Author accepted manuscript version (April 2003)

Which technology for urban public transport? –

A review of system performance, costs and impacts

Date of last revision: 22 April 2003

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Keywords: Public transport planning, public transport technology, investment costs, operating costs, economic impacts, environmental impacts, transport externalities, transport integration, accessibility.

5,518 words excluding synopsis, references and tables.

4 tables, no figures.

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Synopsis

The merits of alternative urban and inter-urban public transport systems have been the subject of some debate, particularly since the publication of the 1998 Transport Policy White Paper "A New Deal for Transport". This paper aims to assess some of the conflicting empirical evidence in the UK and abroad in order to allow an objective assessment of the policy implications. Part one presents an overview of technical and financial characteristics of mainly urban public transport systems, including capital and operating costs of recent light rail, guided bus, bus priority and suburban rail systems. In part two, we explore the evidence on the wider costs and benefits of systems in the UK, including wider environmental and socio-economic impacts.

Although more expensive to build (under similar conditions), light rail systems often carry more passengers than 'intermediate' bus based systems such as guided bus and segregated busways. There is not much between public transport systems on the basis of operating costs per passenger-km, except metro systems which are twice as expensive to run than bus based systems. When comparing revenues and operating costs directly, all modes except suburban regional rail appear capable of covering operating costs overall, with light rail and some of London's suburban rail services providing a marginal surplus of revenue. Average speeds of light rail and bus-based systems are comparable. In heavily congested corridors, new light rail systems can reduce journey times significantly, but such reductions are lower for bus-based systems, mainly due to the relatively limited amount of segregated right of way and priority at traffic signals. This highlights the fact that bus priority systems act primarily as 'congestion busters' at hot spots, which can be implemented more flexibly and gradually than for rail-based systems. Currently, electric propulsion appears to be the best option to mitigate

air pollution and noise. However, new clean vehicle technologies will soon be in a position to play a major role in reducing emissions, in particular for bus-based systems. In terms of external costs per bus/train-km, environmental costs appear higher than accident costs, however lower than congestion externalities.

[Number of words: 331]

Introduction and objectives

The practical need for this paper stems originally from the 1998 Transport Policy White Paper "A New Deal for Transport" (DETR,[1]) which states:

> *"Light rail, and similar, rapid transit systems, can have a role to play in delivering integrated transport in urban areas – particularly if planned as part of an overall strategy. The capital costs of light rail systems are, however, high – particularly in comparison to bus priority measures and more modest guided bus schemes which may offer a more cost-effective alternative."*

The general tone of this quotation is supported by some research, both from the UK and overseas (e.g. Walmsley and Perrett,[2] Mackett,[3] Mackett and Edwards,[4] Kain,[5]). However, a subsequent report for the then Department for the Environment, Transport and the Regions (Hass-Klau *et al*,[6]) has come out strongly in favour of light rail systems because they permit a more radical approach to car restraint to bus-based systems. At the time the Deputy Prime Minister, in a significant change of policy, hailed light rapid transit as "the transport mode of the future" (LTT,[7]). As a result, new modern light rail schemes have been built or are currently in the pipeline, for example the two new London tram schemes (TfL,[8]). On the other hand, busways are claimed to be far cheaper than light rail and operate with the speed, reliability and efficiency of light rail at only a fraction of the cost (see e.g. Hensher and Waters,[9]). Bus lanes are claimed to be even less expensive to implement and run, however their overall impacts are believed to be less significant (Hass-Klau *et al*,[6]).

The aim of this paper is to assess the conflicting empirical evidence in the UK and abroad in order to allow an objective assessment of the policy implications. In the first part, this paper presents the summary findings of a desktop study aimed at bringing together the most up-to-date information on the technical and financial characteristics of urban and inter-urban public transport systems, including light rail, guided bus, bus priority and suburban rail. For this purpose, we have updated previous inventories (White,[10] Leake,[11] Sussman,[12] Vuchic,[13]) and extended the source list by national and overseas references (e.g. Pattison,[14] Vuchic,[15] Daugherty *et al*,[16]). The second part explores recent evidence on the benefits and wider impacts of systems in the UK and abroad. The collated evidence is meant to be an information source for public transport planners, operators and academia.

Part 1 – Performance and Costs

Public transport planning and investment decision making require reliable data on system characteristics including vehicle and infrastructure characteristics, performance and costs. These are explored below with the emphasis on comparing between modes.

