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1. Introduction

The energy efficiency of buses on scheduled local services can be analysed in two respects:

1. Vehicular energy consumption, typically in diesel fuel, usually expressed as kilometres per litre[1] (or its inverse, litres per 100 kilometres). CO_2 emissions may be regarded as roughly inversely proportional to kpl (i.e. as kpl worsens, CO_2 emissions increase).
2. Energy consumption per passenger-kilometre, which is also dependent on average load carried.

For example, if a bus attains 2.0 kpl with an average load of 10 passengers, then passenger-km per litre will be 2 x 10 = 20. Similar calculations may be made with respect to cars, both for petrol, and diesel versions. Average load - driver plus passenger(s) will likewise vary. For example, if a petrol car attains 11 kpl with an average load of 1.6 (the overall average for all trip purposes and lengths from the National Travel Survey) then 17.6 occupant-km per litre will be recorded.

Vehicle energy consumption in turn is affected by:

1. Rolling resistance at a given speed
2. Energy used each time the vehicle accelerates to running speed, proportional to mass of the vehicle multiplied by square of speed.
3. Engine idling, etc. at stops

The mass of the vehicle thus becomes an important factor, and in this respect buses typically produce a lower figure than for rail vehicles, approximately 125 kg per passenger space[2], compared with about 250 kg for rail. As stop spacing becomes closer, the energy used in repeated acceleration from stops tends to become predominant rather than that due to rolling resistance. The component due to engine idling also increases. Estimates about thirty years ago by a German manufacturer suggested that for a standard-size single-decker, energy use rose from about 30 litres per 100 km (3.3 kpl) at one stop per kilometre run, to 60 litres per 100 km (1.7 kpl) with four stops per kilometre[3]. Such stops will be of all types, i.e. fixed stops at which passengers board or alight, pedestrian crossings, junctions, and the 'stop-start' pattern associated with congested traffic flows.

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[1] In some cases, use is still made of miles per gallon (mpg). This indicator may be converted to kpl by applying a factor of 0.3611.

[2] For example, the ADL Enviro 400 MMC with 93 passenger spaces and unladen weight of 11,435 kg (Coach & Bus Week 3 March 2015. p18), i.e. 123 kg/pax space; and a somewhat lower figure for the Optare MetroDecker prototype with 99 passenger spaces and unladen weight of 9,800 kg (Bus and Coach Professional, 10 Oct 2014, p12), i.e. 99 kg per space

[3] Motor Transport 27 October 1982

Energy consumption may thus be reduced by cutting the number of such stops (for example, if bus priorities enable buses to avoid some of the stops imposed by congestion, or use is made of busways with wider stop spacing is made). In addition, recovery of kinetic energy otherwise wasted in the deceleration (braking) phase will enable such energy to be used in the next acceleration phase, reducing both total energy consumption and maximum power needed from the engine – for example, through diesel-electric hybrids (with battery energy storage) or flywheel systems[4]. A more immediate energy saving may be made where telematics systems have been installed to encourage safer and smoother driving, for example through smoother acceleration, giving gains of about 5%.

Bus priorities and busways may also improve energy efficiency by enabling buses to attract more passengers as a result of improved speed and reliability of service, both by encouraging higher use by those already using buses, and modal shift, notably from car. Average loads are thus increased, improving passenger-km per litre, and energy savings are also provided through elimination of car vehicle-km.

2. A starting position

There has been a general decline in energy efficiency in local bus services in Britain in recent years. Until recently, Bus Services Operator Grant (BSOG) was a reimbursement of 80% of the fuel duty paid for bus operations on registered local bus services. Using known total BSOG payments and km run on local services, estimates can be made of litres of fuel used (since BSOG pence per litre payment can be derived from the full duty payable per litre for the years in question, multiplied by 0.8, kpl can be estimated[5]). Note that this method can be applied up to 2009-10, but not thereafter due to growing complexity of BSOG allocation (which has also been used to provide incentives to adopt smart cards, for example).

The overall average (England) may thus be estimated as:

1999/2000	3.17 kpl
2003/04	2.3 kpl
2009/10	2.15 kpl

(i.e. a worsening of 35% over the whole period)

DfT data on CO_2 emissions per bus-km in urban conditions show rise from an estimate of 400g in 2000 to 500g since 2007[6], broadly in line with BSOG-derived data.

Why did this decline occur?

- Increasing size of vehicles (phasing out of smaller minibuses following peak around 1990, and a return to standard-size single and double-deckers)

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[4] A wide range of fuel consumption reductions with diesel-electric hybrids has been reported. As working assumption an average of 20% is assumed in this report.

[5] Calculations shown in the text are derived from DfT statistics tables BUS0502a (BSOG total payments by region, in money terms) and BUS0203b (local bus-km run by region), and total duty per litre from Transport Statistics Great Britain table 3.3

[6] Transport Statistics Great Britain 2012, table 0309

- Earlier Euro-compliant engines tended to be less efficient than predecessors (providing a gain in reducing local pollutants damaging to health, at expense of fuel efficiency and CO_2 emissions)
- Growing congestion (with 'stop-start' operation, and engine idling)
- An increased proportion of total bus-km operated within London (which tends to use larger vehicles than other areas, especially with a high proportion double-deckers, and also experiences greater congestion). Note that the greatest decline in kpl occurred within London - from 3.17 in 1999/2000 to 1.85 in 2009/10 - with smaller changes elsewhere. Very rapid fleet renewal early 2000s may have been a major factor. However, there is evidence from at least one major operator in the capital of substantial improvements more recently, associated with earlier 'Euro' engined vehicles being replaced, and use of hybrids.

