LAND USE TRANSPORT RULE OF THUMB CAPACITIES

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Introduction

The aim of this note is to set down some easily applied guidelines on transport capacity and the demand that could be expected to arise from associated developments.

Public Transport Capacities

At their simplest public transport capacities are the product of service frequency, vehicle consists and vehicle capacities. In real life the estimation of effective public transport service capacities is rather more complex and requires consideration of access capacities, operating conditions and demand profiles. For the purposes of these estimates we take simple rules of thumb and make appropriate qualifications in the accompanying text.

Street Running Buses

Maximum capacities for conventional London bus operations are shown in table 1.

Frequency Bus Type	**4 bph**	**8 bph**	**12 bph**	**16 bph**	**20 bph**	**24 bph**
Midi[1]	160 pph	320 pph	480 pph	640 pph	800 pph	960 pph
Single[2]	212 pph	424 pph	636 pph	848 pph	1,060 pph	1,272 pph
Double[3]	320 pph	640 pph	960 pph	1,280 pph	1,600 pph	1,920 pph
Artic[4]	480 pph	960 pph	1,440 pph	1,920 pph	2,400 pph	2,800 pph

Table 1: Bus Service Capacities

Whilst in theory higher capacities can be achieved, in practice it is unrealistic to try and provide a capacity of more than about 2½ thousand passengers an hour with a single service along a mixed traffic route. Whilst higher capacities can be provided using several services this will require multiple sets of bus stops and service speeds and reliability will be at risk.

These capacities represent peak availability and will not be effective in normal operating conditions. Variations in loading patterns, variations in directional flows and unevenness of service combine to reduce the effective capacity and, with double-decker buses, some upper deck capacity may remain unused, even with heavy loadings, because of unwillingness/inability to climb/descend stairs by some passengers. It should be borne in mind that the very high capacity achieved with articulated buses comes at a price of a

[1] Capacity based on an Optare Solo M920 (8.5 metre), 33 seats plus 7 standing.
[2] Capacity based on a Wright Bus Commander (11.8 metre), 43 seats plus 10 standing.
[3] Capacity based on Optare Spectra (10.7 metres), 70 seats plus 10 standing
[4] Capacity based on Mercedes Citaro Articulated bus, 120 in all.

high proportion of standees and courts problems of bus stop congestion when service irregularities arise.

Some of the operational problems can be reduced by providing bus priorities and TfL's own studies[5] suggest a maximum capacity of a bus route in mixed traffic of 2,500 pph and a maximum capacity with intensive bus priorities of 4,000 pph.

Busways

Busways provide an exclusive right of way for buses along the section of route that they are provided. However one of the advantages of busways over light rail is that they allow buses to operate off the exclusive right of way and therefore operating conditions on mixed traffic roads used by the busway services must be taken into account in estimating capacities and service levels for busway based bus services. Bus operations on busways can be by driver steering or using kerb (or centre plough[6]) steering. The use of guidance allows buses to operate at higher speeds through more constrained envelopes and to dock more rapidly and precisely at stops.

Busway systems are most common in South America and carry heavy passenger loads.

City	Number of Routes	Daily Boardings (thousands)	Average hourly boardings per route assuming 18 hour day
Porto Allegre	16	1,743	6052
Bogotá	7	1,610	12777
Curitiba	6	532	4925
Sao Paulo	4	481	6680
Quito	1	210	11666
São Mateus - Jabaquara	11	200	1010

Table 2: Busway Utilisation in South American Cities
Source: Urban Transit Factbook, Santos Pereira (2004), Castro (2004).

Although these busways differ in length, vehicle type and operating procedures they generally attract over 200 thousand boardings per day. As well as these South American examples substantial busways have been built in Adelaide (South Australia) and Ottawa (Canada)

The Adelaide O-Bahn is 12 kilometres in length and is the longest and fastest guided bus service in the world. It can operate at speeds up to 100 kph and claims to be capable of moving 18,000 people an hour in each direction but has only two stops between the out of town end and the feed in the central Adelaide street network. However this capacity has never been achieved and would require operating high capacity articulated buses at

[5] TfL Light Transit Workshop Information Note page 3.
[6] Ventéjol P & Laurent D (2004). (Philippe Ventéjol is in the planning Dept, RATP)

headways of twenty seconds or less which, with stopping services (even allowing for off guideway stops), is not a practicable proposition in normal service. Its capital costs were about £5m per kilometre[7] – not much different from the estimates for the proposed light rail system it supplanted.

The Ottawa system uses a combination of (31 kms) busways and priority lanes on highways to serve the three main radial corridors south of the Ottawa River into the CBD. The system has been implemented over almost twenty years and has cost a total of about £250m (£8m per kilometre). Again the control of development has favoured the busway corridors so promoting the use of public transport. However overall bus ridership has changed little over the last twenty years, despite an 80% increase in population.

The Brisbane system comprises a series of busways and has been in development since 1995 as part of an integrated transport plan aimed at increasing public transport's modal share in the city from 7% to 10.5% by 2011. Two major corridors are served and extensive engineering works have been undertaken to give high quality exclusive rights of way. The 16½km South East Busway has cost about £9m per kilometre[8] and the peak throughput of the busiest section is claimed to be 150 buses/hour. Real time information, purpose designed stations and park and ride also feature and the main busway accommodates 2,300 buses a day carrying 80,000 passenger trips. If 12% of traffic is in the peak hour this gives an effective capacity of 10,000 passengers per hour. It must be emphasised that this busway is a major facility as can be seen from figure 1.

Figure 1: Brisbane Cultural Centre Busway Station

[7] Prices adjusted to current levels.
[8] Banks (2004)

The 4.7km Inner Northern busway is expected to cost about £11m per kilometre but usage will be lower than on its predecessor with 24 bus/hour in the peak and 400 per day. Time savings are estimated to be about 1¼ minutes/kilometre.

The Curitiba system comprises five bus corridors between 8 and 12 kilometres long[9]. It uses very long (26½ metre) bi-articulated vehicles and has give doors with pre payment and level boarding which allows very rapid embarkation/disembarkation (up to 270 people in 20 seconds) and achieves carryings of 14,000 passengers per hour in the peak direction[10]. The average operating speeds are 21 kph (twice that for normal bus operations in the city) but bus stops are around ½km apart. Planning policies have concentrated populations and commercial activities into corridors centred on the busways so strongly orienting demand towards buses. It capital costs come out at about £1m per kilometre.

In the late 1990s, Bogotá began operating a high-speed, high-capacity bus system, which built on Curitiba, Brazil, and its much-celebrated success with dedicated busways. Bogotá's system has much more substantial infrastructure. The centerpiece of its bus network is an 80 kilometre, three-line busway (Phases I and II of the network) called Transmilenio. Eventually, this network will serve the whole region with 22 lines spanning 385 kilometres.

Transmilenio carries up to 35,000 passengers an hour in each direction and bus speeds in the busway corridors have increased from 8 kph to 27 kph. It has two exclusive lanes in each direction and 110 high platform stations with prepayment.

Busway capacities can be very high – depending on their physical and operational features. In some South American cities capacities well in excess of 10,000 passengers per hour are achieved in intensively trafficked corridors with infrastructure footprints similar to rail systems. In London the space availability and demand conditions are such that these are impractically high throughputs and the TfL figure of 7,000 per hour[11] is more realistic, if a little conservative, as indicated in table 14.

Light Rail

Light rail is popular in Europe – particularly in central and eastern parts but has seen a renaissance in the west since the 1980s. It is now being developed in China with ten lines opened since 2001 and as many again in planning and construction[12].

Light rail has an advantage over most busways in accommodating larger vehicles and therefore providing higher capacities. Over 20,000pph has been claimed in a number of sources[13]. Operations with 2 minute headways and bi-car (300 passenger capacity)

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[9] Curitiba's "Bus Rapid Transit" – How Applicable to Los Angeles and Other U.S. Cities?
[10] Jane's Urban Transport Systems.
[11] Light Transit Workshop Information Note page 3.
[12] Lawrence (2004).
[13] E.g. TEST PWP1.

consist are capable of carrying 9,000pph and this can be improved by increasing the consists to tri-car (60 metre length) to 12,000. In theory these can be increased further by operating larger trains and reducing headways even further. In practice to provide this takes light rail into the domain of metros. Table 3 illustrates the capacity range of light rail systems which are capable of operating in a less then fully segregated/full infrastructure mode. At present the longest permanently coupled street running light rail vehicle is the Flexity Classic (made by Bombardier) at 45cmetres long[14]. (An even longer one in Linz, Austria?) (The Classic is used in at least 8 German cities, e.g. Bremen)

The maximum capacities indicated are unlikely to be required in the UK. Croydon Tramlink and Manchester Metrolink, the two busiest mixed running systems in the UK, run peak services of 15tph. The DLR, which carries over 150,000 passengers a day operates 25 trains an hour in the peak over its busiest section and Tyne and Wear Metro, which carries 180,000 passengers a day on larger trains, operates 15 trains an hour in the peak.