Technical characteristics and performance

Some of the main technical characteristics of urban and inter-urban public transport systems are shown in Table 1. This shows that in terms of passenger flows and capacity, light rail can usually carry more passengers than conventional bus-based systems. However, some overseas systems show that the same number of passengers can be transported by busways as with light rail, notably Ottawa (Canada), Curitiba and São Paulo (both Brazil) (Hass-Klau *et al*,[6]). Light rail has the advantage over bus-based systems in that it can cope with increased capacity with a lower increase in operating costs – one driver can drive two or four car units. A perceived downside is route inflexibility but this inflexibility allows a more long-term approach to car restraint to bus-based systems as argued by Hass-Klau *et al*,[6]. Ottawa claims up to 10,000 passengers per peak hour and direction, while São Paulo is quoted to cope with up to 25,000 passengers (Hensher,[17]). However, the latter is only possible with multi-vehicle stopping bays and more than one busway lane per direction. Also, new "trams-on-tyres" (e.g. the Guided Light Transit by Bombardier Transportation, STREAM by Ansaldo-Breda, PHILEAS by Fokker) and other guided bus systems show similar passenger capacities and vehicle costs to light rail (Hass-Klau *et al*,[6] Brand and Preston,[18]). Metro vehicle capacities are similar to light rail, however system capacities for metros are higher than for any other urban public transport system. New personal public transport such as the proposed Urban Light Transport (ULTra) system planned for Cardiff are claimed to have passengers capacities similar to bus-based systems (Lowson,[19]).

Table 1: Technical and operational characteristics

In addition to the maximum allowable speed, average operational speeds are mainly influenced by the number and distance between stops, the maximum practical acceleration and deceleration, and the degree of segregation from general traffic (White,[10] Vuchic,[13]). Average bus speeds on busways (40-50 km/h in the U.S.) and guideways (30 km/h in Essen; up to 60 km/h in Adelaide) have been found to be faster than light rail on its own right of way (average 30km/h) (Disley,[20] Read et al,[21] Hass-Klau *et al*,[6]). However, this is mainly because of different stop densities and corridor characteristics (urban vs. inter-urban) rather than inherent speed advantages. For instance in Ottawa, bus speeds on the busways is on average 50km/h whereas in normal streets this speed halves to about 23 km/h (Hass-Klau *et al*,[6]). In Pittsburgh, the buses along the busways travel on average between 37 and 53 km/h whereas in mixed traffic the speed is reduced to 23 km/h. These speeds are comparable to average light rail speeds where light rail shares space with road traffic (about 20-25 km/h).

For buses, junction design and priority when switching between segregated and mixed traffic modes are crucially important. Some guideway sections have not shown any benefit overall, e.g. the approach to a busy intersection in Leeds for both buses and general traffic increased bus journey times by about 2min, eroding much of the benefit accrued within the guideway (Daugherty and Balcombe,[22]). Edinburgh's Greenways schemes showed similar teething problems at some junctions. An inspection of some of the junctions on the A8 and A900 *Greenways* by the Scottish Executive,[23] revealed that though most were operating reasonably well, there were some where the design was definitely and significantly reducing the capacity available for general traffic and thus increasing congestion for both bus and general traffic. Urban bus lanes show some improvements in overall travel time for buses (0.5-5 min), however sometimes at the cost of delays for general road traffic sharing the same corridor (Grant-Muller,[24] Daugherty *et al*,[16]). Operational speeds are higher for suburban railways and dual mode rail on heavy rail tracks than for metros. Again, this is due to lower stop densities.

Land take is obviously a major issue in urban centres. In terms of required track width, busways need most space, trams, guided buses and metros the least. Bus lanes and suburban railways are in between. The ULTra system is claimed to require the least track width of all (Lowson,[19]). As mentioned above, efficient busways require large stations and sometimes multiple lanes. This raises the question whether this increased land take would be technically and politically feasible in some of the historic cities in the UK. On a different note, alternative fuelled vehicles (e.g. buses running on 'clean fuels' such as compressed natural gas) may require the operator or local authority to invest in additional refuelling infrastructure, with obvious land-use and cost implications.

System costs

The cost to provide one kilometre of system infrastructure varies significantly within each mode, depending on local conditions and terrain (Table 2). As expected, the cheapest option by far is bus lanes on existing road infrastructure. Metro is the most expensive (due to 100% underground infrastructure). New suburban rail is relatively expensive, although converting disused BR lines to suburban rail has proven to be successful and relatively cheap. For example, the Robin Hood Line North out of Nottingham cost only £0.66m per route-km (NCC,[25]).

Overall, busways appear to be cheaper (average £8.0m per km for seven schemes, including some tunnel sections) than light rail (average £13.3m per km for 25 schemes, including some tunnel sections). However, the high figure for the Standard Deviation (SD) of light rail costs (£13.6m per km) indicates that there are substantial differences between systems. Indeed, excluding cost forecasts for *proposed* schemes and schemes *with tunnel or bridge sections*, light rail costs average at £6.6m per km (SD £2.3m). Given the range of costs between £3.3m and £10.5m per km it can be concluded that an economical light rail infrastructure can cost as little as a two-way guideway for buses (average £3.7m per km, SD £1.3m). A similar argument holds for busways: excluding schemes with tunnel sections, the average cost is £6.1m per km (SD £3.2m). Therefore, under similar conditions, infrastructure costs for busways, guided buses and light rail are at least comparable.

