What's New in European and Other International Light Rail Transit Projects?

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The paper takes a broad look at the pattern and nature of recent developments in light rail transit outside North America. In so doing, it uses a liberal definition of "light rail" to include both conventional street tramways and unconventional automated systems. It looks first at the distribution of the light rail operations and describes the recent revival of interest in light rail in the United Kingdom, including recent developments in London's Docklands. The broad pattern of recent innovation in Western Europe is described with fuller accounts given of developments in Hanover and Grenoble. The paper goes on to review the status of light rail in the Eastern Bloc countries, Japan, and the Pacific Rim. As an example of good state-of-the-art development, the new Tuen Mun line in Hong Kong is described. Brief reference is also made to examples of other forms of innovative low- and intermediate-capacity guided passenger transport, and their attributes are contrasted with modern light rail. It is concluded that the flexibility and performance of modern light rail make it a suitable and affordable technology for improving public transport in a wide range of cities.

OUTSIDE NORTH AMERICA MORE than 300 light rail transit (LRT) systems of varying age and size are in service in 33 countries. As Table 1 shows, this total is heavily dominated by the fairly conventional streetcar systems of the Eastern Bloc countries. All but six systems are in the northern hemisphere, yet one of the largest (Melbourne) is the most southerly of all. Outside the Eastern Bloc, systems are concentrated in western Europe and

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TABLE 1 COUNTRIES OUTSIDE NORTH AMERICA WITH LIGHT RAIL SYSTEMS

Country	Number of Systems	Country	Number of Systems
Argentina	1	Italy	5
Australia	2	Japan	20
Austria	5	Mexico	1
Belgium	5	Netherlands	4
Brazil	2	Norway	2
Bulgaria	1	Paraguay	1
China	7	Philippines	1
Czechoslovakia	10	Poland	14
Egypt	4	Portugal	2
Finland	1	Romania	9
France	6	Spain	3
East Germany	26	Sweden	4
West Germany	31	Switzerland	5
Great Britain	3	USSR	118
Hong Kong	2	Vietnam	1
Hungary	4	Yugoslavia	4
India	1	Total	305

NOTE: Includes systems nearing completion.

Japan. Within Western Europe light rail is used more intensely in the north (especially in the Federal Republic of Germany) than in the south.

Most systems use single-deck rigid or articulated vehicles with overhead power collection (Blackpool and Hong Kong are exceptions with their double-deck vehicles), but track gauges vary considerably. In Western Europe the normal gauge is 4 ft 8 in., whereas in the Soviet Union the standard is 5 ft and in Japan, 3 ft 6 in. The 1-m (39.4 in.) gauge is common in central Europe, but there are a dozen or so others, ranging from 35 in. in Lisbon to 5 ft 3 in. in Rio de Janiero.

Few developing countries have LRT systems, presumably because, during the heyday of light rail construction, the necessary paved streets and electricity supplies were not generally available.

Manufacturers of light rail vehicles (LRVs) are also distributed unevenly around the world, but in rather different ways than the systems. Western Europe unquestionably dominates state-of-the-art light rail systems, with over 20 manufacturers. The Eastern Bloc is the biggest manufacturer of light rail equipment, with Tatra's (Czechoslovakia) production dwarfing that of any western supplier. Japan's limited production reflects its small domestic market. The "higher tech" manufacturers outside these areas (e.g., Comeng of Australia) generally use Western European-derived technology. It is to be expected therefore that in looking into light rail technological innovation outside North America, Western Europe is the principal focus of attention.

LIGHT RAIL IN THE UNITED KINGDOM

The first trams appeared in the United Kingdom at Birkenhead in 1860; however, the number of these horse-drawn systems grew slowly. Around the turn of the century electrification changed this, and the number of tramways grew rapidly up to the outbreak of World War I. During the 1920s trams were at their peak with over 200 systems carrying 15 million journeys in British towns and cities on an average working day. During the 1930s the motorbus started to replace the tram and by the outbreak of World War II the number of systems had halved. Growth in automobile ownership and the consequent traffic congestion this created in the 1950s accelerated the process of closure until the penultimate system closed in Glasgow in 1962 (London having lost its trams 10 years earlier), leaving the sole surviving system at Blackpool. Blackpool is a seaside holiday resort on the northwest coast of England, and its tramway system contained a long coastal line largely segregated from highway traffic and virtually free from traffic intersections. Although the system survived, and still does today, mixed traffic operations were progressively reduced and the system has shrunk to the coastal line.

During the 1960s and 1970s most British cities conducted land use transportation studies, usually along lines developed in North America, and these resulted in transport plans heavily biased towards the needs of road traffic. However as the 1970s dawned and the first oil crisis left its mark, it became clear that plans strongly oriented towards the motorcar were less appropriate and this was clearly reflected in those drawn up for the Tyne and Wear (Newcastle upon Tyne) metropolitan area.