Frequency LRV Type	**4 vph**	**8 vph**	**12 vph**	**16 vph**	**20 vph**	**24 vph**	**30vph 2 min headway**
Blackpool double decker	320pph	640pph	960pph	1,280pph	1,600pph	1,920pph	
Croydon bi-car (30m)	960pph	1,920pph	2,880pph	3,840pph	4,800pph	5,760pph	
Bi Car 300 capacity							9000
Tri car (45m)	1,440pph	2,880pph	4,320pph	5,760pph	7,200pph	8,650pph	
Double bi-car	1,920pph	3,840pph	5,760pph	7,680pph	9,600pph	11,520pph	

Table 3: Light Rail Service Capacities

This assessment supports TfL's own estimate of the maximum capacity of a modern tramway of 10.000+ passengers per hour[15].

Public Transport Ridership Potential

The potential usage of public transport services is influenced by a range of network and environmental factors. The denser the network, the higher the quality of service offered the greater levels of connectivity, and the more attractive vehicle comfort, fares, ticketing and information the more likely it is to attract riders. The denser the residential, commercial and industrial areas in which the system is set, the more mobile the population and the lower car ownership the greater the propensity to use public transport.

[14] Müller Eberstein (2004)
[15] Light Transit Workshop Information Note page 3.

The overall outcome of these factors is reflected in current trip making rates by Londoners as shown in tables 4 and 5.

Mode	Trips	%	Distance (kms)	%	Trip Length (kms)
Walk	274	29	262		0.96
Bicycle	10½	1	47½		4.5
Car/van driver	278	29	3,373		12.1
Car/van passenger	172	18	2,144		12.5
Other private	9	1	161		17.9
Stage bus	104½	11	574½		5.5
Underground	52	5	670		12.9
National rail	36	4	1,084		30.1
Other public	17	2	292		17.2
All modes	953	100	8,607		9.0

Table 4: London Resident's Travel by Mode 199/2001/2002 (Annual Main Mode)
Source NTS

Purpose	Trips	%	Distance (kms)	Trip Length (kms)
Commuting	147	15	1,871	12.7
Business	36		777	21.6
Education	68	7	339	5.0
Escort education	47½		145	3.1
Shopping	195		824	4.2
Other escort	74½		501	6.7
Other personal business	109½		616	5.6
Visit friends at home	115		1,590	13.8
Visit friends elsewhere	44½		325	7.3
Sports/entertainment	58½		555	9.5
Holiday/day trip	25½		1,010	39.6
Other	32½		54	1.7
All purposes	953		8,607	9.0

Table 5: London Resident's Travel by Purpose 1999/2001/2002 (Annual)
Source NTS

These tables have been complied from the results from the three year 1999/2001 sample and the 2002 sample as results from individual rounds at the London level are subject to significant errors because of the small sample size. Even these consolidate figures should be treated with caution, especially for the lesser modes and purposes.

The numbers in the tables will differ from those implied by operator statistics in a couple of material respects. Firstly they are for main mode and thus a trip involving travelling by bus to the station, riding on the train, then completing the journey on the Underground is counted as a 'surface rail trip' whereas the operators will count each of the individual legs in its statistics. Indeed if the bus section involved two buses this would be counted as two bus trips as each boarding is counted separately on the buses (but not the Underground). The most obvious example of this is in the morning peak travel to central London where of the 450 thousand rail commuters over 200 thousand transfer to Underground to complete their journey[16]. These are classed as surface rail in the NTS but the 200 thousand are included in London Underground passenger journey totals and amount to over 10% of LUL (passenger journey) traffic.

Secondly they do not include trips made by non-residents. Visitors to London staying one or more nights make about 60m bus journeys and 200m Underground journeys a year[17].

It is possible, using London Area Transportation Study data to convert NTS main mode trip rates to public transport journey trip rates and the results of this process are set out in table 6. This illustrates, for example, that for one hundred Underground main Mode journeys there will be 140 Underground boardings and 22 bus trips. It is based on the assumption that trips involving National Rail will have national rail as their main mode, followed by the Underground. The data does not permit ancillary mode trips to split into boardings (this is only significant for bus as the Underground counts station to station links rather then boardings) so it is likely that the bus legs will be higher - as shown in italics.

Mode/Trip Type	Main Mode	NR legs	Underground	Underground legs	Bus	Bus legs
National Rail	100	106	36		15	*18*
Underground	100	-	100	140	22	*26*
Bus	100	-	-	-		140

Table 6: Composition of Main Mode Public Transport Trips[18]

If these factors are applied to the NTS rates we get trip STAGE generation rates for London residents as shown in table 7.

Mode	Main mode	Rail feeder	U/G feeder	Total
National Rail	36	-	-	36
Underground	52	19	-	71
Bus	105	16	23	144
Bus Boardings	147	19	28	194
TOTAL	340	54	51	445

Table 7: Public Transport Trip stage Generation Rates (trip stages/cap/year) London Residents 2002

Grossing these up to annual totals gives 522m trips on the Underground compared with an annual total of 942 million[19]. With 200 million journeys by visitors this leaves a gap

[16] LTR 2003, table 5.1.
[17] Based on LTR 2003, table 9.2 and chart 9.3.
[18] Based on LATS 2001

of 220 million which will comprise journeys by commuters from out of London (the onward journeys by central London rail commuters amount to 130 million[20] although some of these will be by residents) and day visitors. For buses the total comes to 1,420 million compared with an overall total of 1,534 million which seems reasonable as the use of buses by non residents is much lower than on the Underground

Stop & Station Catchments

The distances people are prepared to walk, cycle or go by car to access public transport depends on the quality of public transport offered, the alternative options and their individual circumstances (able bodied or not, car available or not, etc).

In London a distance of 400 metres is usually regarded as the maximum desirable for convenient access to a bus service. For rural areas the national criterion is a ten minute walk (to an hourly or better service)[21]. In practice the closer a journey beginning or end is to a bus stop the more convenient the service will be and the greater the propensity to make use of it. The distribution of access journey lengths for bus users in London is given in table 8.

Distance	**0 – 400 metres**	**400 – 800 metres**	**800 – 1,200 metres**	**>1,200 metres**
% of users	86%	12%	1%	1%

Table 8: Distance of Home Location from Bus Stop for London Residents[22].

For the Underground longer access distances are regarded as reasonable and for the Jubilee Line Impact Study a reasonable access distance was taken to be 800 metres but up to 1,000 metres was felt to be within scope[23]. The distribution of access journey lengths for Underground users in London is given in table 9. This shows quite a different pattern with much longer access distances. This is reflected in the fact that some Underground legs are at the 'town' end of a surface rail journey (about 13%) and substantial proportions travel by bus (18%) and car (11%) to get to/from the Underground[24]

Distance	**0 – 400 metres**	**400 – 800 metres**	**800 – 1,200 metres**	**>1,200 metres**
% of users	13%	16%	10%	61%

Table 9: Distance of Home Location from Underground Station for London Residents[25].

[19] LTR 2003 table 1.1
[20] 0.2 million each way per weekday: LTR 2003 table 5.1.
[21] BPTSG 2003 page 56.
[22] Based on LT Market Report 1998, page 24.
[23] JLE Impact Study Summary Report, Definition of Catchment Areas.
[24] Market Report 1998 page 14.
[25] Based on LT Market Report 1998, page 24.

Excluding Inner London - and the use of Underground by rail commuters we get a rather different picture with 64% of passengers walking and 17% travelling each by car and bus[26].

There is no comparable data for light rail in London but it is reasonable to expect the distance profile to be somewhere in between those of bus and Underground. It is therefore possible to construct a graphical relationship between the distance from a stop/station and the proportion of usage from that and this is shown in figure 2. The curves are not asymptotic to the vertical axis as might be expected as, whilst the propensity to use public transport increases with proximity to the stop/station the pool of potential users shrinks until, at the limit, it reaches zero.