Table 2: Investment costs (2000 prices and values)

Vehicle or train costs differ significantly between modes, reflecting the wide range of passenger capacities, speeds and safety designs (Table 2). In terms of costs per seat installed, dual mode/voltage light rail and "trams-on-tyres" are more expensive than conventional light rail. Modern buses and guided buses are 4-5 times less expensive per seat installed than light rail. However, assuming the longer lifespan of trams (typical a factor of 3) and typical UK passenger loadings, the discounted capital cost *per passenger* for buses is only about 80% of the figure for trams over a 30 year lifespan (6% discount rate).

Operating costs and fare box revenue

Average operating costs have been derived from published sources, as shown together with revenue data in Table 3. The review shows no surprise. On a cost per vehicle-km basis, urban bus operations are about 4 times less expensive than light rail, followed by suburban rail (7 times) and metro (14 times). However, there is little difference on a cost per passenger-km basis, except metro systems which are twice as expensive to run than bus-based systems.

Note that the bus market is somewhat different in London (and is excluded from 'Urban Bus' in Table 3), as operational speeds are significantly lower, passenger loadings higher and the share of free concessionary travel higher, providing substantially higher operating costs at 150 pence per vehicle-km and lower mean fares at 50 pence per passenger (TSGB,[26]). Also, the average figures presented for suburban rail include both London commuter and regional services. Averaging conceals the fact that while regional services find it almost impossible to cover costs with fare revenue income, some suburban services around London can cover operating costs, albeit with overcrowded trains at peak times (SRA,[27]). For example, fare revenue for the Robin Hood Line covered about half of annual operating expenditure (Central Trains,[28]), whereas Thameslink nearly covers operating costs (Transit,[29]).

Table 3: Summary of annual operating costs and revenue income of systems in the UK

Further data obtained on overseas systems broadly confirm the picture in the UK. For instance, the national US average operating cost is slightly higher than the UK for light rail (17.9 pence per passenger-km) but much higher for buses and coaches (21.9 pence) (adopted from APTA,[30] with own calculations, all 2000 prices). For busways, the example of Pittsburgh (operating light rail, conventional bus and busways; discussed e.g. in Kain,[31]) shows that operating costs are comparable to conventional bus-based systems, if not slightly cheaper (with higher fixed costs offset by lower variable costs). Note that the average costs reported for Pittsburgh are, however, significantly higher than the US national average, and hence higher than the UK figures. This has been explained by the unusually high wage rates in Pittsburgh of £19 per hour (converted from USD to GBP at 2000 prices). This highlights the fact that while the infrastructure and vehicle market is more or less international, local differences in wage rates, load factors and fuel costs can result in significant cost differences. Given the high share of wage-related costs in bus operations, high wage rates alone may render buses more expensive to run than light rail. Note that the US has a largely regulated, publicly owned public transport system, whereas the UK has developed a deregulated, privately owned system. Therefore, the UK is likely to be more cost-efficient.

Revenues per vehicle-km and passenger-km mirror what was said about operating costs above. Mean fares per passenger of the two underground systems in a sample (92.9 pence) are slightly higher than for light rail (77.1 pence) or conventional buses (63.8 pence). Suburban rail revenues per passenger can be substantially higher (but note the much lower fare *per km*). Obviously this makes sense because average trip lengths on most suburban rail services are a lot higher than for the other modes. When comparing revenues and operating costs directly, all modes appear to cover operating costs overall, with light rail and suburban rail providing a marginal surplus of revenue.

Part 2 – Benefits, Costs and Impacts

This part of the review gives an overview of impacts beyond narrow financial analysis and includes:

- The benefits to users over and above those captured by the fare box, including time savings and reliability improvements;
- The benefits to non-users as a result of reduced congestion and reduced accidents;
- An assessment of the environmental impacts, including local and global air emissions;
- An assessment of the impacts on the wider economy, accessibility and integration.

User benefits

Journey time savings

Total journey time is made up of walking, waiting and in-vehicle (including boarding/alighting) times. Walking time depends mainly on distance between stops and the number of interchanges. Waiting time is mainly influenced by service frequency. Therefore, urban bus systems with high frequencies and stop densities tend to show advantages over other systems – in particular when on segregated tracks.

