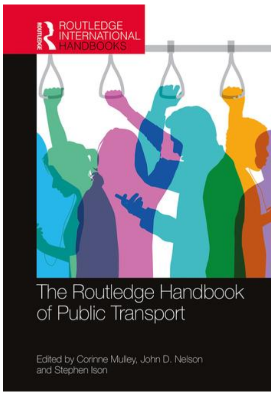

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RAIL – URBAN, SUBURBAN AND REGIONAL

Simon Blainey and John Preston

Introduction and overview

This chapter provides an overview of 'conventional' rail systems, focusing particularly on urban, suburban and regional heavy and light rail systems and variants thereof. It begins by discussing how different types of rail system are defined and differentiated, followed by a historical overview of the development of urban rail systems. It then goes on to consider the issues involved in planning, implementing and operating such systems, reviewing the range of decisions that need to be taken. Several exemplars of best practice in urban rail provision are briefly described, and current and future challenges facing urban rail systems are discussed, along with the potential for future innovation in the area.

Types of rail system

What is a rail system?

In order to discuss issues relating to rail systems, it is first necessary to have a clear understanding of what they are. Vuchic (2007) characterises public transport (or transit in U.S. English) by three basic characteristics: right-of-way, system technology and service type, and these are detailed with respect to rail.

There are three broad categories of right-of-way (ROW). Category A is a fully controlled ROW that is fully grade separated. Urban metro systems are of this type. Category B has longitudinal separation, but there may be at-grade pedestrian and vehicle crossings. Mixed traffic railways are often of this type but with a growing tendency in some countries (such as the United Kingdom) for level crossings to be removed on safety grounds. Category C represents on-street running with mixed traffic. Conventional tramways (streetcars in the United States) are of this type, as are some light rapid transit systems.

System technology has a number of aspects. For rail, the main system of *support* is steel wheel on steel rail, which has the advantage of low friction. However, there are variants, including the rubber-tyred French Metro and VAL systems and magnetic levitation, as in Shanghai, which might be thought of as part of the extended rail family. Other variants include suspended and straddle systems. The Wuppertal Schwebebahn and the Chiba monorail systems in Japan are examples of the former; the Chongqing and Tokyo monorail systems are examples of the latter. *Guidance* for rail is usually provided by the contact between steel wheels (and their flanges) and steel rail, although there can be other types of wheel and guidance surfaces. *Propulsion* for modern rail systems was largely provided initially by steam engines (and horses before that – see the later discussion on historical development of urban rail systems), but during the 20th century, electric motors (for urban and heavily used suburban services) and diesel (for more lightly used regional services) became more prominent. Tractive forces are usually transferred through friction/adhesion, but methods may also include cables or magnetic forces. *Control* is the means of regulating the traffic. Rail systems may be fully automated, manual signal (most heavy rail) or manual visual (some light rail).

Last, there are various types of services. Most rail services are regular all-day services, but there may be peak supplements and special services to exhibition halls, sporting arenas and the like. For the types of rail services that are covered in this chapter, there are three broad service types, urban services serving the central city, short range suburban service (typically up to 25 miles/40 km from the central business district) serving the inner hinterland of the central city (although this is complicated when a conurbation has multiple nuclei such as the San Francisco Bay Area, Randstad or the Ruhr) and regional and long-distance suburban services serving the outer hinterland. Services may be local, all-station services, as for most urban and short-range suburban railways; semi-fast, skip stop services for some longer services (as on the New York subway) and non-stop, express services serving the outer suburbs.

Mixed traffic heavy rail

Railways were historically first developed for the movement of freight, but the opening of the Liverpool to Manchester railway in 1830 demonstrated the demand for mechanised passenger travel (Wolmar, 2007) and from that time onwards, railways were developed as mixed traffic systems with a belief that there were economies of scope from carrying both passenger and freight services, although that belief has waned in recent years, at least in terms of operations (see, for example, the findings of Cantos-Sanchez [2001] that European railways exhibited diseconomies of scope between passenger and freight operations). In the past, it was common for passenger trains to have goods wagons as part of the composition (not least for parcels). However, that practice has waned as fixed formation passenger trains sets (multiple units) have become the norm, although there have been some experiments with modular designs that permit the carriage of some freight. The ‘standard’ all-purpose (or mixed use) railway remains the default for regional/suburban rail, but at high traffic densities, such as urban Metro systems, economies of specialisation kick in and rail operators exclusively focus on passengers.