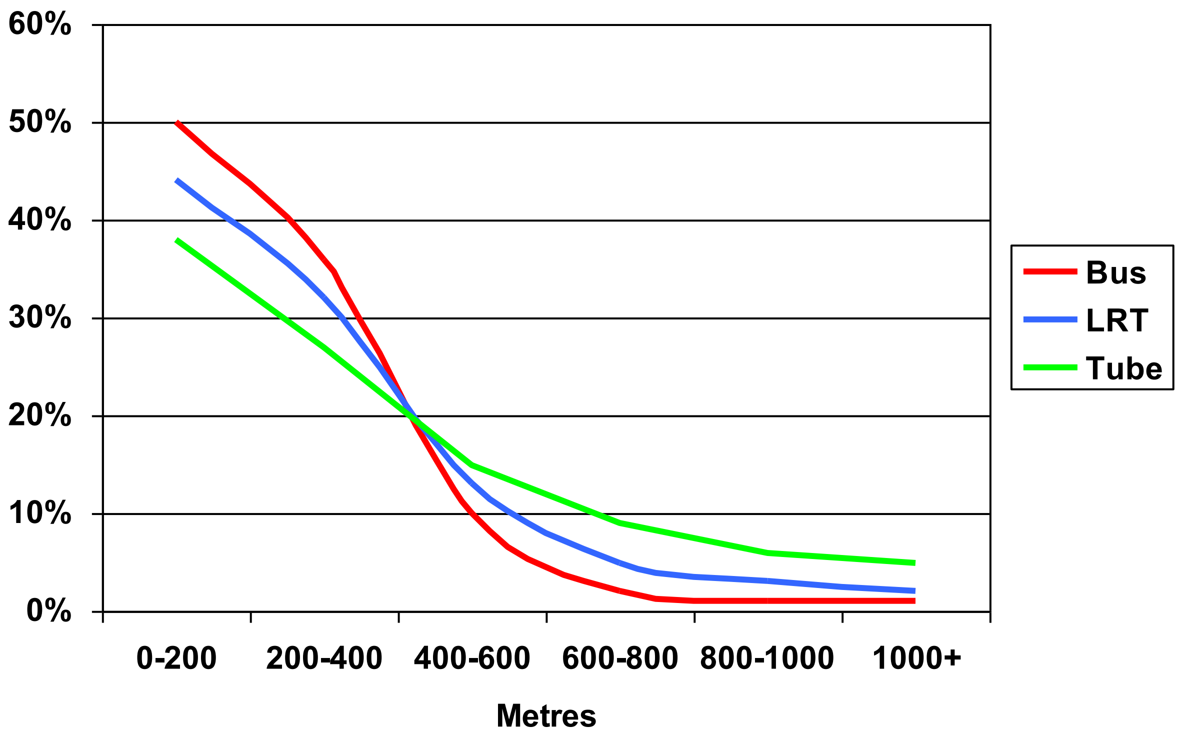

Figure 2: Public Transport Catchment Profiles

What this doesn't show (which would be useful) is the % of all trips to/from various catchments that are made by public transport. One might expect similar shaped curves, but are there surveys that show this information?

One reason why bus access distances are less than rail is that there are more bus stops. In Greater London there are approximately 17 thousand bus stops but only 250 Underground stations. Table 10 gives an idea of the stop and station spacing on London's public transport networks along with other UK light rail systems. This

[26] Market Report 2000 page 14.

indicates that bus stop spacings are about 400 metres. Light rail stop spacings about 750 metres where there is a significant degree of street running and metro station spacings about 1,600 metres.

System	Route Length (kms)	Number of Stops	Average spacing
Surface Rail	2,269	940	2,400 metres
Underground	408	253	1,600 metres
DLR	27	34	800 metres
Croydon	28	38	735 metres
Metrolink	39	37	1,055 metres
Sheffield	29	48	600 metres
Centro	20	23	875 metres
London bus	3,500[27]	8,500	410 metres

Table 10: Stop and Station Spacing on Public Transport Systems

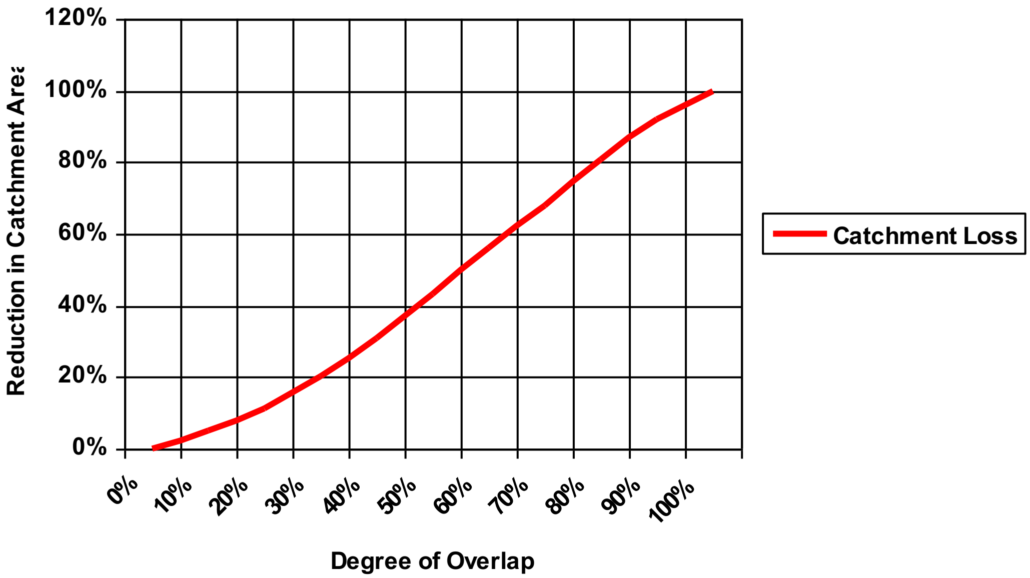

Figure 3: Reduction in Net Catchment Area with Encroachment

Estimating the catchment of a line or service is not simply a matter of adding together the individual stop/station catchments. If we take the 'catchment of a bus service as 400 metres and stops at 400 metres apart one stop will encroach onto another's 'territory' This 50% overlap will lead to a reduction in the catchment of the total catchment of about 40% as can be seen from figure 3. The relationship between overlap and catchment loss is not quite linear as can be seen from figure 3.

[27] TfL (2004b)

Balancing Land Use and Transport Provision

This section considers traffic generation and transport service capacities looking particularly at public transport. Travel generation by an area depends on a number of factors but two of the most influential are population density and car ownership. Looking at London as a whole there are 7.355 million people in an area of 1,584 km^2 – a population density of 4.7 thousand people/km^2. Residential densities vary considerably and in inner London average 2.45 times those of outer London[28]. In London the average household size is 2.3: 2.2 in inner London and 2.4 in Outer London[29].

Car ownership affects both overall travel rates and the use of public transport. This is illustrated in table 11. At present 37% of London's households do not own a car and 18% own two or more[30]. In inner London the balance is different being 51/41/8 and in outer 27/48/25[31]

Trip Rate → Main mode ↓	People in car owning households	People in non car owning households	People in all household
Bus	59	265	100
Rail etc.	85	140	100
Taxi	64	245	100
Walk	87	149	100
Total	72	107	100

Table11. Index of modal use by car ownership (National 2002)[32].

Conventional bus corridors

This section looks at the amount of residential development conventional bus services can be expected to support. It is necessarily based on a number of simplifications and, in real situations these will need to be refined to reflect actual circumstances. The way the calculations are done is described in the appendix and the results are shown in figure 4.

[28] Focus on London 2003, table 2.1.
[29] Focus on London table 2.14.
[30] LTR table 3.3.
[31] Focus on London table 10.1.
[32] From NTS 2002 table 5.2

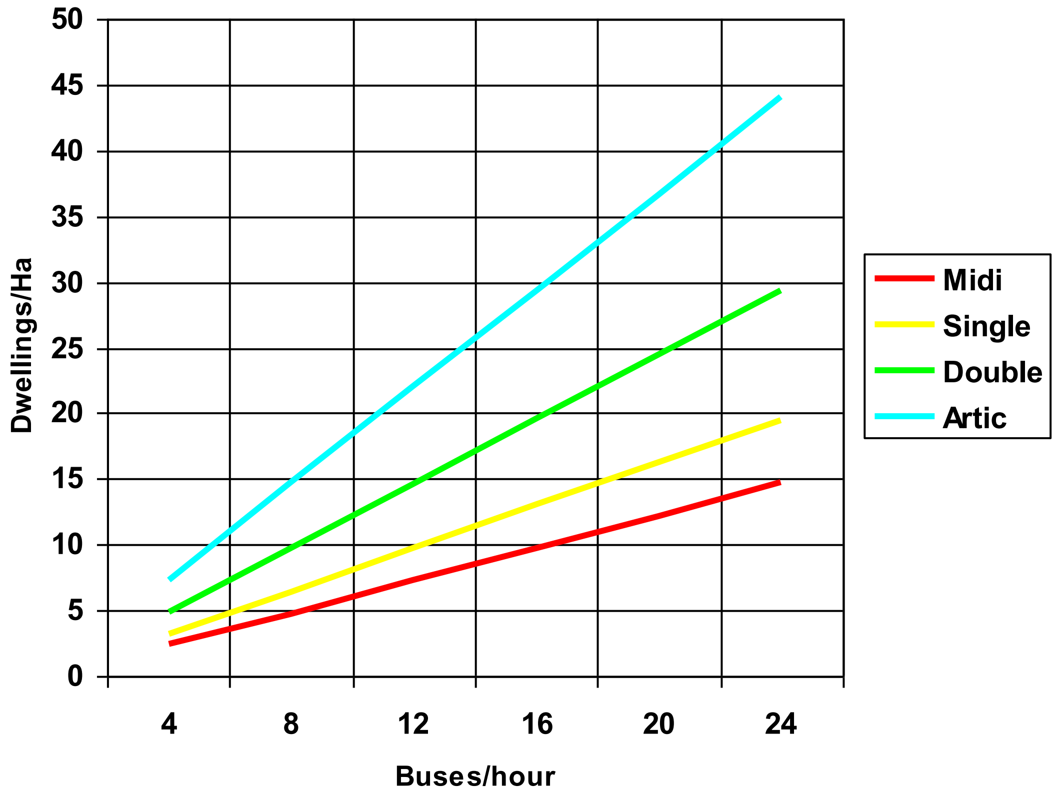

Figure 4: Residential density capacities of bus services

I presume these are gross densities (i.e. density of the catchment overall). Note that the densities (add at least 50% to account for net densities) are relatively low compared to the London Plan density table, implying that higher capacity public transport will be needed to support the upper ranges.

