection system like the LRT launched by Bordeaux in December 2003. Such systems were used by trams years ago in Washington, London and other cities. The various available technologies are promoting LRT acceptance in historic city centres where appearance is important.

Noise pollution is another growing issue; LRT noise emissions are much lower than older tram systems due to new resilient wheel designs and improved tracks. Noise can also be reduced by grassing over the right of way as more cities are doing. For example, Zürich in Switzerland reports that a grassy right of way reduces noise levels by 10 dBA, improving the environment of residential neighbourhoods. In Germany, Infund has developed a system of placing rails over excavated depressions and fastening with poured resin. This system has been adopted in a number of places and further reduces noise and vibrations.

Grassy rights of way are also attractive. In places where they extend laterally into parkland, they form a natural carpet that accentuates the park. Since 2002, the Japanese cities of Hiroshima, Kochi and Kumamoto have grassed some sections of their rights of way for trams.

Modernization of Operations

To maximize its role, LRT must be integrated within the overall transit system. This can be achieved by developing a joint network with existing railways and bus lines, by using Transportation Demand Management (TDM) strategies that encourage Park & Ride and other links with motor vehicle traffic, and by establishing convenient fare-payment systems. In Europe, such methods have greatly contributed to improving the urban fabric and increasing LRT ridership.

City residents favour LRT systems only if they offer relatively high schedule speeds and reliability. Schedule speeds in the West are close to 20 km/h even for LRT systems sharing the road with other traffic (17.4 km/h in Grenoble; 19.2 km/h in Karlsruhe; and 21.1 km/h in Strasbourg). Japanese trams generally average only 10 to 15 km/h, making them unable to satisfy today's urban transit needs.

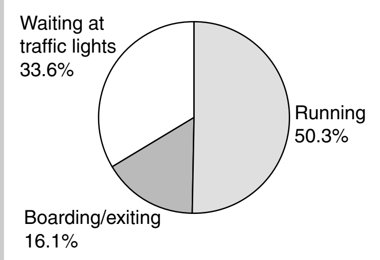
Japanese tram operators aim to raise average schedule speeds to the 20 km/h achieved in other countries but they cannot do so unless the length of times for stops at traffic lights and when boarding/exiting are shortened. Trams in Japan are actually stopped for almost half the travel time (Fig. 4). It is generally agreed that raising schedule speeds requires trams to run on their own right of way with priority at traffic lights and a fare system with no payment when boarding or exiting.

Priority at traffic lights

One way to reduce travel time is to give trams priority at traffic lights. A number of different systems have been introduced to control traffic lights so that trams waste less time waiting at intersections, making it possible to raise the schedule speed.

Priority traffic light systems generally involve either linking tram operations to individual sets of traffic lights, or establishing an operation control centre that coordinates both tram and motor vehicle movements. Generally, a transponder on

Figure 4 Average Operation Pattern of Hiroshima Trams



the tram activates the traffic light, extending the green time or shortening the red time. Some buses have such a system too.

If an operation control centre performs coordination, each tram is located using either a global positioning system (GPS) or ground coils, etc. Wireless signals from the GPS, etc., are transmitted to the control centre, which then controls the traffic signals to give the tram priority. In Zürich, data transmission devices are installed along routes and location code receivers are installed on trams. When a tram passes by, the ground-based device sends a signal via the onboard receiver to a tram control device at the operation control centre. The control centre uses software to calculate the optimum flow pattern at specific intersections and for the general traffic, taking into account the current road traffic information. Trams approaching a traffic light are given priority within these parameters. Tram schedules are input into the control equipment memory and this data is used to compare actual tram locations with scheduled locations. The difference is displayed at the control centre and on onboard monitors, making it possible to bring operations closer to the schedule.

A number of German cities are attempting to optimize traffic flow through information from operation control centres. One example is the Stuttgart Transport Operation by Regional Management (STORM) project in Stuttgart. The aim of this and other such projects is to develop comprehensive operation control systems that give priority to public transport and reduce car traffic.

But LRT vehicles cannot be given priority at all intersections. For example, tramways almost always have to cross major roads and national highways somewhere; in some cases they cross through tunnels, underpasses, etc.

Wireless transmissions

Operation control centres can also use tram location data to control other tram operations and provide information to passengers. In Amsterdam, tram locators are installed along all routes. They transmit wireless signals to the operation control centre where the location data is displayed for all trams. The data is used to give schedule-related instructions to tram drivers and to provide information on departure times at major stops.

Location systems give European LRT operators the opportunity to provide information at stops. The information is displayed on LED panels, and includes the arrival times and destinations of approaching trams. Wireless transmissions from the operation control centre send the data to LED panels along the routes. Arrival data is also transmitted to tram cabs so that drivers can coordinate departure times at transfer terminals shared by buses and LRT vehicles.