Passenger rail systems can be delineated by a trade-off between capacity and cost (see, for example, Vuchic, op cit., p. 79). At one end of the spectrum, there are dedicated light rail systems with relatively low costs but also low capacity. At the other end of the spectrum are dedicated heavy rail systems such as urban Metro systems with high capacity but also high costs. In between, there are mixed heavy systems in which costs are shared amongst different traffic types: long-distance intercity traffic, short-distance regional and suburban services and freight. Light variants of these systems might merge into the light rail categories such as tram-train technology, as pioneered in Karlsruhe (discussed in the case studies section subsequently) and now common elsewhere (e.g. Nottingham, Sheffield and Sunderland in the United Kingdom). As costs are shared, suburban services may demonstrate medium cost levels, but capacity is also moderated by sharing infrastructure services with other services, particularly if those services are operated at different speeds. Using total social cost models, Brand and Preston (2003, 2006) found that light rail was the cost-minimising public transport technology for a 12-km corridor with a demand level of between 30,000 and 60,000 passengers per direction per day (pdd). Between 60,000 and 100,000 pdd, suburban and regional heavy rail systems were cost minimising, whilst underground Metro-style operations were cost minimising at demand levels above 100,000 ppd. This indicates that one would only expect to see Metro systems in the world's largest cities.

For reference, Jane's Transport Systems provide directories of the world's railway and urban transport systems, whilst data can be obtained from the International Union of Railways (UIC) and the International Union of Public Transport (UITP).

Heavy rapid transit/metro

Heavy rapid transit (HRT) systems are found in the world's major cities and are typified by systems such as the London Underground, the Paris Metro, the New York Subway and Hong Kong's Mass Transit Railway (MTR). Generically known as Metro systems (despite the eccentricities of the Parisian system) or U-bahns in Germany, they have capacities of up to 60,000 passengers per hour, although the Hong Kong Mass Transit Railway achieves 80,000 per hour (White, 2002 – and also discussed in the case studies section). They are usually exclusively segregated, at least in the central city, although they may share tracks with other services in the outer suburbs. Category A rights of way may be provided by underground operation in the central area, either through shallow 'cut and cover' tunnels (also known as subways) or deeper tube tunnels. Alternatively, exclusivity may be provided by elevated rights of way, as with the Chicago Loop or the Sky Train services in Bangkok or Vancouver. They have full signalling, frequent stations (with spacings as low as 400 metres in central sections but more typically 1 km) and conventional platforms. Rolling stock is high capacity, with crush loads as high as 300 per car but more typically 150, and with a typical stock life expectancy of around 30 years. Trains are run in formations of at least 8 cars, usually in fixed formations, and have good performance in terms of acceleration and deceleration, with rates of 1 metre per second squared or more. This is assisted by the hump-back design of the track at stations. Trains are powered by electric motors. The electricity supply is typically up to 750 volts dc (direct current) and, given loading gauge constraints, usually delivered via a third rail. This requires frequent substations (typically every 3 to 5 km) but less electrical equipment on the trains. Trains have full crash worthiness and typically have a mass in excess of 1.42 tonnes per metre (De Leuw, Cather and Company, 1976), although more recent initiatives have seen attempts at light-weighting. White (op cit., p. 68) gives a typical weight for a heavy rail vehicle of 250 kg per passenger space compared to 125 kg for a bus. Full signalling is provided, with short blocks, and in the most advanced systems may be of the moving block type. Advanced systems will also have automatic train operation, a feature that in theory dates back to the Victoria line on the London Underground in 1968 (although the trains on this line have drivers). Early examples of fully automated systems with moving block signalling (or similar) include the Lyon Metro Line D (1992) and the Paris Metro Meteor Line 14 (1998), and some existing systems are gradually transitioning towards full automation, particularly where there is a simple route structure, as is the case for the Glasgow Subway, which plans to transition in 2021.