These densities are based on current average London modals splits and car ownership levels. If these change then the lines will shift accordingly: upwards as car ownership rises and downwards if lower car ownership levels prevail in the catchment areas. A 10% change in car ownership, based on national relationships, can be expected to change bus trip rates by 17%.

Busways

Busways offer the prospect of higher capacities and service levels than conventional bus services. There is a range of options for busways and little direct experience of these in Europe so we have constructed a hypothetical range which would appear to be reasonable in the European context.

Frequency Bus Type	30 bph	35 bph	40 bph	45 bph	50 bph	55 bph	60 bph
Double	2,400	2,800	3,200	3,600	4,000	4,400	4,800
Artic	4,500	5,250	6,000	6,750	7,500	8,250	9,000

Table 12: Capacity of hypothetical London Busway (persons per hour)

For the highest frequencies to be achieved would probably require a degree of service regulation at access points and stopping arrangements which allowed buses to pass each other. Because of the higher capacities and service levels the catchments of busways are likely to be greater than for conventional buses and we have taken a range of 600 metres, stops 600 metres apart[33], an average journey length of 6 kms and a 20% uplift in bus trip rates in the corridor served. Using this and the same calculation methods as for conventional buses relationships can be estimated for service frequencies and residential densities. These are given in figure 5.

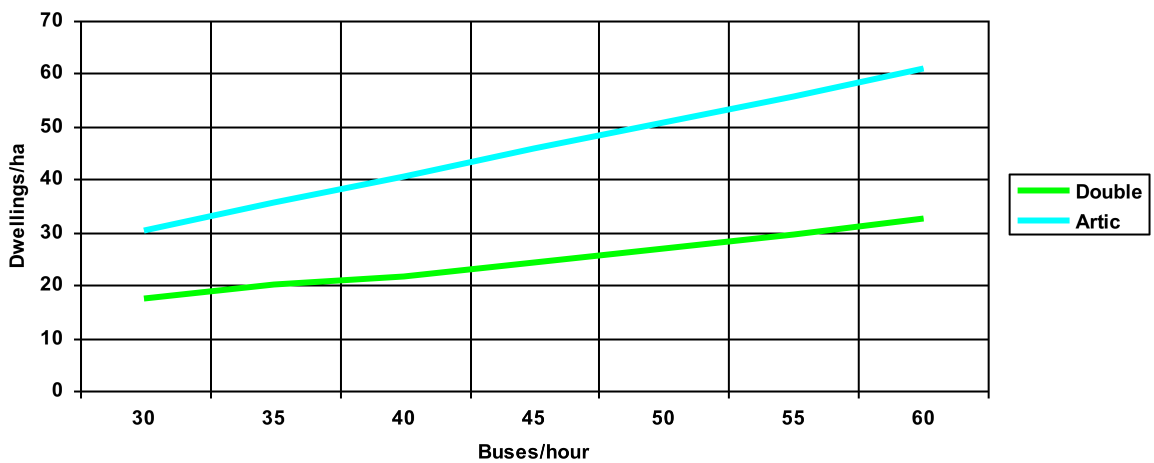

Figure 5: Residential density capacities of busway services

The range of densities that can be accommodated by busways is not that much greater than by buses because, under normal conditions, the additional capacity being partly offset by the increased catchment. By extending the catchment from 400 metres to 600 metres the area served expands by 125%. This is rather like the situation in Ottawa and Brisbane where, whilst the downtown busway stations are frequently integrated into high density employment and retail developments the suburban terrain is largely traditional medium to low density North American housing. The alternative model is that in South American cities where residential densities are very high in the immediate vicinity of the busway stations, falling away after a couple of blocks into more conventional apartments; then low rise dwellings.

The much higher capacities of a busway regime (up to four times the boarding capacities of those of conventional buses, despite assumed longer journey lengths) allow extensive

[33] This is significantly higher than in South American cities where busways typically function as trunk rail alternatives. In Europe we would expect busways to be more oriented to express bus type operations.

high densities in the immediate vicinity of the stations. If the busways environs were planned on the basis of their catchments being contained to within 400 metres, higher densities would be possible as illustrated in figure 6.

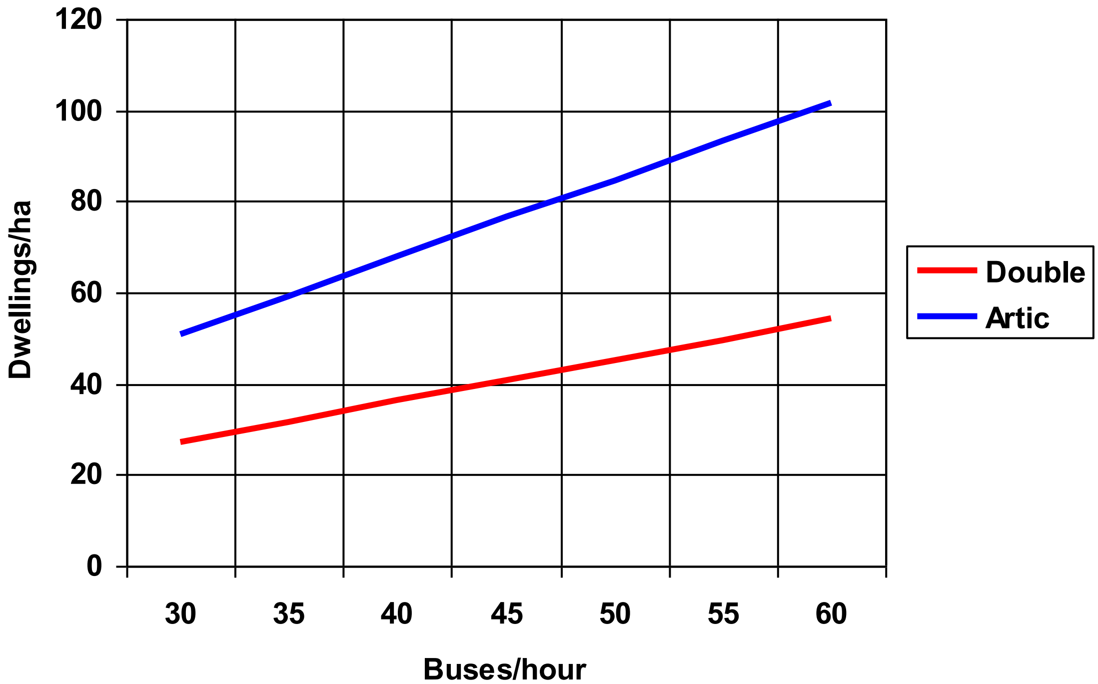

Figure 6: Constrained catchment residential density capacities of busway services

Light Railways

Light rail also has the capacity to provide substantially higher capacities and service levels than conventional buses and its capacities to support development are calculated below but on the basis of 750 metre station spacings. The highest capacity vehicles (red line) would have to be about 60 metres long and, as such would require very substantial stops and would not be suited to mixed running on London's roads but is included as long consists of this kind are operated in some cities at peak periods.