In-vehicle time (IVT) is mainly influenced by operational speed (see above), hence factors such as number of stops, vehicle acceleration, fare collection systems and traffic priority all play a crucial role. Clearly, the modes with higher operational speeds (e.g. guided busway, light rail on segregated tracks, suburban rail, personal public transport) and off-vehicle fare collection (e.g. underground, light rail) show IVT advantages over some of the slower modes (e.g. buses and light rail in mixed traffic). It has been shown that light rail (between 10% and 55% of IVT) and suburban rail (21% to 31% of IVT) schemes appear to improve IVT when compared to bus-based alternatives serving the same corridor (Tyson,[37] Brand and Preston,[32]). Savings compared to car travel at peak times are lower but still positive (e.g. 10-30% for Manchester Metrolink, >25% for Karlsruhe *S4* dual mode rail). IVT savings are generally lower and spread more widely for buses on bus priority schemes (-10% to +30%). However, savings can be considerably higher at peak times, e.g. a 50% saving on some of Oxford's bus lanes in the morning peak (Oxfordshire County Council,[33]). For bus lanes, evidence from Daugherty *et al*,[16] suggests that there is no real correlation between the total scheme length and the bus IVT savings in minutes. From the review of a number of schemes, most journey-time savings were observed in the range between 0 to 5 minutes regardless of the length of the scheme. As may be expected, data on the relationship between the original bus speed and bus travel-time savings (min/km) indicate that the greatest improvements are seen where the original speed is lowest. Further evidence from Grant-Muller,[24] suggests that bus journey-time savings could be as high as 25% of the pre-scheme figure where there is no reduction in general road capacity. Evidence from an Aberdeen bus priority scheme (Astrop *et al*,[34]) suggests that improvements in journey time for bus passengers may be no greater than increased delays incurred by non-priority traffic in peak periods, suggesting that non-bus users suffer disbenefits in terms of increased travel time.

The only motorway bus lane in the UK along the M4 spur at Heathrow shows significant IVT savings (60% during the four-hour Monday-morning peak and 81% for the busiest peak hour) and reliability improvements (83%, Monday morning peak hour) (White, Walsh and Ashley,[35]).

Journey time reliability

At peak times, track segregation seems to be a major factor to maximise journey time reliability, particularly for travellers-to-work as they comprise the majority of peak travel. For example, bus operators in Edinburgh and Oxford have reported significant reliability improvements (in terms of adherence to timetables) on route segments with bus lanes (Brand and Preston,[36]). In addition, fare collection systems and traffic priority are the main factors affecting journey time reliability. Off-vehicle fare collection and high traffic priority (and segregation of track) for modern rail-based systems show an advantage over bus-based systems (Daugherty *et al*,[16] Tyson,[37] Dorey,[38]).

Multiple public transport interchanges add considerable uncertainty to the reliable timing of journeys. In practice, passengers are unwilling to make journeys that involve more than one interchange by public transport. Hence the more a new scheme covers corridors where before implementation the user had to change more than once, the better the improvement in journey time reliability. For example in Karlsruhe, passengers had to change at least once to get into the main shopping area *before* dual mode light rail operation; after introduction of the new scheme most trips were direct, reducing journey times and reliability alike (Griffin,[39]).

Non-user benefits

Journey-time savings and decongestion benefits

In terms of non-user impacts, the key components are journey-time savings and accident effects due to decongestion. As the bulk of congestion costs are internal to the transport system (increased travel time), external congestion costs are usually valued on the marginal cost basis (e.g. congestion cost of one additional vehicle on the road or rail network). This review found typical external marginal congestion costs caused by buses and coaches at 16 to 19 pence per bus-km (national average), going up to about 36 pence (low estimate) for weekday peak travel in outer conurbations (see e.g. Sansom *et al*,[40]). In contrast, the marginal congestion costs for adding another train service to the London network is about 0.3 pence per train-km.

The main advantage of light rail systems appears to be achievement of a higher and longer sustained modal shift away from car travel, with apparent journey-time (and occasionally accident) benefits for general traffic users. In the UK, between 18% and 25% of light rail users were former car drivers (18-25% for Croydon Tramlink, 22% for Sheffield Supertram, 17-19% for Manchester Metrolink) (Dorey,[38] Tyson,[41] SYPTE,[42]). This compares to 47% for the Robin Hood Line, 11% for Leeds Scott Hall Road guided bus scheme, and 7% for the *elite* QBP scheme in East Leeds after one year of operation (forecast 18%) (NCC,[43] Steer Davies Gleave,[44] WYPTE,[45]). According to one source (Sansom *et al*,[40]), decongestion benefits of "major rail-based urban public transport" per car-kilometre removed from the road network range from 13 to 53 pence per PCU-km (in 2000 prices, PCU = passenger car unit).

In contrast, the foremost advantage (or "beauty" as one bus operator called it) of guided bus or bus lane schemes is that they can be gradually implemented wherever there is a bottleneck on the roads affecting public transport and general traffic alike. They therefore act primarily as congestion busters at hot spots. Note that we do not compare like-with-like as bus priority and guideway sections often signify only a small percentage (<5%) of the total service line whereas, for example, light rail benefits are a result of the performance of the entire line/service.