Tyne and Wear

In Tyne and Wear transport plans featured a new LRT system as well as a substantial program of highway improvements. The choice of LRT rather than an alternative bus system reflected the extensive, underused rail rights-of-way that could be adapted by the proposed system to feed into the new tunnel under the city center and bridge across the River Tyne. The system comprises four lines with a combined route length of 35 mi. There is no mixed running and the 39-ton, 91-ft cars operate singly or in pairs with an overhead 1500-volt power supply. With a maximum gradient and minimum curvature of 3.3 percent and 690-ft radius respectively, this system is at the heavier end of the light rail performance spectrum.

After 8 years of operation the LRT system has become the backbone of the transit system in Tyne and Wear and, prior to bus deregulation, ticketing and services were fully integrated with the bus and ferry services in the region. The Tyne and Wear "Metro" carries about a million journeys a week and yields an 8 percent first-year rate of return on the £284 million historic capital costs (about U.S. $501 million at the present exchange rates of $1.7645 per £1). A number of extensions are being studied, including one to the airport, and it may be necessary to use lighter technology on the extensions to avoid prohibitive land and property take.

The other post-war LRT system to be built in the United Kingdom is in London's Docklands and is described below. The success of these two systems, the need to improve the quality of public transport in Britain's metropolitan areas, and the prohibitively high cost of heavy rail systems initiated and reinforced interest in light rail in about a dozen British towns and cities. This interest has been further excited by the potential role of LRT in stimulating urban renewal, which is a major policy issue in Britain's older cities. Systems at the study and planning stage in the United Kingdom are listed in Table 2. Of these, two raise particularly interesting issues.

TABLE 2 LIGHT RAIL SYSTEMS IN THE PLANNING AND EVALUATION STAGE IN THE UNITED KINGDOM

System	Length (mi)
London (Docklands)	4.5 (Beckton)
London (Croydon)	14.5 (1st phase)
Manchester	19 (1st phase)
South Yorkshire	14 (1st phase)
West Midlands	12 (1st phase)
West Yorkshire	14 (1st phase)
Avon	37 (1st phase)
Strathclyde	Unspecified
Lothian (Edinburgh)	Unspecified
Southampton	3
Gloucester	Unspecified

Greater Manchester

Greater Manchester has been considering a variety of rapid transit schemes since the early 1960s and has looked at systems ranging from monorail to conventional heavy rail, but the government funding on which such schemes traditionally rely has not been forthcoming. As the current national administration's transport policies have clarified, it became obvious that any new rail transit scheme would only proceed if substantial private sector participation could be secured. This presented the promoters of Manchester's scheme with a dilemma because, if all the costs and risks of the project were set against the forecast operating surpluses, the balance was not attractive to private funding; yet the project was worthwhile in overall cost-benefit terms.

This project was at the public tender stage in the first half of 1988. The bids were being invited to design, build, operate, and maintain the initial 19-mi phase, which involves 1.7 mi of street running through Manchester City Centre. The successful contractor will be granted an operating concession for a fixed period under which he will be responsible for maintaining the operating assets owned by the client (the Passenger Transport Executive) and operating the railway and will receive the commercial revenues. Work for the initial phase was expected to start on site by September 1989, to be followed shortly by a second phase.

Avon

The Avon transit scheme is being promoted by a private consortium (Advanced Transport for Avon), which already has a parliamentary bill (the process for promoting new railways in the United Kingdom) for the first stage of the system before Parliament. The system would operate for most of its length over disused and lightly used British Rail rights-of-way, but would also penetrate the center of Bristol, the largest city in the area. Long sections of the proposed route run through areas with considerable potential for development and redevelopment and it is intended that the enhanced land values that the new light railway would bring could be captured to help provide the capital needed to build the system. Loans, to be repaid by future operating surpluses, would also be a major source of construction funding.

London Docklands

The most remarkable light rail development in the United Kingdom in recent years is the Docklands Light Railway (DLR). The Docklands area covers about 5,000 acres of land and water and was the site of the historic Port of London. During the 1960s and 1970s port activities declined and moved downstream to Tilbury, which is closer to the main shipping lanes and has the backlands and road access needed for a modern container port. The area opened up a huge urban redevelopment challenge, because it is cut up by the serpentine path of the River Thames and the massive enclosed docks, which make it very inaccessible even though the western parts are within sight of the Tower of London and St. Paul's Cathedral.

To improve accessibility, particularly to central London and the Underground network, a new subway line (the Jubilee Line) stretching from the West End through the City of London and out into Docklands was proposed in the 1970s. Being in a deep tube the line could cross and recross the river, thereby stitching together the main dock areas as well as connecting them to central London. However the high costs [about £800 million at today's price levels] at a time of tightening public expenditure restrictions precluded building this line.