Coordination with other transport modes

The biggest difference between tram/LRT systems and other forms of urban transport is that the former are a key urban transit mode in the backbone of the overall network. Buses are feeders for the tram system and the locations where the two systems intersect are passenger transfer points. Suburban Park & Ride facilities provide a link between the car and LRT because free parking encourages people to leave their cars in the suburbs and ride the rails to the city centre.

Coordinated fare systems also promote transit use. In Germany and other countries, transit operations are integrated and joint fare and zone systems are established to offer convenience and easy recognition. To encourage people to choose rail over road, some Japanese operators have recently introduced a reduced-fare pass system, billed as protecting the environment. These and other measures are boosting public transport ridership and reducing car use.

Fare collection systems

In Japan, low schedule speeds prevent trams from becoming the cornerstone of any urban transit system. The fare collection system is one major reason for sluggish speeds. In most cases, the driver verifies that each passenger has paid the fare. The reason is to ensure company profitability and fairness to all passengers, but the time-consuming process keeps trams stopped for considerable periods, increasing travel time.

In the West, the driver is generally not involved in fare collection at all. Passengers are responsible for paying their fare, buying the ticket at the stop or on board and presenting it at the designated place. If the ticket has no date and time stamp, they are responsible for getting it stamped. To inhibit fare dodging, ticket inspectors make spot checks and violators must pay a fine that is many times more than the cost of a regular ticket.

This system began in Europe in the 1960s. It lets passengers board and exit from any door, which also increases schedule speed. Even a long articulated LRT vehicle requires only one employee, reducing wage and equipment costs, and increasing profitability.

Tramways still operating in North America used to have a fare box and an employee verifying payment, but since the introduction of LRT systems in 1978, they have switched to the European system. The motive was putting passenger convenience ahead of operator profitability, since convenience attracts more passengers and contributes to urban renewal. In the early stages, there were fears that fare dodgers would increase and revenues would fall, but stringent random inspections has kept the rate low. This encouraged other tram companies to introduce the new system as a way to cut wage costs. San Francisco's Proof of Payment system is a case in point.

In the West, it is felt that offering greater passenger convenience is more important

Bus & Ride in Portland (Author)

Octopus non-contact card fare payment in Hong Kong (Author)

than preventing a slight drop in revenues. In any case, the revenue drop may be compensated for by the fines. The priority is on lower equipment costs, shorter stops, fewer delays and a smaller wages burden. Meanwhile, governments have tended to promote low-fare policies rather than profitability, to encourage the use of public transport and reduce car traffic.

Japan stands out in contrast; transportation companies are expected to make a profit and the principles of fairness for all passengers and respect for the fare system have created a perceived need to verify each passenger's fare payment. Another factor is that fare dodgers pay a fine that is no more than twice the regular fare. The low fines are regulated by law, making it difficult to adopt an honour system even with spot checks. Fines would have to be raised to Western levels, but this would require legal changes. This environment makes it difficult to change.

One solution is greater use of non-contact IC cards. However, information technology (IT) cannot solve the inherent problems of the honour system, because possession of a card or proof of fare payment would still have to be verified. Hong Kong launched its *Octopus* non-contact IC card system in 1997, but continues with rigorous on-board spot checks to promote use of cards and inhibit fare dodging.

The non-contact IC card might not be a final solution to Japan's fare collection problem, but it is one way to raise schedule speed. The non-contact *Setamaru* IC card introduced in July 2002 on Tokyu's Setagaya Line in Tokyo encourages use by awarding points that can be used to travel for free on a subsequent journey as well as discounted travel on Saturdays and Sundays. If other companies introduce such incentives, cards would become more popular, and if the cards could be used on other operators' networks, the city transit system would become even more convenient. Japan's fare collection system may evolve to take advantage of this potential, but will probably not adopt the honour system used in the West.

The Future

It is important to realize that worldwide interest in trams and LRT systems springs not from a desire simply for modern tram systems but from a general consensus that LRT systems open the door to urban renewal. Although such systems can become an essential part of the urban fabric, like roads, parks, water, and telephone and electric lines, there is a limit to what companies can do on their own to use LRT systems to promote sustainable urban renewal. Responsibility for constructing and improving LRT systems is being assumed by both the public and the private sectors, with financial assistance from national and local governments to support both construction and operations.

In Japan, tram systems (especially vehicles) are being modernized. Increased interest has prompted more than 70 regions to study the feasibility of constructing their own LRT systems. However, only a few cities have any chance of reaching the construction stage, mainly because cars are still considered to have priority on city streets. It is difficult to form a consensus regarding securing land for tram rights of way; urban transit is expected to make a profit and the capacity of LRT systems is limited, making it difficult for the public to differentiate between LRT systems and buses.

These obstacles must be removed before Japanese cities start building advanced LRT systems and that day is probably still far off. ■

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