Safety impacts

Bus travel is safer than travel by private car in terms of the number and severity of accidents per passenger-km (TSGB,[26]). However, buses appear to be less safe when compared to light rail, bus lanes and segregated bus systems on their own right-of-way because of higher accident rates per passenger-km (Brand and Preston,[32]). There are significant safety benefits in reduced accident rates where services run on segregated alignments (e.g. off-street light rail, guided bus). Based on total occupant casualty costs, for example, Manchester Metrolink (£1,171 per million passenger-km) has improved occupant safety on the Bury to Altrincham line by 65% and 87% when compared to bus (£3,322 per million passenger-km) and car (£9,085 per million passenger-km) travel in the corridor respectively (GMPTE,[46] all 2000 prices). In terms of pedestrian casualty cost per million passenger-km, Metrolink (£1,441 per million passenger-km) performs better by 34% and 52% when compared to bus (£2,196 per million passenger-km) and car (£3,013 per million passenger-km). Note that (suburban) rail has a higher proportion of serious accidents *per vehicle-km* than for bus, indicating that accidents happen less frequently but have more severe consequences.

When valuing safety impacts it is important to consider that external accident costs only include human costs not covered by insurance payments, and may also include the individual's willingness to pay for risk reduction. There are different views on what methodology should be used to value accident costs. Common methods range from valuing costs at the full value of statistical life (VoSL, £0.8-£1.5m) to more conservative methods taking into account the years of life lost (VoLL, £2,720-£115,000). Based on the VoLL approach, a recent study (Sansom *et al*,[40]) has shown that fully allocated costs are between 0.2 and 2.4 pence per bus-km. Marginal costs are higher at 3.8 to 6.8 pence per bus-km (all 2000 prices). For rail, external accident costs are often not estimated, since the *external* element is believed to be small once the level of liability placed on rail operators is taken into consideration. If they are, however, the most common method still applies the full value of statistical life method.

Environmental, wider economic, accessibility and integration aspects

Environmental impacts overview

Environmental impacts include noise and pollutant emissions (and the latter effects on air quality), climate change, land use changes and water pollution. Table 4 gives an overview of the main impacts, showing little difference in energy use at point of use (in terms of Mega-Joule per passenger-km travelled) between the systems once full account is taken of the actual levels of utilisation (Brand and Preston,[32] Accutt and Dodgson,[47]). Note that car energy use per passenger-km is about double that of most public transport modes. The most promising technologies to combat climate change currently are (Moon *et al*,[48] USEPA,[49] DfT,[50]):

- Improved diesel engines, with new de-NOx and particulate trap technology leading to vehicles with better fuel economy and hence CO_2 performance but, potentially, without the present penalty in terms of air quality emissions;
- Advanced electric propulsion and energy saving technology such as flywheel or ultra capacitor energy storage or by returning electricity to the power line through the process of braking (regenerative braking);
- Bio-fuels (e.g. locally produced bio-diesel for adapted compression ignition engines) and hydrogen produced from renewable energy sources (for use in either traditional internal combustion engines or for fuel cell electric propulsion).

As technology develops, and costs come down, the benefits and cost-effectiveness of clean and low-carbon technologies change. Over the next ten years and beyond, two technologies in particular – hybrid electric vehicles and fuel cells – appear likely to move towards commercial viability and start entering the market in material numbers, in particular in the bus market. This is reflected in the Government's *Powering Future Vehicles* strategy, which amongst others sets a target for new bus sales: "By 2012, 600 or more buses coming into operation per year will be low carbon, defined as 30% below current average carbon emissions" (DfT,[50]).

Currently, local air and noise pollution considerations still favour light rail. In terms of local air pollution, this is due mainly to two factors: (a) particulate emissions of diesel-powered vehicles are highly damaging in urban areas (human health, buildings) and (b) electric propulsion (light rail, trolley buses, metro) has zero emissions in urban areas. However, cleaner and quieter propulsion systems and fuels for bus-based systems (e.g. advanced particulate traps and 'no sulphur' diesel, hybrid-electric propulsion, gas-powered internal combustion engines) are poised to close the gap in the near to medium term (Moon *et al*,[48] DfT,[50] TTK,[51]). Note that when compared to the transport sector as a whole, air quality related pollutant emissions from public transport are relatively small, in particular outside London. This is one of the key factors influencing decisions on whether or not to invest in low emissions bus fleets. Therefore, there may be more cost-effective measures to meet air quality standards, for example traffic management and road pricing in urban areas.

The noise levels of bus and light rail at acceleration and braking are about 70-75 dB and 60-65 dB respectively, with guided buses being allegedly 'perceptibly quieter' on the guideway than on normal streets (Read *et al*,[21]). Also, conventional buses running on compressed natural gas (CNG) are about 4-8 dB quieter than conventional diesel buses in urban areas

(CVTF,[52]). Similarly, tests on liquid petroleum gas (LPG) buses have shown a reduction of 2-3 dB over diesel buses.