Following the change of government in 1979 a series of new initiatives to promote the redevelopment of Docklands (and a number of other decayed inner city areas) was introduced. The theme was that the public sector would provide the basic infrastructure and, assisted by tax concessions and a loosening up of planning controls, the private sector would handle the main redevelopment task. To carry these ideas through, special development corporations were established; in the case of London this was the London Docklands Development Corporation (LDDC). In 1980 the LDDC, the Greater London Council (which was abolished in 1986), London Transport (the LRT's predecessor), and the government agreed that a package of road and public transport proposals should be progressed as a matter of high priority. Out of this the Docklands Light Railway was born.

The DLR was conceived initially as a manually operated LRT with some street running; careful design and routing allowed a segregated right-of-way to be determined and consequently automatic operation was a possibility. Although the cash limit for the railway of £77 million at outturn prices was set while it was still thought of as being a manual system, with the assistance of a keen design-and-build contract the fully automated segregated railway has been built within budget and program. It is now operating successfully with ridership slightly higher than expected.

The costs of the initial railway were shared equally among the government departments responsible for transport (the Department of Transport) and urban renewal (the Department of the Environment). It presently comprises two lines, one connecting the Isle of Dogs development area to the edge of the City of London and the other connecting it to Stratford, which is both a major interchange with the regional and Underground rail systems and a town center in its own right. It is well on its way to achieving a trading surplus (i.e., covering operating and depreciation and renewal costs out of commercial revenue). Initial teething problems have now largely been overcome and, despite some localized noise problems, operation is generally quiet.

A major objective of the Docklands Light Railway was to stimulate the redevelopment of Docklands and this it has done with a vengeance. Present plans for the area envisage about 100,000 jobs on the Isle of Dogs by the mid-1990s compared with only 10,000 in 1980 when the scheme was conceived. A major element in this redevelopment is Canary Wharf, which is to be a new financial complex with an ultimate size of 12.2 million ft^2, making it larger than the World Trade Center in lower Manhattan. To carry the heavy loadings this development will generate and to provide the direct connection into the heart of the City of London required to make Canary Wharf attractive to firms there, the initial railway is being extended and upgraded.

The extension under the city will connect the DLR into Bank Station, providing direct access to the heart of London's financial district and connections with the District, Circle, Central, and Northern lines on the Underground, and to British Rail's Waterloo and City tube line. The upgrading will increase the capacity from 16 single trains per hour to 30 double trains per hour and ultimately the system will be able to take three-vehicle trains over its most densely trafficked sections. Each articulated car can carry up to 260 passengers. Because the upgraded and extended railway is critical to the viability of the Canary Wharf development, the developers (Olympia and York) have agreed to pay £68 million towards the cost of approximately £156 million. Work is already under way on the Tunnel and Bank Station (TABS) contract and on the upgrading of the existing system. An order has been placed for an additional 10 cars.

Because the present system does not serve the other major development area of Docklands, the Royals area, a further 4-mi easterly extension is being planned. The necessary bill is going through the parliamentary procedures and funding for this £150 million scheme is to be provided entirely from increases in the value of land in the corridor it serves via the LDDC. Although the nature of the development in this area is not as intensive as on the Isle of Dogs, it does include proposals for several million square feet of offices, hotels, a business park, a STOLPORT (already operating), a 26,000 seat Londondome, and a 1-million ft^2 shopping mall. It is intended that construction begin in the first half of 1989 with the opening in 1992. With this extension the DLR is forecast to carry over 80 million passenger journeys per year by 1996—i.e., more than the San Francisco Bay Area system (although journey lengths will be much shorter). A particular feature of this scheme is its integration with both a new highway in the corridor and major developments around the stations.

The possibility of further extensions is now being studied. The most obvious candidate is extending the service down the Isle of Dogs and under the river to the densely populated areas of Greenwich and Lewisham to the south and connecting with the commuter rail network serving the southwest sector of the metropolitan area. This extension also offers the possibility of a better balance of traffic on the several arms of the DLR, thereby relieving the heavy loadings between Canary Wharf and the city. However the committed expansion of the £77-million light railway, in a period of 4 years, to a £400-million network capable of carrying a quarter of a million trips a day means that further early expansion is being treated with some caution.

Studies have been made of other opportunities for light rail in London and several promising possibilities have emerged. An important general conclusion was that there is little benefit to be obtained in a simple one-for-one replacement of conventional rail services with light rail. The operational savings that light rail can bring are also largely available by using new low-cost, lightweight, high-performance stock, with lower manning levels on trains and at stations. The main scope for worthwhile light rail applications lies where its particular attributes of very low-cost stops, improved performance, greater flexibility, and street running capability can be used to advantage.

This conclusion is reinforced by the Railbus experience in the United Kingdom. This used a bus body to form a light (nonbogied), diesel-engined rail vehicle. These vehicles did not perform well or achieve any great cost savings although a similar vehicle is currently being marketed by a Hungarian manufacturer.