Heavy suburban rail

Suburban rail systems have some features in common with Metro-style HRT systems. Outside the central city, they tend to be category B right-of-way. They will usually be electrified but will tend to share main line overhead line electrification (typically 25 kilovolts ac [alternating current]), although there are still some examples of diesel operations. They share some tracks and stations with other rail services and tend to be operated predominantly at surface level, although with short sections of underground running in central areas, as typified by the approaches to the single central area station (Hauptbanhof) in the German S-bahn systems. Double-deck operations are commonplace, as with Randstad Rail in the Netherlands or City Rail in Sydney, as there are fewer restrictions on loading gauge given the preponderance of surface running. Station spacings may average 2 km but be even greater in the outer suburbs, and as a result, typical average speeds may be 70 km/hour or more. Given the more complex operations in mixed traffic, full automation is difficult, although some advances are being made in terms of signalling and train control. In many cities, most notably London, Paris and New York, suburban services have historically had their own termini in the central area, with Metro systems providing interconnections (Harris & Godward, 1992), although in some cases, these interconnections may be provide by the national rail system, such as the circular Yamanote line in Tokyo. Furthermore, in some cities, suburban services have been transformed through underground central area connections so that they become more akin to heavy rapid transit Metro systems, albeit with higher operation speeds. The Réseau Express Régional (RER) in Paris (see the case study section subsequently) and the Great Train Express (GTX) currently under construction in Seoul, South Korea, are examples.

Light rapid transit/light rail

> Light rail transit (LRT) is a mode of transport utilising predominantly reserved but not necessarily grade-separated rights of way. Electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of passenger capabilities and performance at moderate costs.
>
> (De Leuw, Cather and Company, 1976)

In essence, modern tramways or LRT systems have low to medium capacity of up to 20,000 passengers per hour. They have lighter vehicles, below 1.42 tonnes per metre, which run in sets of four cars or less. The maximum crush load capacity per car is 200. They can have sharper curves and involve on-street running, often in the central area where they can link former suburban branch lines that previously had separate termini (as with the Manchester Metrolink). Train control tends to be based on line-of-sight operations with low platforms and step-free access the norm, although humpback platforms may be used to provide the latter.

Heavier variants may have exclusive rights of way but still relatively low-capacity vehicles. Examples include the Docklands Light Railway (London) and Tyne and Wear Metro (in essence, systems with heavy infrastructure but light vehicles). In some cities, such as Brussels, traditional tram systems operate underground in the central area and are referred to as pre-Metros or, as in Stuttgart, semi-Metros. In other cases, suburban rail systems have used central city tram tracks as in the tram-train system typified by Karlsruhe (Axhausen & Brandl, 1999), with a recent example being the demonstration project between Sheffield and Rotherham. There have also been various attempts to further refine the LRT concept, such as the very light rail system being developed by the University of Warwick, whilst LRT has also been configured in automated versions such as the Docklands Light Railway mentioned previously and the VAL system in Lille, France. Given its low costs, it has been championed as a start-up system for cities in low-income countries (Allport, 1986, 2010), such as Manila,

Table 14.1 Summary of the characteristics of heavy and light rail systems

		Light rail	*Heavy rail*
Right-of-way		Capable of street running or semi-exclusive right-of-way (Categories B and C)	Dominantly exclusive right-of-way (Category A)
Motive power		Electric	Electric, some diesel
Vehicles	Weight	<1420kg/m	>1420kg/m
	Max. capacity (crush load/car)	200	300
	Typical length	4 cars	8 cars
	Passenger loading	Low level	High level
Normal operating speed		20–45km/hr	25–60 km/hr (Metro) 40–80 km/h (HRT)
Station spacing		800 m	HRT 2 km/Metro 400 m
Maximum capacity		Up to 20,000 pax/hr	HRT up to 60,000 pax/hr Metro up to 70,000 pax/hr

Source: De Leuw, Cather and Company, 1976, supplemented by Vuchic, 2007

the Philippines, albeit with the flexibility to upgrade capacity at minimal additional costs, although this may require some initial redundancy.