Table 4: Summary of energy use and external environmental costs (low-to-high estimates, 2000 prices and values)

In terms of environmental costs, recent studies (Sansom *et al*,[40] EC,[53]) have shown that for buses external air pollution costs are higher (about a factor of two) than noise and climate change costs. In contrast, noise pollution is more significant for rail-based systems. Note also that diesel trains emit much higher levels of particles, the key pollutant in health impacts, therefore yielding higher costs in urban areas. The ranges of values reflect different methodologies (e.g. VoSL vs. VoLL) and levels of uncertainty (in particular valuations of climate change effects are uncertain). Note that by comparison, environmental costs are higher than accident costs, however lower than congestion externalities.

In urban areas, however, air pollution costs can reach much higher levels due to higher population densities and congestion effects. According to Sansom *et al*,[40] total environmental costs for buses are about 56 pence per bus-km (their 'central' estimate) in Central London, compared to the national average of about 10 pence per bus-km; air pollution costs are about three times higher than noise costs. In comparison, suburban rail and urban (here Passenger Transport Executive, PTE) services show average costs of about 44 and 33 pence per train-km for electric trains, and 35 and 32 pence per train-km for diesel trains. Assuming typical average utilisation factors for bus and urban rail (~25%), total environmental bus costs (~1.0 pence per passenger-km) are higher than urban rail costs (~0.7 pence per passenger-km). Obviously, the outcome is very much dependent on local conditions.

By contrast, water pollution costs of motor vehicles range from major spills (0.08 pence per vehicle-km) to the sum of oil spill, road salt, and hydrologic impacts (0.4 pence per vehicle-km, 2000 prices). These are relatively low compared to other impacts such as air quality and noise (Litman,[54]).

Land-take efficiency (the ratio between land used and the infrastructure's traffic carrying capacity) varies strikingly from one infrastructure type to another. For example, compared to road transport, railways require the lowest land take per passenger-km and tonne-km – land take per passenger-km by rail is about 3.5 times lower than for passenger cars, and 1.5 times lower than for bus (EEA,[55] Bruun and Vuchic,[56]).

Wider economic impacts

The wider economic impacts of a scheme have usually been assessed only qualitatively. Quantification is often not possible due to the limited data availability and the complex interactions with other economic activities of the scheme, making it difficult to isolate, say, economic regeneration effects and increases in house prices along a corridor (Brand and Preston,[36]). For example, each of the three planned Metrolink extensions (Phase 3) are claimed to have a "strong relationship with regeneration in the corridor they serve" (GMPTE,[57]); and Tyson[37] claims that the entire Manchester Metrolink network (existing phases 1 and 2 plus planned phase 3) will have created 9,500 permanent jobs. However, the studies acknowledge there is considerable uncertainty in these figures.

The nature and extent of both direct (immediate economic impacts of transport investment) and indirect (e.g. multiplier effects of direct impacts, induced impacts) impacts have been discussed elsewhere (e.g. DSC,[58]; DETR,[59]) and are not further investigated here.

Accessibility impacts

In terms of community severance there seems to be no significant difference between the modes and technologies considered in this paper (Brand and Preston,[32]), although this depends obviously on the degree of segregation and provision of easy-access crossings. Underground systems seem to be ideal in terms of community severance, however they have traditionally lost out in terms of accessibility to, for example, the mobility impaired. Most new modern systems are likely to provide easy access for all as well as sufficient crossings to avoid negative accessibility impacts.

Accessibility in terms of walking distance to the nearest stop is highest for bus-based systems in urban areas, with stop densities averaging at 2.5 stops per km, or 400 metres between stops (Brand and Preston,[18]). Average walking distances can be derived by a common geometric model giving:

$$WD = (WCA/4 + DS/4) * BF$$

where:
- WD = average walking distance to/from stop,
- WCA = mean width of the route's catchment area,
- DS = average distance between stops,
- BF = 'bendiness' factor, allowing for obstructions, crossing roads etc.

Assuming a width of a route's catchment area of 500 metres (typical in urban areas) and a 'bendiness' factor of 1.2, this provides average walking distances of 270 metres (taking 4.1 min to walk assuming 4 km/h walking speed). Typical figures for light rail are 2 stops per km, giving on average 4.5 min to walk the 300 metres distance to/from the stop. This implies that accessibility is reduced considerably when distances between stops exceed 1,000 metres. For this reason new stations were added to the heavy rail lines on the Karlsruhe dual mode network (with inter-stop distances of about 500 metres) to improve accessibility for suburban dwellers, with particular benefits for the mobility impaired (EC,[60]).