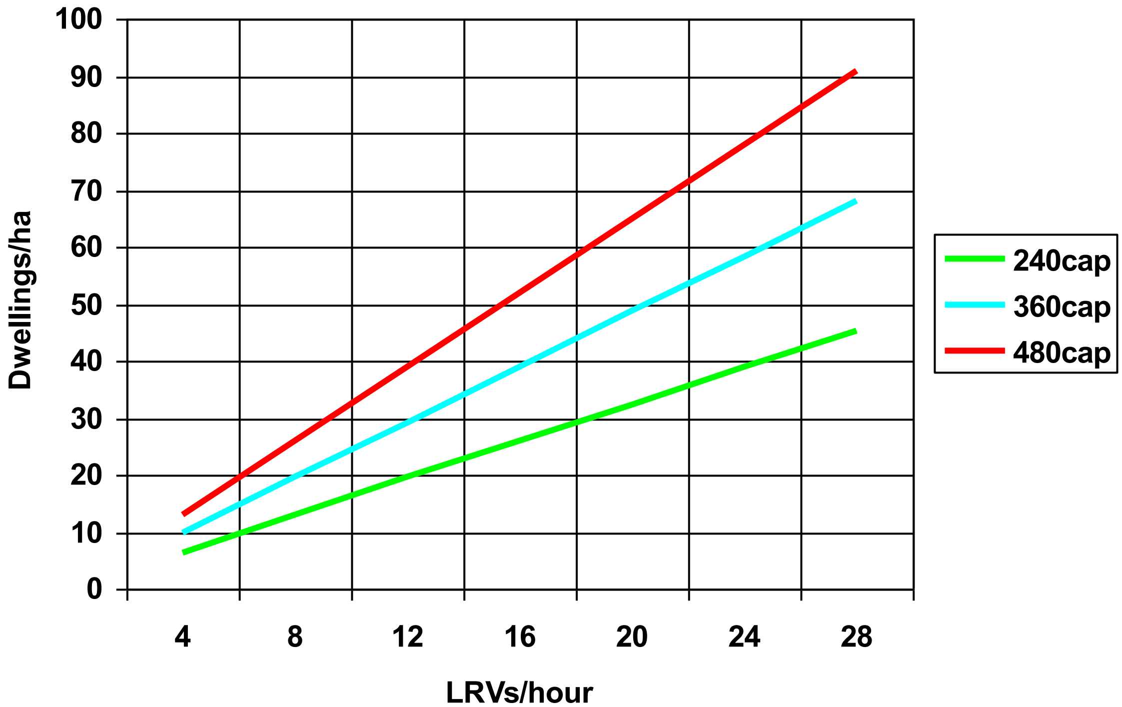

Figure 7: Residential density capacities of LRT systems

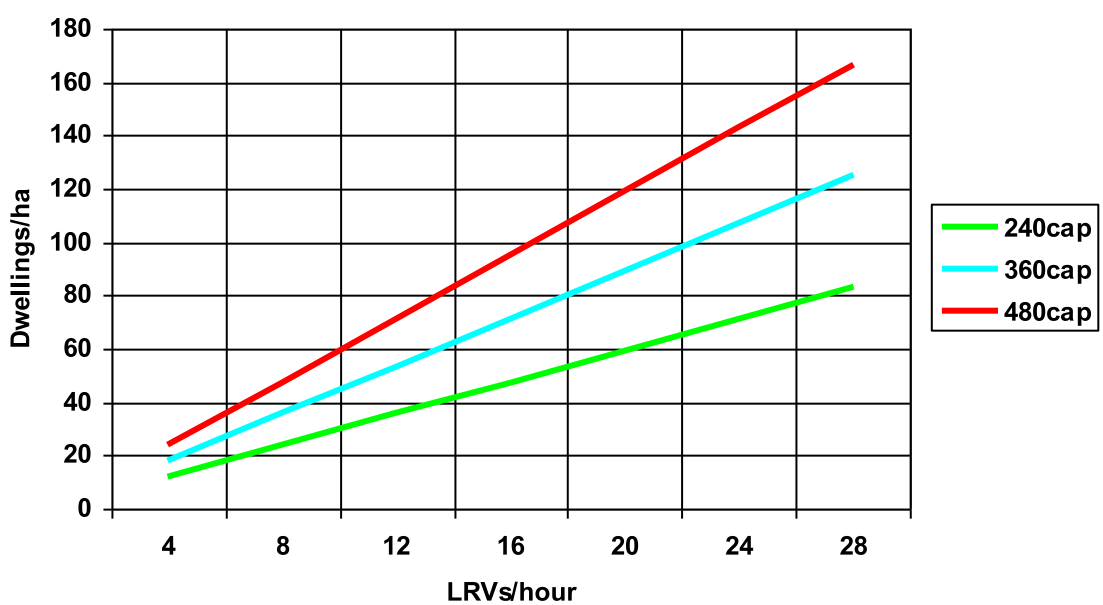

Figure 8: Constrained catchment residential density capacities of LRT systems

Again it is possible to support higher densities if the catchment areas are constrained to zones around the LRT stations as is to be seen in Tuen Mun (Hong Kong). The effects of constraining the catchment to a 400 metre radius is shown in figure 8.

The ranges in this figure reach out towards the extremes of linking high density residential development with high capacity public transport. The extreme dwelling densities are such that car ownership would be suppressed and the use of light rail could be even higher. The Tuen Mun example provide an illustration of this with over 11 thousand daily passengers per route kilometre[34] compared with around 2 thousand on Croydon Tramlink.

Other Motive Systems/Technologies

In the intermediate public transport capacity range there are other technologies that can be used such as hybrid vehicles, trolley buses, fuel cell buses, lightweight monorails and GLT (Guided Light Transit). These can offer local environmental benefits compared with internal combustion-engined vehicles and performance advantages compared with light rail[35]. However overall their service performance falls with the envelope defined by buses, busways and light rail and they will often be more costly. The choice of technology should therefore be based on local circumstances and overall costs effectiveness and not any general preference for a particular technology.

Improved Walking and Cycling

Londoners already 25% walk more than the average in Great Britain[36] but walking as a means of transport has been declining over the last three decades[37]. Generally walk trips are short with 90% less then 2 kms in length. Most walk trips are not for work but to and from school, shopping and leisure - and 30% of all journeys by Londoners are on foot[38]. Moreover many walk journeys made by Londoners are relatively short: over half are less them two kilometres in length[39]. The average length of walk trips nationally is about one kilometre[40]. Walking is more common in Inner London, because there are more local destinations, than in the outer suburbs. On average Londoners cover 380 kms year on foot either as walk journeys or as legs of motorised journeys.

There is little evidence of the effects of improving walking facilities on the amount of travel by foot although Mackett and Robinson[41] have estimated that it is possible that increased walking could reduce car traffic by 0.4%. This would be equivalent to an additional 17 kms/capita/year by direct substitution. However improved walking would attract travel from other modes as well and if the pattern were similar to that estimated for

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[34] LRTA Fact Sheet 45
[35] Ventéjol P & Laurent D (2004) & Korovich B (2004).
[36] RTS 2003, table 1.2
[37] NTS 2003 Provisional Results, table 4.
[38] NTS London Tabulations 1997/2001.
[39] LATS 2001.
[40] Personal Travel Factsheet 4.
[41] Mackett & Robinson (2000).

cycling (see below) we would expect the total increase in walking to be around 70 kms/capita/year. This compares with a London wide target of 38 kms (10% of 380 kms). This might seem ambitious overall but in an environment designed to make walking appropriate for a greater proportion of journeys and more agreeable perhaps not inconceivable. It would therefore be realistic to plan for average levels of walking of 450 kms/capita/year in suitable developments.

Higher levels of walking activity should not lead to any congestion problems as normal footway provision is usually well above what is needed in pure capacity terms. The design challenge is one of quality, security, minimising conflicts with motor vehicles and provision for safe and convenient crossing of carriageways.

Cycling is a limited form of transport in London comprising about 1% of journeys and ½% of travel. Nationally cycling has been in decline[42]. Cycling rates in London are low when compared with some other European cities[43]but have increased of late being 62% higher in Spring 2004 than in Spring 2000[44]. Moreover the amount of cycling varies significantly in London from between 0.3m to 0.7m a day[45]. Nationally cycling rates in July are 2½ times those in December[46] About half London's cycling trips are for commuting/work purposes and there fore are potentially susceptible to workplace travel plans as well as general schemes to improve cycling.

Evidence of impacts relevant to London has been pulled together in Halcrow (2004) and is summarised below.

Scheme	Measures	Impact
Hillside School, Norwich	£6,000 project to improve cycle storage facilities.	A 10 fold increase in cycling to school and over 10% of the school population now cycle to school
Millennium Bridge, York	Built in 2001 links two established traffic-free section of the NCN, providing cyclists and walkers with an alternative to a potential 2km detour	By 2002 cycling trips rose by 31% from 220,000 to 290,000
Royal College Street (LB of Camden	A two-way off-carriageway cycle track	An increase in cyclists by 58% over 3.5 years
King Charles Street (RB Kingston)	A range of measures such as traffic calming, counter flow cycling, speed humps for cars and a	The number of cyclists increased by 49% over 2 years

[42] NTS 2002, table 3.1
[43] A Business case and Evaluation of the Impacts of Cycling in London.
[44] Halcrow Travel Demand Management Study, Supporting Information, Section 6.
[45] The Near Market for Cycling in London.
[46] DfT Cycling Factsheet.