Findings in this section are summarised by Table 14.1.

Historical development of urban rail systems

The early origins of railways are shrouded in historical uncertainty, with some authors tracing their roots back to the Diolkos trackway in Corinth (Salmon, 2015) in around 600 BC. By the 17th century, wooden guideways were used to transport raw materials such as coal at a number of locations across Europe, but the first passenger rail service did not appear until 1807, when horse trams were introduced on the Swansea and Mumbles Railway (Lee, 1942). Horse power provided the traction for passenger services on several early regional and urban railways, but once the Liverpool and Manchester Railway had demonstrated the viability and superior performance of steam traction in 1830, horse-drawn passenger railway services rapidly disappeared. Horse power did enjoy a second era of dominance in an urban setting when street tramways (the forerunners of today's LRT systems) began to spread from the 1850s in the United States (the earliest example is thought to be the New York and Harlem Railroad in 1832 [Wright, 1908]), and, for example, at their peak in the United Kingdom, horse tramways served 750 miles of route and carried 750 million passengers per year (Mulley et al., 2013). Legislation and technical issues limited the transferability of steam traction to urban tramways, and therefore it was not until the widespread adoption of electric traction from the 1890s that the horse was finally superseded.

The first dedicated urban railway targeted primarily at commuter travel was the steam-hauled London and Greenwich Railway, which opened in 1836 and set the precedent for many similar lines around the world. While steam locomotive power was not universally adopted for all early lines, with some early lines testing alternatives such as cable haulage (e.g. the London and Blackwall Railway, opened 1840) or 'atmospheric' power supplied via a vacuum tube (e.g. the London and Croydon Railway between 1844 and 1847), such alternatives were not long lasting, and steam locomotives were dominant for the remainder of the 19th century. Fitting new railway infrastructure into existing densely built-up urban areas was already a problem at this time, since while widespread demolition of buildings was not uncommon, this was not always an option. In response to this challenge, the first underground railway, the Metropolitan Railway, opened in London in 1863, although other cities were initially slow to follow this lead (partly due to the high costs). An alternative solution (in some ways pioneered by the London and Greenwich Railway) was to build elevated railways on viaducts or girders above streets, and extensive systems of this type were built in some North American cities in particular (e.g. New York and Chicago). As noted previously, following pioneering installations in St Petersburg and Berlin in the early 1880s, electric power began to gain market share on urban street tramways. It also enabled the construction of deep-level underground railways, with the first, the City and South London Railway, opening in 1890. This was also the first 'heavy rail' system to make use of electric traction and was quickly followed by the first electric elevated railway (the Liverpool Overhead Railway) in 1893 and the first main line electrification on the Baltimore and Ohio Railroad's 'Baltimore Belt Line' in 1895 (Nock, 1979).

There was a trend towards the 'municipalisation' of urban public transport in the late 19th and early 20th centuries, with an early example being the Huddersfield steam tram of 1893, and this in some cases included both heavy and light rail systems. This was often (but not always) associated with a greater level of integration and co-ordination both between and (particularly) within transport systems and modes. This was exemplified by the marketing of both underground and overground rail systems as city-wide networks rather than as individual routes. In some European systems, this process of co-ordination saw cross-city lines constructed to link previously disconnected routes, offering a high-frequency service on a central corridor. Such systems are often termed S-Bahns, although this is not always the case and not all S-Bahns include a cross-city link. This term was first formally used in 1930 for parts of the Berlin suburban network (Hiller & Straschewski, 2008), although the network itself predated this renaming. The first decades of the 20th century saw extensive suburbanisation taking place around many urban areas, often largely facilitated by heavy rail and tramway networks and in some cases with railway companies also acting as property developers with the aim of generating new traffic. This suburbanisation led to substantial growth in passenger numbers in many urban areas. However, the growing prevalence of motor bus services and (particularly) private car ownership meant that in some cities this growth was short lived. The impact of the car was particularly severe for regional rail systems where traffic congestion was less of an issue, but urban systems were not immune to competition, and many heavy rail and (particularly) tramway networks declined or disappeared completely in the middle decades of the 20th century.