Integration – modal, policy and ticketing

In the current transport policy climate, any new system is likely to have a positive impact on modal integration and attract new passengers as a result (generated trips). More specifically, the technology that can more easily be integrated in the current transport system will show higher public acceptability, for example a busway scheme connecting existing interchanges with the city centre shopping area, or a light rail extension using existing or disused heavy rail corridors, with stops added at (new) commercial, housing and work locations. Also, dual mode rail (Karlsruhe, Saarbrücken) has proved to be successful in integrating urban light rail and suburban heavy rail, at comparatively low capital expense and lower operating costs (up to 50% lower than previous heavy rail operations) (EC,[60]). In the wider transport policy context, light rail, guided bus and busway systems fit well into the current drive to provide cost-effective, reliable, clean and integrated urban public transport.

Integration of ticketing is another important factor in the success of transport systems; it is not always well developed in the UK, even within modes (e.g. several bus operators sharing the same urban corridors but not the ticketing). In the UK, London stands out as a good example of how to do it better across modes. For more information on the apparent benefits of integrated ticketing and the use of Smartcards in the UK and overseas see, e.g., CfIT,[61] CfIT,[62] Carr,[63] DETR,[64].

Conclusions

The up-to-date information presented here contributes to an objective assessment of the policy implications of public transport investment. The review has highlighted the following:

- Although slightly more expensive to build (under similar conditions), light rail systems often carry more passengers than conventional bus-based systems and show a higher modal shift from car, implying decongestion benefits for non-users.
- Operating costs per passenger-km are similar for most systems except metro systems, which are twice as expensive to run than other systems. When comparing revenues and operating costs directly, all modes appear capable of covering operating costs overall, at least in the UK, with light rail and suburban rail in large conurbations providing a marginal surplus of revenue. However, suburban rail in smaller conurbations seems unlikely to cover operating costs (SRA,[27]).
- Overall, new light rail systems improve in-vehicle times significantly in heavily congested corridors, whereas overall savings are lower (and sometimes negative) for bus-based systems. The lower savings for buses are mainly due to the relatively short bus priority track lengths compared to overall route lengths. This highlights the fact that bus priority systems act primarily as congestion busters at hot spots, which can be implemented more flexibly and gradually than for rail-based systems.
- Currently, electric propulsion (light rail, metro, trolley bus, hybrid electric bus) appears to be the best option to mitigate local air pollution and noise. However, new vehicle technologies such as advanced diesel propulsion (near term) as well as hybrid electric vehicles and fuel cells (longer term) are poised to play a major role in reducing emissions in the future, in particular for bus-based systems (DfT,[50]).
- Externalities of quantifiable impacts due to water pollution, land use, use of non-renewable resources and severance effects are smaller than the costs of airborne

emissions, noise and accidents. In particular, environmental costs are higher than accident costs, however lower than congestion externalities. This confirms other important work done in this area (e.g. Bickel and Friedrich,[65]).

- Some of the effects above are a direct result of recent developments in system and vehicle technology. Technology has evolved mainly to ease access (most new vehicles are now low floor), to reduce energy use and pollutant emissions, to reduce overall costs, and to increase accessibility and modal integration.

Acknowledgements

This research has been funded by the U.K. Engineering and Physical Sciences Research Council and Department for Transport under the Future Integrated Transport Programme. The authors would like to acknowledge the assistance of the various experts in providing the information used. Any errors of interpretation or otherwise are the responsibility of the authors.

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Tables and figures

Table 1: Technical and operational characteristics

Characteristic / *Mode*	*Light rail*	*Metro*	*Suburban rail*	*Bus lanes*	*Busways*	*Guided bus* [(b)]	*ULTra* [(c)]
Vehicle/train capacity (pax)	350	600	800	75-125	75-200	75-125	4
Typical system capacity (pax per hour)	1,000-21,000	10,000-40,000	1,000-32,000	4,500-7,500	4,500-25,000	4,500-7,500 (9,600)	500-1,500
Operational speed (kph)	21-45 (60 [(a)])	25-60	40-70	15-25	22-50	20-35 (22-40)	20-25
Width (double track) (metres)	5-6.5	5-6.5	5.5-7	6-8	8-13	5.8-6.2 (7.0)	4-5

[(a)] Dual mode light rail vehicles on suburban heavy rail tracks.

[(b)] Information in brackets relate to the Guided Light Transit type systems.

[(c)] Based on available ULTra pilot scheme data – no system has been implemented yet.