Scheme	Measures	Impact
	segregated section.	
Forest Road (LB Waltham Forest)	New cycle lanes and special traffic lights giving cyclists priority.	An increase of cycling levels of up to 118% over 4 years
Kings Road	Cycle lane improvements	An increase in cycle flows of 31% over 4 years
High Street Kensington	The introduction of a new street layout , a high number of new cycle parking stand and the congestion charge,	cycle flows have gone up by over 50%
Hanover	450km cycle routes, 120 20mph zones, cycle parking service points	Share of cycling trips up from 9% (1979) to 16% (1990) 78% increase
Munster	£24m programme for upgrading old cycle routes 3,300 parking spaces a the station, hire fleet of 300 bikes, 7 Park +Ride sites	Share of cycling trips up from 29% (1981) to 43% (1992) 48%increase
Munich	Cycle route network of 700km, 22,000 cycle parking spaces	Share of cycling trips up from 4% (1980) to 13% (2002) 225% increase
Zurich	Cycle network of 246 km, one way streets opened to two-way cycling during the last 10 years	Share of cycling trips up from 7% (1981) to 11% (2001) 57% increase
Graz	Cycle promotion programme 220km of cycle routes cycle parking at public transport links 770 km of streets in 20mph zones	Share of cycling trips up from 7% (1979) to 17% (1999) 143% increase
Vienna	Cycle route network extended to 900km, opening of one way streets and 20mph, £13 million spent between 1986 and 1999.	Share of cycling trips up from 1.5% (1991) to 4.5% (2001) 180% increase

Table 13: Evidence of impacts of cycling schemes
Source: DfT (2004), Sloman, (2003) TfL, (2004)

At present a third of households in London own bicycles and purchase and running costs are not a significant obstacle for cycle ownership or use and most people know how to ride a bike.

It is claimed that the increase is cycling in London is largely due to the improved road conditions due to increased investment in cycling measures including:

- Improvements to cycling infrastructure - over 100km links, junctions and access
- nearly 3000 additional cycle parking spaces, on street, at stations and at schools
- free cycle maps showing quiet routes and bike shops
- free cyclist training across London

Although it is not possible to be certain what the relative weight of the different factors it is clear that these recent initiatives have had positive effects. From the experience presented in table 13 a doubling of current cycling rates with ‘cycling friendly’ developments and safe and convenient routes and parking is quite plausible. This would match the TfL’s London Cycling Action Plan aims to achieve a 200% increase by 2020 compared to cycling levels in 2000 and would result in winter rates of 45 cycle trips per one thousand population per day and summer rates of 110 cycle trips per one thousand population per day.

Because of its short length, a relatively small proportion of cycle travel will focus on networks but if cycle-ways attracted travel from within a 200 metre radius and two thirds of cycle travel was on these peak hour summertime flows would range from 30 cycles per hour with residential densities of 20 dwellings per hectare to 130 cycles per hour with residential densities of 80 dwellings per hectare. These flows are well below the capacity of even a one metre cycleway of over one thousand cycles an hour.

These additional cycle journeys are estimated to come from[47]:

- 25% of new cycle trips came from car journeys
- 25% from bus journeys
- 25% from tube journeys
- 10 % from train/DLR journeys
- 2% from motorcycle journeys
- 13% from walking journeys

Car Based Urban Development

The growth of car ownership over the last fifty years has meant that many areas have become largely dependent on cars for their mobility as can be seen from figure10. This shows that in small towns (population under twenty five thousand) and rural areas mobility is already very much car based. Given that 27% of households in small towns and 15% of households in rural areas do not own a car, much of the non car travel must be by people who have no choice but to travel by means other cars.

[47] Halcrow Travel Demand Management Study, Supporting Information, Section 6.

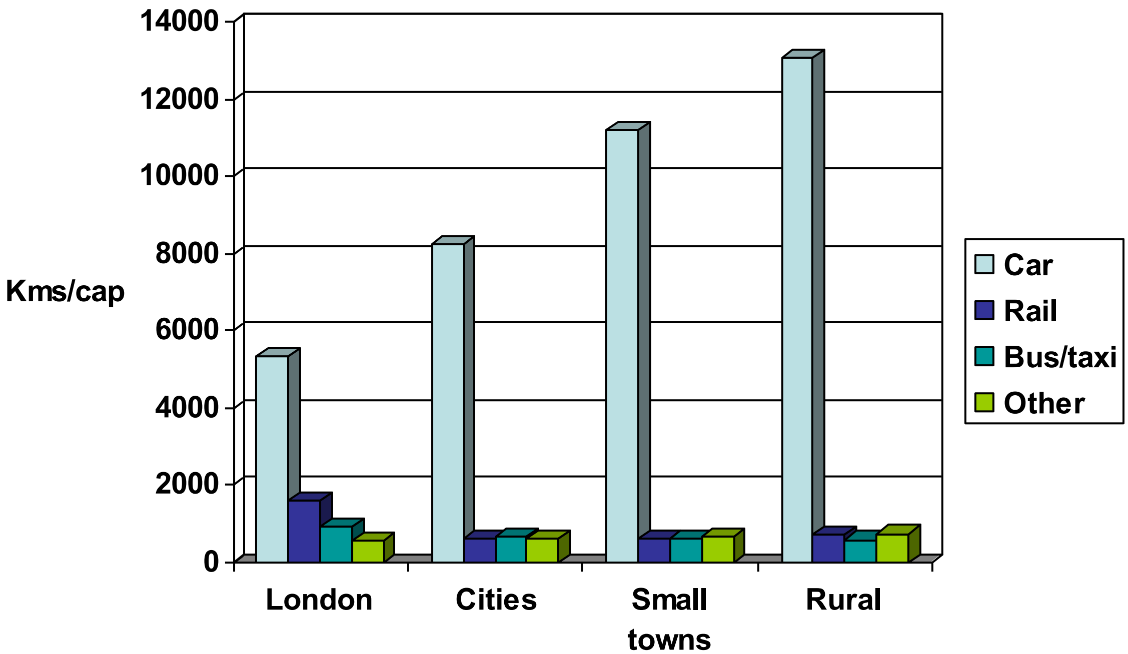

Figure 10: Annual personal travel by mode and type of area
Source NTS 2002 table 3.4

In London this degree of car dependence, except in very exceptional and small pockets, is very unlikely because of the general availability of public transport services and the greater difficulties of making a significant proportion of journeys by car. An illustrative scenario for car base development in London would be rather like that of the cities (non metropolitan areas with populations in excess of a quarter of a million) shown in figure 10. This would lead to a travel profile of say:

- 8,000 kms/capita by car
- 800 kms/capita by rail
- 600 kms/capita by bus and taxi
- 600kms/capita by other modes making
- 10,000 kms/capita in total

This would give an 80% car share for London residents compared with the current average of 64%.

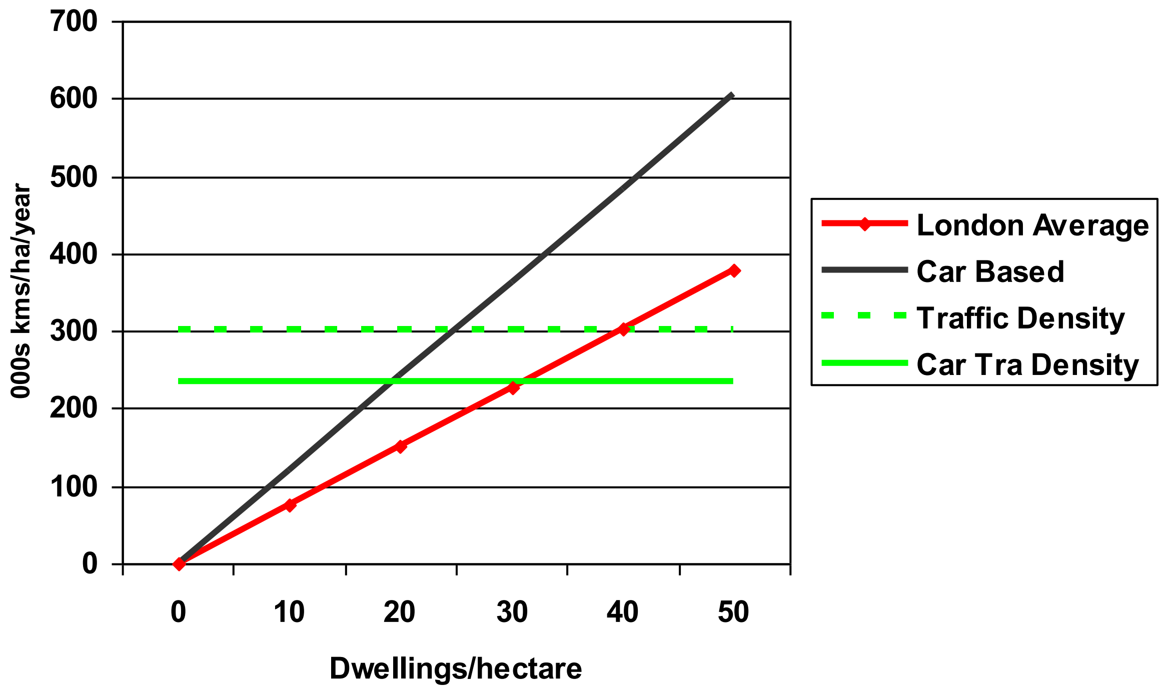

Figure 11: Residential car traffic generation densities

If we plot traffic generation densities with current car use and in the car based scenario, outlined above, and compare then with current traffic densities in London we get the picture shown in figure 11. The current densities (dashed green line) include all traffic – external and commercial as well as cars and the solid green line just car traffic[48]. This indicates that to match current car traffic densities residential densities of about 30 dwellings per hectare are practicable. However with car based development the acceptable residential densities should be under 20 dwellings per hectare.