This decline was, though not always terminal, and from the 1960s, urban and transport planners became increasingly aware of the negative impacts caused by motor vehicle traffic. As a result, rail transport has enjoyed a gradual renaissance in a large number of cities. This has been associated with the development of new forms of urban rail transport. Perhaps the most prominent of these have been 'light rapid transit' systems (discussed earlier). These seem to have first originated in the 1960s, although there is little agreement as to when the term was first used. It seems to have originated in North America and was being used by the U.S.'s Urban Mass Transportation Administration (UMTA) by 1972 (Thompson, 2003a). Edmonton in Canada is often acknowledged as the first LRT system, opened in 1978. Other developments have included further cross-city heavy rail links, new underground metro systems in a number of cities and the introduction of tram-train services linking city centre street tramways with suburban heavy rail routes. As a consequence of these new developments and upgrades to existing systems, urban rail services continue to play a crucial role in enabling the economic and social activities of many cities around the world. There are, though, a number of issues which have to be addressed when designing and operating such systems, and these are discussed further in the next section.

Issues in planning, implementing and operating rail systems

Urban railways may be viewed as complex systems, and as a result, governance has been an ongoing issue. Railways were originally envisaged as a vertically separated industry in which the owners of the rail track would hire out train paths to individual operators (Lardner, 1850). However, from the very beginning, it became apparent that co-ordination was required to ensure passenger safety, and thus vertical integration became the norm. In Japan and elsewhere, including the Metropolitan Railway in London, this would extend to undertaking housing development in the suburbs and the development of retail, leisure and commercial facilities, as well as to the production of rolling stock.

By contrast, rail systems were characterised by horizontal separation, often on geographic lines, with different companies serving different corridors. However, over time, centralised agencies were created to co-ordinate services, fares and information, such as the London Passenger Transport Board, set up in 1933, the forerunner of Transport for London. Urban rail systems tend to be under local government control, although some lines might be operated as concessions by the private sector, as is the case in Kuala Lumpur (Malaysia). Similarly, different mainline railways' regional systems were often brought under public ownership in a process of nationalisation, with examples including Italy (1905), Japan (1906/7), France (1938), Spain (1941) and Great Britain (1948), although in some smaller countries such as Belgium, the railways were always a state enterprise. More recently, in some jurisdictions, some parts of the railway have been returned to the private sector, most notably in Great Britain and Japan of the countries listed previously. As a result, most suburban and regional services are under national government control, although this may be devolved to regional governments (as in France), and tendering is commonplace in some countries (such as Sweden). There is a large literature on how railways should be organised in terms of ownership, organisation, regulation and competition which is beyond the scope of this chapter – the interested reader is referred to Thompson (2003b).

The planning of public transport can be characterised by the strategic–tactical–operational (STO) framework popularised by van de Velde (1999). For rail systems, this might involve determining what needs to be done (strategy), how it will it be done (tactics) and doing it (operations). This is illustrated by Figure 14.1.