Table 2: Investment costs (2000 prices and values)

£2000 prices	*Light rail*	*Dual mode light rail* [a]	*Suburban rail*	*Bus lanes*	*Busways*	*Guided bus* [c]
Infrastructure costs (£m/km, 2-way)	3.3-10.5 (3.0-60 [e])	1.1-7.6	4-15 (0.66 [g])	0.01-1.29 [f]	2.8-11 (2.8-14 [e])	2.5-5.8 (2.2)
AVERAGE costs (£m/km, 2-way)	6.6 (13.3 [e])	3.1	-	0.49	6.1 (8.0 [e])	3.7
SD of costs (£m/km, 2-way)	2.3 (13.6 [e])	3.1	-	0.54	3.2 (4.7 [e])	1.3
Vehicle/train cost (£m)	0.8-2.0	1.2-1.8	1.8-3.0 (1.8 [g])	0.11-0.19 [b]	0.11-0.19[b]	0.12-0.2[b] (1.1)
Vehicle/train capacity (seats)	70-150	70-150	170-375	35-78	35-78	35-78 (60)
Vehicle/train capacity (seats + standing)	200-350	200-350	250-750	75-125	75-125	75-125 (160-180)
Cost per seat installed (£k)	11.4-13.3	12.0-17.1	8.0-10.6	2.4-3.1	2.4-3.1	2.6-3.4 (18)
Cost per potential passenger) (£k)	4.0-5.7	5.1-6.0	4.0-7.2	1.5-1.6	1.5-1.6	1.6 (6.9)
Economic lifetime of vehicles	25-50	25-40	25-50	8-20	8-20	8-20 (10-15)

(a) Dual mode light rail vehicles running on urban light rail and suburban heavy rail tracks with dual voltage equipment, e.g. Karlsruhe, Saarbrücken (Germany), Tyne and Wear Metro extension.

(b) High values for articulated buses. Add between 15% (e.g. CNG, ethanol) and 85% (battery electric) for alternative fuelled vehicles. Fuel cell powered buses such as DaimlerChrysler's NEBUS are not commercially available yet.

(c) Information in brackets relate to the Guided Light Transit system (representing "trams-on-tyres").

(d) Based on scheme appraisal estimates.

(e) Including proposed schemes and schemes with tunnels and bridges.

(f) The high figure corresponds to the motorway bus lane on the approach to Heathrow Airport.

(g) The low-cost figure refers to the Robin Hood Line North of Nottingham and represents a *conversion* of ex-BR rail to modern suburban rail.

Table 3: Summary of annual operating costs and revenue income of systems in the UK

£2000 prices	*Light rail* [a]	*Metro* [a]	*Suburban rail* [a]	*Urban bus* [a]
Costs per VKM [b]				
- AVERAGE (£)	4.2	14.0	7.5	1.1 [c]
- SD (£)	1.2	4.9	4.0	0.3
Costs per PKM [b]				
- AVERAGE (pence)	13.0	21.2	9.6	11.3
- SD (pence)	4.8	8.8	3.4	2.4
No. of cost observations	*5*	*2*	*10*	*9*
Revenue per VKM				
- AVERAGE (£)	5.0	13.0	8.2	1.0
- SD (£)	2.7	6.6	3.3	0.1
Revenue per PKM				
- AVERAGE (pence)	12.5	18.4	8.9	10.8
- SD (pence)	3.6	4.7	1.3	1.6
Mean fare				
- AVERAGE (pence)	77.1	92.9	261.3	63.8
- SD (pence)	14.1	33.2	76.7	3.6
No. of revenue observations	*5*	*2*	*10*	*4*
Implied average loads	32.3	66.2	78.5	10.2

(a) 'Light rail' includes all modern light rail systems in the UK, but excludes London's DLR (because the costs include financing and depreciation whereas others do not) and proposed schemes (e.g. South Hampshire Rapid Transit); 'Metro' includes London and Glasgow undergrounds; 'Suburban rail' includes the Robin Hood Line, eight London and South East lines and the regional rail average; and 'Urban bus' includes English Metropolitan areas, Leeds, Oxford, Ipswich *Superoute 66*, Dublin (only costs) and operators' averages for radial corridors (excludes London).

(b) Excludes financing and depreciation of vehicles.

(c) In London, average bus operating costs per vehicle-km were 150 pence in 2000/01 (excluding depreciation).

Table 4: Summary of energy use and external environmental costs (low-to-high estimates, 2000 prices and values)

Mode Impact	*Diesel bus (national avg.)*	*Regional rail*	*Suburban rail (London)*	*Urban rail (PTE)*	*Car*
Energy use (MJ/passenger-km)	0.7-1.6	0.8-1.8	0.3	0.7-1.0	1.7-3.5
Air pollution (pence per vehicle-km)	3.3-16.1	4.3-37.6	7.0-80.5	11-12.8	0.2-0.9
Noise (pence per vehicle-km)	1.3-4.3	4.4-14.5	9.2-30.4	15.9-16.9	0.2-0.5
Climate change (pence per vehicle-km)	0.6-2.3	3.2-12.9	3.9-15.4	6.1-6.4	0.1-0.5