LIGHT RAIL IN CONTINENTAL WESTERN EUROPE

Unlike the United Kingdom, many continental countries retained their tramway systems in the face of rising post-war traffic congestion. Undoubtedly a major factor in this was the extensive creation of central areas, usually circumvented by a new high-capacity road within which vehicular traffic was restricted. This often allowed the street tramways to operate in relatively congestion-free conditions in the urban core and gave them a penetration advantage over the private car. As a result there are over 70 light rail systems operating in continental Western Europe. These systems vary greatly in age and extent, ranging at one extreme from the Lisbon tramways with their tiny two-axled cars negotiating 35-ft curves and 14 percent gradients to the driverless, rubber-tired system in Lille.

Naturally the balance of development of light rail in Western Europe is more heavily weighted towards modernization, upgrading, and extension of existing systems than is to be found in the United Kingdom and North America. The main exception to this rule is France, where trams did not survive well and several new light rail systems have been built recently or are under construction. Herbert Felz, Director of Planning and Development of USTRA Hannoversche Verkehrbetriebe, has classified European light rail developments into three main groups:

Group I—Upgrading of existing streetcar systems that involves more exclusive and protected rights-of-way with preferential treatment for public transport at traffic lights (e.g., Basle, Zurich, Karlsruhe, Stuttgart, Cologne, and Hanover). This upgrading often involves renewal of the equipment itself with new modern cars and improved trackwork that is easy to maintain.

Group II—New systems involving running in mixed traffic as well as on exclusive rights-of-way (e.g., Nantes, Grenoble, Utrecht, and Valencia) and new systems on exclusive rights-of-way (e.g., Lille and Toulouse).

Group III—Extension and conversion of existing metro and suburban rail to light rail operation. This will often involve right-of-way features such as steep gradients, tight curves, and street running that can only be negotiated by light rail (e.g., Rotterdam, Stockholm, and Paris).

All of the Group I systems have seen recent modernization and extension. Before describing one of these, Hanover, it is worth identifying the main features of a typical Group I system. The route will be partly segregated, but with significant street operation usually running through pedestrian areas in the city center. It will occasionally have grade separation, usually in tunnel rather than on viaduct. Stations are predominantly low-platform but the cars typically have a high floor, thus making access for disabled people inconvenient. The vehicles are most often six-axle triple-bogied cars between 80 and 90 ft long and weighing 35 to 40 tons each (6 to 7 tons per axle). They will usually operate singly but are sometimes coupled in high-demand corridors.

Improvements to these systems include replacement of rolling stock with more modern designs (often with lower floor heights), line extensions and additional grade separation to reduce the effects of congestion, at-grade priorities (e.g., exclusive lanes and traffic signal priorities), improved trackwork including resilient mountings to reduce noise, and better integration with bus services and surrounding developments.

Hanover

Hanover, West Germany, retained its conventional tramway network, but during the late 1960s and early 1970s ridership began to fall and authorities decided to upgrade the system. The first route was converted from tramway to light rail in 1976 and today 43 of the 60 mi of route have been converted to full light rail. All tramways are to be converted to light rail eventually and the length of the system is to be expanded to 67 mi.

This conversion has involved building tunnels and segregated rights-of-way so that 70 percent of the light rail operation is protected from the problems of running in mixed traffic. Service reliability is improved by the use of green waves in the traffic signal patterns that reduce LRV delays where there are traffic conflicts. Also the use of vehicle location and status monitoring and radio allows centralized service control, which, as well as improving reliability, assists the full utilization of the capacity of the central area tunnels that are shared by several services and can carry 35 to 45 trains per hour during peak periods.

Bus and LRT services are fully integrated with purpose-designed transfer stations with real-time LRT service information. Above-ground stops have a low, raised platform and, at 195 ft long, can accommodate two-vehicle trains. (Platforms on the route serving the fair site are 295 ft long.) In tunnel the stations are 335 ft long with high-level platforms. The 93-ft cars are double articulated and can carry 150 passengers each. They have both high and low steps for above-ground and tunnel operation and are chopper-controlled for smooth acceleration. The light rail system carries about 60 percent of all the public transport journeys in the area and the cost recovery ratio for the public transport in the region is about $^2/_3$ to 1. Public transport ridership rates are approximately 150 trips per capita per annum—a high level of public transport orientation for a city with a population of just over 1 million and high car ownership.

Of the new light rail systems built in Western Europe over the past few years, the most advanced is the Lille system in France. This is a rubber-tired fully automated system that necessarily uses completely segregated guideways. Service headways of as low as 60 sec can be operated reliably and the 8-mi system has been a notable success. However there have been a number of more conventional, but equally important, systems in other French cities, including Nantes and Grenoble.

Grenoble

Grenoble lost its old trams in 1952 and started planning its new system in 1979 and 1980. The objectives were mainly to achieve an efficient and balanced transport regime for the area and also to assist economic development. The Grenoble system, which opened in autumn 1987, represents high-quality, state-of-the-art LRT technology for an onstreet system. The single main line extends for 5 mi and serves 21 stations. The level of sophistication and quality is reflected in the cost of $30 million (U.S.) per route mile (i.e., three times the Sacramento LRT rate). The track is at-grade yet segregated by barriers or by raising it above the level of the adjacent highway. When the line was opened both the other public transport services and the general traffic arrangements were substantially reorganized to help establish the LRT line's role as the spinal transport facility for the city and to facilitate its efficient operation. In fact the route directly serves 40 percent of residents and 35 percent of jobs.