Generally the road systems of residential developments, industrial estates and commercial parks, provided they are not cluttered with on street parking and are of reasonable geometric standards do not suffer from traffic congestion. It is the traffic routes to which they are connected that experience this problem. London's main roads are already busy and are frequently subject to congestion, especially at peak hours. For each thousand additional dwellings, car base development would impose about 1½ thousand vehicles on the road system in the peak hour and about 12 thousand vehicle kilometres on the main road system – most heavily concentrated in the vicinity of the development.

[48] TSfL 2001 table 13c.

Cost Effectiveness of the Different Modes

The different modes of transport have different capital and operating costs. Those requiring costly infrastructure (e.g. light rail) consequently require higher usage to make effective use of the resources deployed. An indication of the costs of different forms of transport is given in table 14.

Form of Transport	**Cost per Kilometre of Route**
Buses	£0.1m - £1m
Priority bus route	£1m – £2m
Busway	£1m - £15m
Tramway light rail	£10m - £20m
Cycleways	£½m - £1½m
Pedestrian networks	£0.01m - £0.1m

Table 14: Indicative capital cost rates of transport systems.
Source: Halcrow estimates plus TfL (2004b, d and f).

These costs must be treated with some caution as they can vary widely depending on the quality of the scheme and the nature of the environment into which it is being introduced. This is especially so in the case of cycleways and pedestrian networks. As an extreme example improving the pedestrian network between Bankside and the north bank of the Thames cost around £60m/kilometre (by constructing the Millennium Bridge).

Operating costs depend on the nature of the service, the operating environment, industrial practices, age of equipment etc and again therefore generalisations are difficult. Table 15 gives some indicative estimates.

Form of Transport	**Cost per Vehicle Kilometre**
Urban Buses	£1.50 - £3.50
Priority bus route	£1 – £3
Busway	£1 - £2.5
Tramway light rail (bi-car)	£4 - £6 (?)
Cycleways	Local Government current expenditure on roads is about £8/km/year.
Pedestrian networks	

Table 15: Indicative operating cost rates of transport systems.
Source: Halcrow estimates plus TfL (2004b, d and f).

Putting these two sets of estimates together it is possible to produce estimates of relative costs per place kilometre for different levels of capacity. These are shown in figure 9

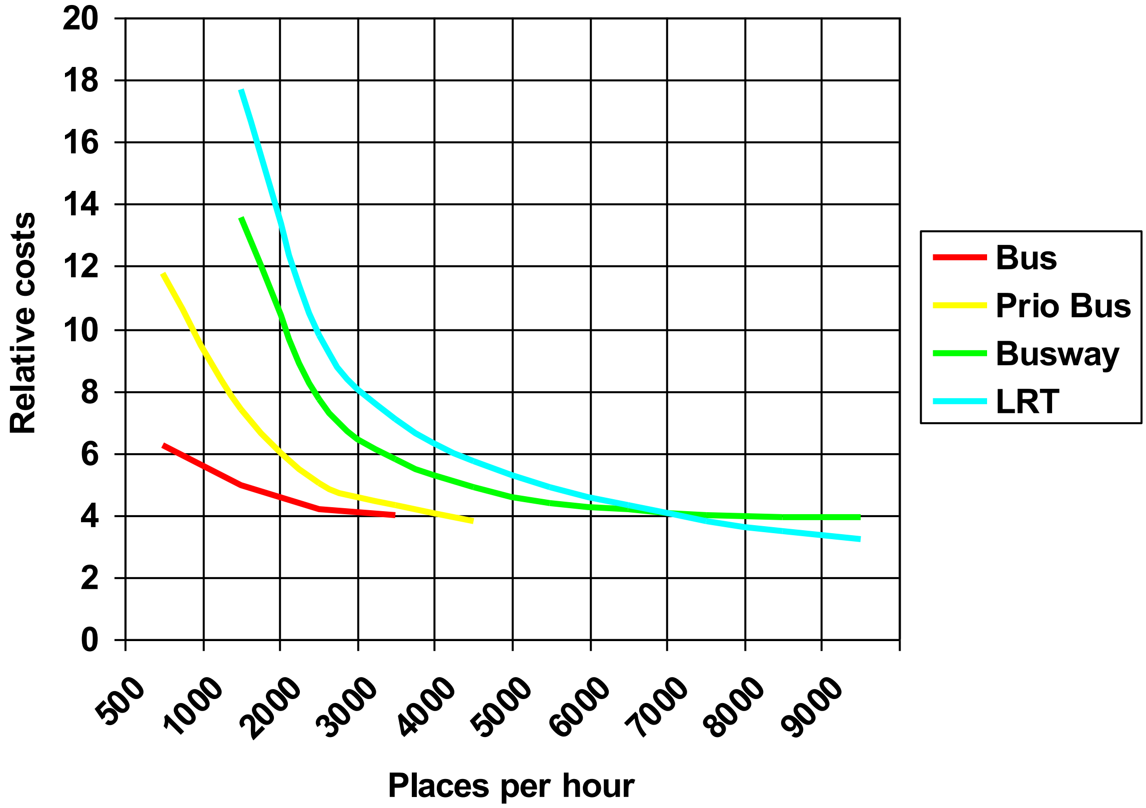

Figure 9: Indicative relative capacity costs by mode

This figure must be treated with caution for three main reasons. Firstly the cost assumptions may not be appropriate for any particular situation. We have assumed light rail capital costs to be £15m/km and busway £10m/km and an asset life of 30 years. We have assumed that both light rail and busway operators will progressively use larger capacity vehicles as the capacity ceiling rises. Secondly the transport cost effectiveness depends strongly on how well the various services are used and this will not necessarily be the same for each mode. Busways have the ability to draw from wider catchment areas as buses can feed on and off the busway but light rail has a special appeal which can attract patronage that may not go by bus. Thirdly the value of a service is not measured simply by its relative capacity cost. Reliability, speed, comfort, etc. are all also important and should be taken into account in selecting which mode is most appropriate. This is especially important in respect of bus priorities where the main benefits come in the form of improved reliability and lower journeys times.

The cost effectiveness of providing improved pedestrian and cycling facilities is very uncertain. The London Walking Plan is based on increasing walking by 10% over ten years at a cost of just over £9m a year and some additional walking would also result in a loss of public transport use and revenue. The result of this is that increasing walking would cost about 50p per pedestrian kilometre. However there would be considerable benefits to existing walking and reductions in road and public transport congestion with possible 100 million kilometres of car traffic saved each year[49].

Using a similar analytical approach Halcrow have estimated that improved cycling arrangements could reduce car traffic by perhaps 40 million kilometres a year and, including public transport revenue loss, cost about 25p per cycle kilometre[50]. Again there would be health and public transport benefits from reduced crowding.

There is little recent evidence of the cost of providing additional main road capacity in an acceptable manner in London but if this required tunnelling the costs of this would be likely to lie in the range of £10m to £25m per lane kilometre[51].

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APPENDIX: Calculation of Residential Densities Capacities

Step One: Calculate permissible boardings per stop

These are estimated on a steady 'state basis', that is, one average the number of boardings is just sufficient to use the available capacity given the length of time that the average passenger stays on the bus.
Taking a conventional bus corridor as an example

$N = F \times C \div T_l/S$ where
N = the number of boardings per hour per stop
F = the number of buses per hour
C = the maximum allowable bus loading
T_l = the average bus journey length
S = the distance between stops

Thus for a double decker quarterly hour service:

$N = 4 \times 80 \div 4.8/0.4 =$ **27** assuming an average stop spacing of 400 metres and average (suburban) bus passenger trip length of 4.8 kms. Using this method it is possible to represent table 1 in terms of peak hour/peak direction boardings that can be accommodated: table 12.