Figure 14.1 The rail planning life cycle

Strategy, whether objectives are commercially based (maximise profit) or socially based (maximise net social benefits), will involve choosing the right type of technology (from the heavy to light spectrum detailed earlier), the right type and amount of infrastructure and the right type and amount of rolling stock. It will involve the development of plans, programmes and projects in order to optimise the rail network in terms of either profits or net social benefits. It will involve the long-range forecasting of the demand for rail services, using computerised models, such as the network modelling framework (DfT, 2008) in Great Britain used to determine Network Rail's high-level output specification (HLOS) and the Railplan model used by Transport for London. It will involve supplying the right amount of infrastructure with safe capacity levels determined from scheme plans using formal verification processes from computer science (for example, Roberts et al., 2014). The tactics will involve matching the trains to the infrastructure (for example, using methods such as job shop scheduling used by Liu & Kozan, 2009) and customers to the trains (for example, through improved information on overcrowding – Preston et al., 2017). At the heart of this is the creation (and dissemination) of the timetable and the associated timetable planning rules with respect to station dwell time and sectional running times. Tactics will also focus on the fares and ticketing system. Over time, this has included consideration of season tickets, travelcards and smartcards. Operations involves the delivery of the timetable through the diagramming of rolling stock and the rostering of crew. It will also involve the provision of passenger information systems and the re-scheduling of trains where there are unplanned delays. In the most advanced railways, dynamic simulation tools will enable real-time rescheduling and automated safe and fuel-efficient driving (Ye & Liu, 2016) or inform driver advisory systems where there is semi-automated functionality. The best-performing railways will consider this a cycle of continuous improvement and will monitor and evaluate their performance with a view to future improvements to strategy, tactics and operations, with a key trade-off that requires continuous monitoring being that between capacity utilisation and delays (Armstrong & Preston, 2017).

Case studies of urban rail provision

In this section, exemplars of best practice are considered with respect to urban heavy rail (Hong Kong), suburban/regional rail (Zurich) and light rail (London Docklands). Intermediate systems between urban and suburban (Paris RER) and heavy and light rail (Karlsruhe) are also considered.

Hong Kong Mass Transit Railway

Hong Kong is often cited as an exemplar of the 'public transport city', with public transport accounting for about 90% of passenger trips in 2011, including 41% of trips made by rail (Hong Kong Legislative Council Secretariat, 2016). This is partly a consequence of the city's high population density and relatively limited road network, which makes car travel an unattractive option for many trips, in contrast to the extremely reliable rail network. However, a particularly unusual feature of the Hong Kong system is that the MTR, which constitutes the majority of the rail network, is highly profitable. It has one of the highest farebox recovery ratios (the percentage of operational costs covered by fare income) in the world and also generates significant income from its property interests (Sharma & Newman, 2017). This results from its long-standing policy of financing rail infrastructure construction through its 'Rail + Property' development programme, designed to capture the land value uplift which occurs when new railway stations are opened. MTR purchases exclusive development rights for the land above and adjacent to its stations at a 'before rail' price from the government and then sells them on to a developer at an 'after rail' price, with the positive impact of rail construction on land values enabling them to generate a substantial profit. MTR also usually retains a share in the property development profits, providing it with an additional ongoing revenue stream. The legal status of MTR means that it is obliged to consider the broader public interest, and therefore the development programme has also been used to promote Transit Oriented Development, which then further increases public transport's mode share (and therefore revenue for MTR) (Cervero & Murakami, 2009).

Paris Réseau Express Régional

Opened in several phases between 1977 and 1999, the Paris RER network linked existing suburban railway lines using a series of new cross-city tunnels, enabling the provision of a metro-style high-frequency service. This gave passengers from suburban services the ability to reach city-centre destinations without the need to change to the (relatively slow) Paris Metro network and also provided a high-speed link between terminal stations for longer distance through passengers. By removing many suburban services from the historic terminal stations, the RER system has also freed up capacity in these stations for an expansion in long-distance services following the successful introduction of the train à grande vitesse. While similar in some ways to the 'S-Bahn' type systems found in many other cities, the RER stands out for its multiple cross-city tunnels. However, while network coverage and journey times are exemplary, the quality of the passenger environment is rather less exceptional.

Karlsruhe Tram-Train

It is not uncommon for the main railway station in an urban area to be located some distance from the urban centre, forcing rail users to either change to another public transport mode to reach their destination or to undertake a lengthy walk. In order to overcome this problem, the city of Karlsruhe pioneered an approach where connecting tracks were constructed to link the suburban rail network to an existing street tramway system, thereby allowing suburban trains to directly access the city centre. This has removed the need for passengers from suburban stations to change onto tram services, making access to the city centre more convenient and therefore enabling rail to provide a much more attractive end-to-end service. The initial route (to Bretten-Gölshausen, opened in 1992) was an immediate success, with substantial growth in passenger numbers, and the system has subsequently been expanded to include nine tram-train routes in 2020. These are operated as part of an integrated system alongside a number of conventional tram and heavy rail routes. A number of other cities have subsequently implemented similar systems (Naegeli et al., 2012), although in some circumstances, technical issues may make tram-train operation more complicated, for example, where trams and trains have different wheel/rail profiles or platform heights.