The cars are 95 ft long and high capacity, carrying about 250 passengers (54 seated). They are triple-bogied, six-axle vehicles, but with two-thirds of the floor area only 14 in. above rail height they are easy for disabled passengers to board, allowing unassisted wheelchair access from the low platforms. To achieve this low-floor design, most of the electrics have been installed above the saloon roof. Traction current is controlled by choppers and braking effort is electrohydraulic, making for a very smooth drive. Also, wheel slip is automatically controlled. Similar attention has been paid to wheels and track. The wheels are formed largely of resilient material and have automatic flange lubrication. The track is carefully designed with extensive use of resilient and elastic materials to inhibit structural transmission of noise. On steep curves the rails are lined with antisqueal strips. The combined effect is a smooth and quiet ride.

Services operate at 4-min intervals in the peak hours and service speeds average 12 mph. Service control is centralized using real-time communication and located jointly with the city's road traffic control center. It is forecast that the line will attract 20 million journeys a year, which, if achieved, will make it one of the busiest light rail lines in Western Europe.

The sustained demand over many years for LRVs in Western Europe has resulted in an evolutionary design process that has incorporated general innovations, such as solid-state electronics, as well as technology-specific innovations. The resultant vehicles can have capacities of up to 300 passengers, a top speed of over 60 mph and service acceleration and deceleration rates of 4 ft/sec. Moreover the ride quality and the environmental impact of LRVs have improved greatly over the last two decades. The great strength of this line of technological development is its evolutionary nature in sophisticated operating environments stretching back over many decades.

LIGHT RAIL OUTSIDE WESTERN EUROPE AND NORTH AMERICA

Although the Eastern Bloc with its 180 or so systems has by far the most extensive array of light rail systems, it has not been a major source of innovation for a number of reasons. Low automobile ownership rates and associated centralized policies that favor public transport (witness the opulence and low fares of the metros in Moscow, Leningrad, and Tashkent) have not served to stimulate innovation. Indeed there is a strong orientation towards heavy rail in the Eastern Bloc, and in the USSR transport policy envisages that all cities will have metro systems once their populations exceed 1 million. Light rail vehicle replacement generally uses fairly conventional technology as do the few new lines, such as that recently opened at Volgograd. There are however moves to improve system performance by increasing the acceleration, braking, and cruising speeds of vehicles, but the time it will take to replace the larger fleets (e.g., Leningrad with 2,000 vehicles operating over 350 mi of route) means that the effects on service will be very gradual.

Although Japan has 19 conventional light rail systems, these are fairly traditional and involve extensive mixed running. Typically they are 10 mi or less in route length and services are provided by twin-bogied rigid vehicles driven by 600-volt dc current collected from overhead wires. The longest system is in Kyoto (16 mi) and total length of systems is about 140 mi including the 10-mi high-speed line in Kitakyushu, which is operated by three-section articulated vehicles. Although new vehicles being introduced on a number of systems are good quality state-of-the-art (chopper-controlled, etc.) technology, probably because of the limitations of extensive street running and the smallness of the systems, recent developments have been towards contraction and closure rather than the upgrading and expansion seen in Western European cities. In Kobe, for example, the rubber-tired Portliner has resulted in the closure of the old parallel street tramway, and the same fate awaits that part of the Kyoto system that parallels the new Metro.

Innovation in Japan has frequently been in the form of new systems. The rubber-tired, automatically controlled Portliner in Kobe is being followed by a second line. Similar intermediate-capacity transit systems (ICTSs) have been built on a small scale in Tokyo and Osaka; the Newtram system in Osaka is a derivative of the Airtrans system installed at Dallas-Fort Worth airport. An oriental equivalent, VONA (Vehicle of New Age), is operating at Yukarigaoka near Tokyo. Monorails have also gained a popularity in Japan not found elsewhere, the most recent being the Town Liner at Chiba, which is a suspended system.

An important attraction of light rail is the relatively low civil engineering costs when compared with heavy rail. However the lower-capacity light rail cannot carry the intensity of loadings experienced in many heavy rail corridors. (The peak capacity of 40,000 passengers/hour claimed by the Budapest LRT system is achieved by a continuous stream of slow-moving vehicles.) In Tokyo the loadings forecast for the new Line 12 of the Metro are substantially less than the Tokyo average, yet rather high for light rail (a little under 25,000 passengers/hour in the peak). This has led the designer to opt for small profile stock. This is formed of motorcars 54 ft long, 8.2 ft wide, and 10 ft high, weighing 27 tons each, and with an 88-passenger capacity. This has enabled tunnel diameters to be kept down to 14 ft (compared with the previous standard of 20 ft), which will lead to considerable savings in tunnelling costs. It is worth noting that the London tube tunnels have an internal diameter of less than 13 ft.