Frequency Bus Type	**4 bph**	**8 bph**	**12 bph**	**16 bph**	**20 bph**	**24 bph**
Midi	13 pph	27 pph	40 pph	53 pph	66 pph	80 pph
Single	15 pph	30 pph	45 pph	60 pph	75 pph	90 pph
Double	**27 pph**	53 pph	80 pph	107 pph	133 pph	160 pph
Artic	40 pph	80 pph	120 pph	160 pph	200 pph	240 pph

Table A1: Bus Service Peak Boarding Capacities (Passengers per hour)

Step Two: calculate the annual trips that can served by each stop

These peak hour boardings have to be converted into annual trips. This is done by using this formula:

$T_a = B_{phd} \times 1/0.18 \times 4/3 \times 1/0.9 \times 320$ or $T_a = B_{phd} \times 2{,}634$

Where T_a is the number of trips to be served by the stop
B_{phd} is the peak hour/peak direction capacity

0.18 is the a.m. peak hour factor
¾ is the peak direction loading bias
0.9 is the proportion of bus trips that are home based
320 is the ratio of annual to average weekday traffic

Frequency Bus Type	**4 bph**	**8 bph**	**12 bph**	**16 bph**	**20 bph**	**24 bph**
Midi	34	70	105	140	174	210
Single	40	79	119	158	198	237
Double	71	140	211	281	350	421
Artic	105	211	316	421	527	632

Table A2: Annual boarding capacities (thousands)

<u>Step Three: calculate the population that can be accommodated</u>
This is calculated by dividing the annual trip capacity by the average bus boarding generation rate. In this case 194 trips per capita (table 7). In the case of busways and light rail an allowance has been made for additional traffic generated (+20%) as a result of the higher levels of service. This results in table A3.

Frequency Bus Type	**4 bph**	**8 bph**	**12 bph**	**16 bph**	**20 bph**	**24 bph**
Midi	175	360	540	720	900	1,080
Single	205	410	615	815	1,020	1,220
Double	365	720	1,080	1,450	1,800	2,170
Artic	540	1,085	1,630	2,170	2,715	3,260

Table A2: Bus stop population capacities

<u>Step 4: Estimate the size of the catchment areas</u>

For independent stops this is straightforward being:

$A = 0.0001\pi r^2$

Where A = the catchment area in hectares and
R = the catchment radius in metres

When the catchments overlap (i.e. the stop spacing is less then 2r) the catchment of each stop will be diminished. The calculation of this reduction is rather cumbersome[52] and so is represented graphically in the following figure:

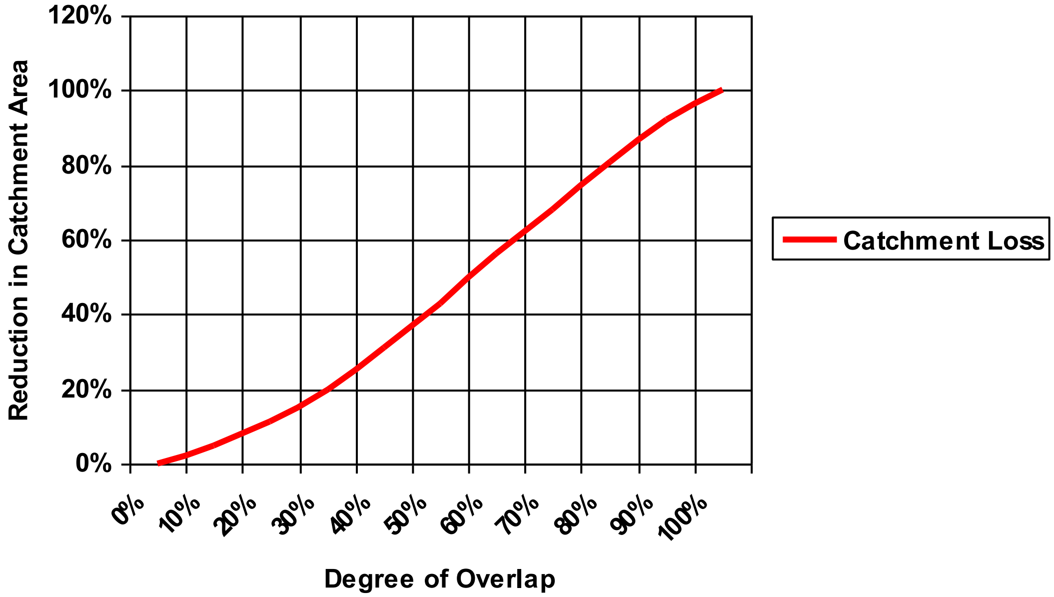

Figure A1 Reduction in catchment area with overlap

Thus for a 400 metre catchment area with 400 metres between stops the overlap is 50% and the catchment area is reduced by 36% from just over 50 to 32 hectares.

<u>Step 5: Estimation of limiting residential density</u>

This is simply the population capacity divided by the average household size (assuming one household per dwelling) divided by the catchment area. This gives table A3.

Frequency Bus Type	**4 bph**	**8 bph**	**12 bph**	**16 bph**	**20 bph**	**24 bph**
Midi	2.4	4.9	7.4	9.8	12.3	14.7
Single	2.8	5.6	8.3	11.1	13.9	16.6
Double	5.0	9.8	14.7	19.7	24.5	29.5
Artic	7.3	14.7	22.1	29.5	36.9	44.3

Table A3: Residential density capacities (dwelling par hectare)

[52] The area of overlap is twice (the area of the sector defined by the intersection of the two circles minus the area of the triangle formed by chord joining the points of intersection and the two radii linking its ends to the centre).

This can be represented in graphical form as figure A2 which appears in the body of the report as figure X.

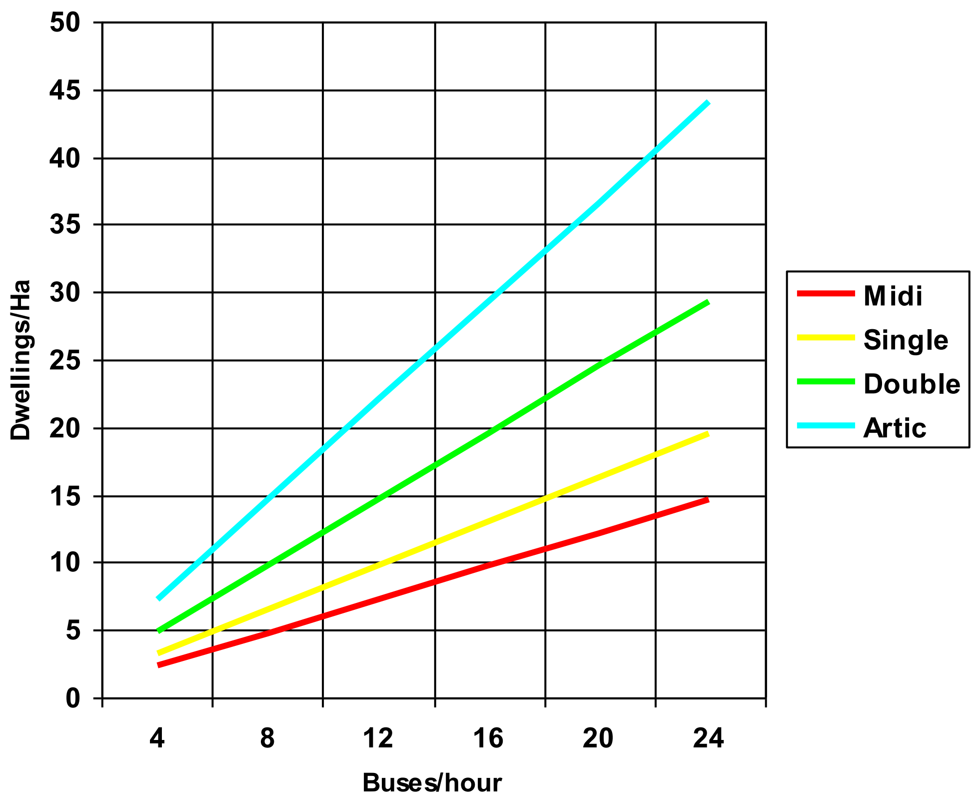

Figure A2: Residential density capacities of bus services

Parameter	**Bus**	**Busway**	**Light Rail**
Journey length	4.8 kms	6.0 kms	6.0 kms
Trip Rate*	194	233	233
OHB %	90	90	90
Stop spacing	400 metres	600 metres	750 metres
Catchment	400 metres 32 ha	600 metres 72 ha	600 metres 90 ha
Constrained catchment		400 metres 43 ha	400 metres 49 ha
Household size	2.3 people	2.3 people	2.3 people

Table A4: Parameter values used in residential capacity calculations
* Boardings per capita per year