Zurich

The Swiss rail network is internationally famous for its 'Taktfahrplan', a fully co-ordinated network-wide regular-interval timetabling system which offers a standard pattern of services and connections throughout the day (Tyler, 2003). This was first introduced by Swiss Federal Railways (SBB) in 1982 and has subsequently been further developed and enhanced so that it also covers connecting local public transport services in many areas. The national Taktfahrplan in the city of Zurich has complemented a sustained policy over a 50-year period of promoting and investing in public transport provision, leading to a situation where levels of car use are much lower than in the majority of comparable cities. The city has taken an integrated approach to improving public transport (including both heavy rail and tram services), bringing together measures such as active traffic management prioritising public transport, segregation of road space for trams and buses, the construction of new rail infrastructure and the provision of a minimum level of public transport service to all inhabitants. This integrated policy has been based on the recognition that promotion of 'sustainable' modes is not enough to generate substantial mode shift unless the negative utility of using public transport for a given trip is less than that of using car (Ott, 1995).

Docklands light railway

While there are a number of cases where railways have acted as enablers for urban regeneration, the Docklands Light Railway (DLR) in London is perhaps the best example. It was first planned as part of the broader redevelopment of the area around the derelict London Docks in the early 1980s. A low-cost public transport system was required to provide access to the new developments, and an automated light rail system was felt to be the most appropriate solution. Two initial routes were opened in 1987 serving 15 stations, partially on new alignments and partially making use of disused railway corridors and infrastructure (Mackett, 1995). In order to save money, the routes were built with low-capacity stations and trains which comprised a single-car articulated vehicle. However, partly facilitated by the access provided by the DLR, high-density development quickly occurred in the areas served by the railway, meaning that traffic levels grew rapidly. In some cases, stations on the railway were integrated within new commercial developments, notably at Canary Wharf and Heron Quays, maximising convenience for users. The Docklands area now acts as a secondary Central Business District for London, and a number of extensions have subsequently been constructed, alongside substantial programmes of platform and train lengthening in order to accommodate additional traffic.

The future of urban rail: challenges and innovation

Many urban rail systems around the world seem to be enjoying a period of unprecedented success in the early 21st century, at least with regard to passenger numbers. However, there are still a number of challenges such systems face. One consequence of the recent growth in passenger numbers is that some systems are facing problems in the management of crowding during peak periods at stations and on trains, with consequential issues surrounding stress and safety (Lam et al., 1999; Cox et al., 2006; DfT, 2019). This has increased the importance of effective management of passenger flows through stations, for example, through the introduction of directional segregation or by optimising the distribution of waiting passengers along platforms. An obvious response to crowding is to increase service levels, but this may not always be practical if routes are already running at full capacity, and there is the risk that introducing additional services may have a negative impact on service reliability. A notable recent example of this has been on the 'Castlefield Corridor' in Manchester, Great Britain, where additional services were introduced on an already congested route where not all planned capacity enhancements had taken place, leading to a major breakdown in service reliability across a wide area. Targeted infrastructure enhancements may therefore be required in order to maximise the effective capacity of rail networks, and there is a need for research to better quantify the benefits of such enhancements. As well as increased crowding at peak times, some urban networks have also experienced increased demand at periods where usage had previously been low, particularly at weekends and in the late evening and early morning. This may result in an extension to train operating hours, but while this provides passengers with an improved service, it can also have negative consequences in terms of reducing the time available for maintenance activities. This can further complicate the already challenging task of minimising the impact of both planned and unplanned service disruptions on passenger satisfaction. Increased application of digital technology has been suggested as one solution to the capacity challenge, although it is not always clear what this would mean in practice, and research is needed in order to identify the magnitude of the benefits which can be obtained from increased 'digitalisation' (see also Chapter 41). As indicated previously, automatic train operation has been possible for several decades and is used on a number of systems worldwide where it provides capacity benefits. These will be maximised if automatic operation is combined with moving-block signalling, which increases the number of trains which can operate on a route compared to conventional fixed-block signalling. However, the installation costs for such systems can be substantial and will need to be offset against the scale of benefits which the systems can deliver.