There is a growing interest in new light rail systems in Pacific Rim cities such as Manila, Jakarta, and Bangkok. A new system is nearing completion in the New Territories of Hong Kong. In Melbourne two former heavy rail lines have been converted to light rail and linked together to provide through-running across the city center and a new direct rail connection between a lowincome suburb and the beach. Other light rail expansion proposals being developed include an LRT route down the center of an expressway.

Hong Kong

The rapid population growth in the constrained geography of Hong Kong and the New Territories over the last two decades has made improved public transport essential. Street congestion is such that urban rail on its own right-of-way has been the main focus of public transport development in the last decade. As a result the electrified Kowloon-Canton Railway (KCR) and Mass Transit Railway (MTR) have been added to the long-established Island Tramway. Currently a new modern light rail system is being built between Tuen Mun and Yuen Long and is to open in 1988.

Tuen Mun is a new town with a population of 270,000 in the Hong Kong Northwest Territories. It is situated on the coast. Inland to the northwest two new towns of Yuen Long and Tin Shui Wai are being built. Yuen Long already has a population of 65,000 and the first phase of Tin Shui Wai, to house 40,000, is under construction. Tuen Mun will be the main employment and service center for these new communities and thus good accessibility along this corridor is very important. The railway will be operated by the KCR company. Its first phase will comprise a fleet of 70 cars running over a 14¼-mi network and is expected to carry over 250,000 passengers per day. If these loadings are achieved, this will be one of the most intensively used light rail systems anywhere in the world, with route traffic densities of 18,000 passengers/route mile/day, higher than those achieved on many heavy rail systems.

The cars are stainless steel, rigid, 66 ft long, and weigh 27 tons each. They have 60 seats and a nominal capacity of 190 passengers, but up to 275 can get in under crush loading conditions. They can operate singly or in pairs and have a maximum speed of 50 mph and minimum service acceleration and braking of 4¼ ft/sec. Power is collected via a pantograph from overhead wires at 750 volts dc. The traction current is chopper controlled with regenerative braking. The vehicles are air conditioned with rubber and air bag suspension, and particular care has been taken to produce overheads and supports that are both unobtrusive and robust against high winds.

The 41 stations have raised platforms with ramps to assist access by the physically handicapped. Ticket issuing is by automatic machines that are centrally monitored. The vehicle drivers have direct radio communication with central control and the movement of vehicles across at-grade intersections is automatically monitored. Of the Phase 1 route one-fifth involves street running. Over the remaining four-fifths there are many at-grade intersections with local streets and arterial roads. The route runs through some high-density areas; indeed the plans for the area locate accommodation for 25,000 people above the depot and terminals. Great care is therefore being taken to minimize the structure-borne sound. Along critical sections the running rails are embedded in flexible grout that both reduces vibration in the vehicle trucks and suppresses ground-borne transmissions.

Perhaps the most interesting features of the Tuen Mun light rail system are the traffic priority arrangements. Although most of the route has a segregated right-of-way there are numerous street crossings at grade—37 minor and 19 major. The number of crossings has been kept down by collecting local access roads along a parallel service road that then has a single link across the LRT route. Clearly if the LRT is to give reasonable service, the delays from traffic conflicts at this large number of intersections have to be strictly limited. The idea of "green wave" priorities (as used in Hanover) was considered but rejected as being infeasible in that the required strict adherence to schedules that this would require is unlikely to be achieved with the passenger loading densities anticipated.

In the system adopted each LRV is equipped with an electronic label that identifies it and that can be read by trackside detectors. This technology is borrowed from an earlier electronic road pricing (ERP) experiment carried out in Kowloon. As an LRV comes up to an intersection its approach is detected and a request for a green signal initiated. This request is sustained until the LRV exits the intersection zone. This means that normally LRVs are confronted with a green aspect at most intersections, although, if an LRV comes up to an intersection just after the phase for the LRV has concluded, a few seconds' delay may be encountered. Time "borrowed" by the LRV priorities is repaid to other traffic during the subsequent cycle when it is of no value to LRV operations.

At the great majority of intersections this regime gives a high degree of priority to LRVs. However at a few busy, complex intersections the delays to other traffic caused by giving full LRV priority would be unacceptably high. A reduced level of priority is therefore being accorded and fine tuning will optimize this in practical operation. Overall it will be possible to complete the end-to-end run, which is about 10 mi, in under 30 min even in peak road traffic hours.

NEOLIGHT RAIL SYSTEMS

Over the years many "cousins" to the light railway family have appeared. The majority of those that have survived have carried out tasks that were in some respect beyond light rail. Thus the aerial tramways of Switzerland and Japan, the ropeways of Burma, and the funiculars in places such as Georgetown (Penang) in Malaysia and Hong Kong are not just different technologies but truly different modes of transport. Other novel systems have been tried from time to time but relatively few have survived. An exception to that rule is the suspended monorail at Wuppertal, West Germany.