In order to alleviate crowding on existing routes, generate mode shift from other more polluting (and/or less space-efficient) transport modes and stimulate economic growth, many urban areas are planning expansion of their urban rail networks, both through the construction of new routes and the enhancement of existing routes. A key challenge for such construction projects wherever they take place is providing accurate estimates of the costs involved and keeping control of project costs once construction is underway. New rail schemes are (like many large infrastructure projects) notorious for substantial cost and time overruns (Flyvbjerg, 2007), a problem which is often exacerbated by poor planning and ineffective project management. This means that it has become almost routine for such schemes to be delivered late and over budget, with obvious negative implications both for the financial success of these schemes and the likelihood of future extensions being funded. The Crossrail scheme in London is a classic example that was due to be opened in late 2018 but is not now expected to open until mid-2021, with costs likely to be £18.25 billion (at the time of writing) rather than the budgeted £14.8 billion. A key problem seems to relate to software integration given the presence of three different trackside signalling systems. System integration seems to be the Achilles heel of urban railways and should be prioritised as an area for future research.

While (as noted previously) many urban rail networks have recently experienced substantial demand growth, broader ongoing societal changes may potentially reduce the need for them to further increase peak capacity. It is increasingly acknowledged that a shift is taking place away from regular working (and therefore commuting patterns) towards a situation where people work in a much more flexible manner. This is likely to reduce the number of people travelling to and from cities in the 'conventional' peak periods while potentially leading to some traffic growth at other times. At the time this chapter was being written, the COVID-19 pandemic was having a profound and immediate impact on working and travel patterns as a result of 'social distancing' policies, and it seems possible that some of these enforced behavioural changes may outlast the pandemic, accelerating the shift towards flexible working practices. This will, no doubt, be an area for further research,

It has often been suggested that the growth of new 'disruptive' modes of transport, particularly those relating to shared and/or autonomous road vehicles, may have a negative impact on urban rail systems in the short to medium term. However, evidence for this actually occurring in reality is somewhat limited, with some evidence that ride-sharing services can have a limited positive effect on rail use (Hall et al., 2018). Mobility as a Service (MaaS) is also frequently cited as being a key part of the future of urban transport systems. Definitions of MaaS vary, but they tend to involve a shift away from privately owned vehicles to a mix of hire cars, shared vehicles and public transport systems, with multi-modal door-to-door journeys booked and paid for through a single app (see also Chapter 3). While MaaS schemes have been widely advocated, many of the attributes most often associated with MaaS, such as whole-journey ticketing and journey planning, already exist on many urban rail systems which are managed in an integrated manner along with other public transport (as is the case in London and Zurich, for example), meaning that (in some contexts) MaaS is at most an evolutionary extension of existing integrated transport systems (Lyons et al., 2019).

Probably the biggest challenge facing transport systems more generally in the 21st century is that of reducing (and ultimately eliminating) their contribution to the climate emergency as a result of their substantial carbon footprint (see also Chapter 43). Urban rail systems already perform relatively well in this respect, particularly when operated by electric power, given their high capacity and energy efficiency. Further mode shift towards urban rail can therefore be an important part of transport's response to the climate crisis and presents a significant opportunity for rail operators. There are, though, still challenges facing urban rail systems in this respect, first in order to ensure that they are powered by low-carbon electricity and second relating to the substantial amount of embedded carbon associated with the construction of new infrastructure (particularly when tunnelling is required). Effective solutions will need to be found for these challenges if rail is to maximise its potential contribution to enabling sustainable mobility in future decades.

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