Since the late 1960s, when urban transit became a potential area of diversification for the aerospace industries of a number of technically advanced nations, there has been a steady stream of new technologies that, in their transportation function, overlap the applications traditionally covered by light rail. Some recent and current examples are listed in Table 3. These only include systems that have reached the stage of successful trials or beyond. There are many other systems that have not gotten that far.

Given the very large amount of effort put into LRT innovation, the results are really rather disappointing. The systems offer little by way of improvements in acceleration, braking, or speed, and those that offer some exceptional capability (e.g., SK's maneuverability) usually sacrifice general performance to this end. Perhaps the only real exception to this is the O-Bahn, which combines the advantages of tracked systems for line haul with the flexibility of the bus for collection and distribution.

The main innovations lie in the areas of traction, suspension, vehicle control, and vehicle size. Linear induction motors are now established as an alternative to rotary motors where dedicated and protected rights-of-way are available but have not yet demonstrated much advantage under normal operating conditions. Rubber tires and magnetic levitation can produce a ride significantly better than steel wheels on steel rails, but only with cost and lateral control penalties. Automated vehicle control is a feature of almost all the new systems (O-Bahn being a notable exception) and, provided a protected operating environment is available, this of course can be used by light rail systems (e.g., Docklands Light Railway). The ability to reduce vehicle size offered by many of these systems can be an advantage in low-demand applications, and light rail is probably not as flexible as some other systems in this respect, although the Belgian TAU system, with its meter-gauge track, 40-ft-radius curves, and 28-ft-long vehicles (6 ft 8 in. wide), shows that miniaturization of modern light rail is feasible and can lead to substantial savings in civil engineering costs.

The general lesson from recent attempts to innovate in this area is that there are no systems offering major advantages over conventional light rail. Features such as automatic vehicle operation can be applied to light rail in the right environment. Rubber wheels can have ride and noise advantages over steel wheels on steel rails, but these have to be weighed against the complex and bulky guideways needed by rubber-tired vehicles unless they are steered. Probably the most interesting recent development is the O-Bahn, which combines the flexibility of the bus with guided transit. However the inability

TABLE 3 INNOVATIVE LIGHT RAIL TRANSIT SYSTEMS OUTSIDE NORTH AMERICA

System Name	Manufacturer	Type	Development/Application
Aeromovel	Coester Air Train	Conventional steel wheel and rails driven by compressed air	A 0.5-mi test track is in passenger operation in Porto Alegre, Brazil
Aramis	Matra Transport	Small rubber-tired vehicles, electric propulsion and electronic coupling	Demonstrated at Orly Airport in the mid-1970s; new trial track being built at Boulevard Victor (Paris)
C-Bahn	Messerschmitt-Bölkow Blohm	Linear induction motor (LIM), small/medium vehicle sizes	Prototype tested during 1970s
Habeggar Monorail	Habeggar Von Rol	Supported lightweight monorail	Demonstrated at several recreational sites (e.g., Expo '86); system being built in Sydney (Australia)
H-Bahn	Siemens/Düwag	Suspended people mover with LIM or rotary motors	0.7-mi system operational in Dortmund (West Germany)
Maglev	GEC Transportation Projects	Small LIM and magnetically levitated vehicles on elevated guideway	0.5-mi system system operational at Birmingham Airport (England)
M-Bahn	Magnetbahn	Medium LIM, magnetically levitated vehicles on concrete guideway	1-mi system operating in Berlin (West Germany)
Mini Metro	Otis	Medium LIM, air-cushioned vehicles on concrete guideway	1-mi system operating in Serfaus (Austria)
Newtram	Niigata Engineering	Rubber-tired vehicles (75 passengers) driven by rotary motors on concrete guideway	4-mi system operating in Osaka and Tokyo (Japan); system is derived from LRV (Airtrans) technology
O-Bahn	Mercedes Benz	Mechanically guided bus	92-vehicle system operating successfully in Adelaide (Australia)
SK	Soulé Fer et Froid	Small cable tracked cars on narrow-gauge track	Prototype operated at Saint-Denis (France)
TAU	ACEC SA	Small-profile light rail, rotary electric motors	Trial operation at Jumet; system being built in Liège (Belgium)
VAL	Matra Transport	Rubber-tired automated medium-size vehicles on concrete guideway	Now operating in Lille (France); systems being planned in Strasbourg and Toulouse (also in Jacksonville and at O'Hare Airport, U.S.)
VONA-One	Nippon Sharyo Seizo Kaisha	Rubber-tired automated medium-size vehicles on concrete guideway	2-mi system operating in Yukarigaoka near Tokyo (Japan)
Westinghouse Metro Mover	Westinghouse Electric Corporation	Rubber-tired people mover on concrete guideway	Operating at Gatwick Airport in London (England); also several U.S. applications

to entrain vehicles limits the scope for increasing labor productivity with rising ridership.

CONCLUSIONS

Light rail outside North America has not seen the dramatic resurgence that has been seen in the United States and Canada. This is simply because, apart from the United Kingdom and France, LRT's fortunes had not sunk so low. This generalization however covers a wide range of situations. In the Eastern Bloc countries, where most of the traditional systems are to be found, the slow growth of automobile ownership and urban population growth have ensured a continued role for light rail systems. This security, along with a slower pace of general technological development, has meant that innovation has been relatively limited; by and large Eastern Bloc LRTs are conventional street tramways using rather traditional technology.

In the United Kingdom light rail had all but disappeared by the 1970s but the pathfinder Tyne and Wear project marked the end of this decline. More recently the London Docklands Light Railway has demonstrated spectacularly how light rail can play a crucial role in the renewal of the inner areas of older cities—a major problem in many developed countries. Light rail schemes are being promoted for most of the other large U.K. cities and the next in line in Greater Manchester, on former railway rights-of-way plus a section of street running, uses modern tram technology and construction and is due to start in 1989. Continental Western Europe has about a quarter of the world's LRT systems. The majority of these has been steadily improved over the last 10 years. Innovations have been comprehensive, covering vehicles, tracks and trackside equipment, system control, and integration with the rest of the urban transport system. Systems in this area include both revolutionary new systems and high-quality, state-of-the-art "traditional" systems.

Outside Europe and the Eastern Bloc there are about 30 systems, mostly in Japan. Innovation in LRT systems here has been fairly limited so far, with the trend in Japan being oriented toward the creation of new unconventional high-technology systems rather than development of existing formats, although there have been improvements to these. However interest in LRT is growing, particularly in the Far East, and the new system in Hong Kong is an impressive example of how to establish a high-capacity, high-quality LRT system in a difficult mixed traffic environment.

The list of contemporary innovations is rather impressive. Modern vehicles are attractive, relatively quiet, and can have low floors to facilitate access by handicapped passengers. Modern electronics make for smooth acceleration and braking, environmental control, and regenerative braking, which can save energy. It is increasingly common for "voice and data-to-control" communications and vehicles to register their presence frequently with trackside equipment to obtain priorities in mixed traffic. Electronic passenger information systems are now being provided on the more modern systems. A still small but growing number of light rail systems are automatically controlled.

Off the vehicle, significant improvements have been made in track design and maintenance that contribute to ride comfort and help keep down noise intrusion. Particular progress has been made in reducing structurally transmitted noise and vibration that can be a serious problem in dense urban areas, especially when new routes are introduced. Progress has also been made in the design of overhead power supply equipment, which is now significantly less bulky and intrusive than that associated with the traditional streetcar systems. Recent projects have seen changes in the relationship between light rail systems and their environment on even wider scales. The provision of priorities for LRVs by local traffic and environmental management now can include selective vehicle detection. In some cities transport has been more widely adapted to make the most effective use of new light rail lines with road traffic circulation modified to reduce mixed running and traffic conflicts and with bus services reorganized to act as feeders to LRT. This invariably has been accompanied by full integration of fares and ticketing to reduce the inconvenience of interchange between bus and LRT.

The most fundamental examples of powerful relationships between LRT and its environment are where LRT has been used to stimulate or complement large-scale development and renewal. Perhaps the most impressive example of this is in London's Docklands where light rail has played a catalytic role in Europe's largest urban redevelopment scheme. This required a modern upmarket image that is also to be found in the new systems at Lille and Osaka (where again there is a strong urban renewal dimension). In these cases the systems have employed exclusive rights-of-way that have undoubtedly allowed a more reliable service to be run and contributed markedly to the systems' image. The associated automation has also reduced staffing requirements and costs.

In an era when concerns about the costs of major public projects are growing, one of the major achievements of recent light rail developments is to provide high-capacity, quality public transport at a cost that is only a fraction of full metro costs. This does not, of course, mean that LRT can always do a full metro's job; but its low initial cost has meant that quality tracked public transport has been provided in cities and corridors where, despite civic ambition, metros were simply not viable. In a few instances light rail schemes have brought with them innovative funding that has further reduced the burden on the public purse. The opportunities for this seem to lie mostly in inner city renewal projects where traffic densities are well suited to light rail and its capacity to thread through the urban environment and piece together former rights-of-way comes into its own.

The most striking feature of innovation in light rail transit outside North America is its great variety. There are still many humble streetcar systems in developing and Eastern Bloc countries where innovation is limited to replacing assets with conventional modern equivalents. At the other extreme the new automated high-tech systems are establishing LRT as a transport mode for the cities of the future. This range of innovation reflects the inherent versatility and adaptability of light rail, which should secure its future in an increasingly urbanized world where the economic and environmental cost of automobile use is driving the search for other, more cost-effective means of handling passenger movements in busy corridors.