Note that the England-wide kpl calculation is an average for all local bus services, but likely to be dominated by urban operations. Application of the DfT's standard Webtag formula[7] for the 'PSV' category (size unspecified) at 16 kph gives 1.98 kpl (to 2 d.p.); at 18 kph 2.12 kpl; and 2.57 kpl at 25 kph, i.e. similar to the BSOG-derived calculations above.

3. Variations by area and mode

Similar BSOG-based calculations can also be carried out for regions within England – the average of 2.15 kpl in 2009/10 varies from 1.85 kpl in London, to 2.23 kpl in Met areas and 2.25 rest of England. However, making reasonable assumptions about average loads – 17 in London, 10 in mets and elsewhere in England, passenger-km per litre are about 32 in London, and 24 elsewhere in England[8].

For cars, NTS indicates average occupancy (driver + passengers) of 1.6 for all trip purposes or 1.2 for journeys to/from work[9]. Applying standard webtag formulae gives kpl for a petrol car of about 11.2 at 20 kph, and 14.4 at 35 kph (diesel about 14 and 17). Translated into person-km per litre this gives about 22 for urban use (all purposes), falling to 17 for journeys to work, but higher for diesel cars and at higher speeds.

In other words, the overall person-km per litre used is broadly similar for bus and car in urban areas (about 20-25), but bus performs better in London, and at peaks especially, when higher bus load factors at these times borne in mind (but worse than car for some off-peak periods). Hence, a simple statement that transferring a person-km from car to bus on present average conditions would produce an energy and environmental benefit is not necessarily true in all circumstances. However, if we could attract car users to fill existing empty seats on buses, clear net gain would be produced by reducing car-km, with negligible effects on bus energy use, for example, by improving the quality of passenger information, or a marketing campaign to make to make non-users aware of what bus

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[7] WebTAG is the standard guidance provided by DfT for transport evaluation and forecasting purposes. See table A1.3.8. The formulae used incorporate terms for speed and square of speed. At lower speeds the direct effect of speed (fuel consumption reducing as speed increases) tends to be dominant.

[8] Based on a London figure derived from 8,258m passenger-km in 2012/13 (TfL Travel in London report no 6, table 3.11), and 486m bus-km run in 2012/3 (DfT Table BUS0203b), giving an average load of 16.97. Rest of England based on NTS 2013 Table 0303 'non-London bus' travel of 233 miles [~372 km] per person, multiplied by England population excluding London of 45 million (estimated from NOMIS data for 2014) to give 16,740m passenger-km, or 10.42 average load.

[9] National Travel Survey 2013 summary, page 22.

services have to offer. This would, of course depend on bus services being sufficiently attractive to produce such diversion.

4. Possible future trends

Some of previous worsening arising from 'Euro' standards has been offset by improvements in the latest designs (vehicles now being replaced are the earlier 'Euro' standards rather than pre-Euro). and associated acceleration of replacement of older vehicles due meeting the requirements of the Disability Discrimination Act. Hybrids produce substantial gains, provisionally assumed as an average of 20% vis a vis conventional diesel. A wide variation is found in practice, with some evidence cited in the technical press that those with the parallel transmission layout generate greater savings than those with the series layout. Operators are also investing in 'micro hybrids' – in these, the energy from the braking phase is used to power ancillary features such as lighting, The net energy saving is lower, at about 10%, but may be more commercially attractive, as a greater energy saving per unit of a capital investment is produced. A substantial shift has occurred in policy-making and manufacturers' responses, from an emphasis on reducing localised pollutants harmful to health, to reversing the worsening of fuel economy and CO_2 emissions by placing greater emphasis on CO_2 reductions in the latest standards[10].

However, substantial improvements for cars are currently forecast (and assumed in latest DfT traffic forecasts).

5. Evaluation of busways

In the process of seeking approval for busway schemes, an ex-ante evaluation is usually carried out, identifying benefits such as user travel time savings, reduction in emissions both of greenhouse gases such as CO_2 and localised pollutants affecting health, safety, reduced energy consumption, etc. Such benefits may include effects of mode transfer, especially in gas emissions and energy usage. These may be expressed in monetised terms and are typically shown in the form of a benefit-cost ratio (BCR) in which total discounted benefits over the evaluation period are divided by total discounted costs (including capital and operating costs). A minimum value of 1 is normally required (i.e. total benefits should exceed total costs). Reference is made to such evaluations of the Fastway and South Hants schemes in the parallel report by KPMG[11], and a number of such studies elsewhere in the world have been documented. A particularly comprehensive analysis is that undertaken by EMBARQ, Washington D C (a programme of the World Resources Institute) in which all these elements are quantified on an ex-post basis[12] . While the systems are very different from those in Britain, especially in terms of

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[10] Goundry, Andy 'Will there be a Euro7?' Buses, October 2014, pp 45-48.

[11] KPMG An economic evaluation of local bus infrastructure schemes. A report for Greener Journeys 10 September 2015

[12] EMBARQ. Social, Environmental and Economic Impacts of BRT systems: Bus Rapid Transit Case Studies from around the World. December 2013. Available at http://www.wricities.org/research/publication/social-environmental-and-economic-impacts-bus-rapid-transit. See pp 14 and 118.

the very high density of passenger movements involved, the evaluation process is essentially the same. Four case studies give the following BCR results:

TransMilenio, Bogota	1.6
Metrobus, Mexico City	1.2
Rea Veya, Johannesburg	1.2
Metrobus, Istanbul	2.8

Diversion from car is likely to be less significant in such cases, given lower car ownership, but it is reported that 8% of the Mexico City busway users were diverted from car.

6. Effects of bus priorities and buswaysThe major effects are likely to be in the form of travel time savings (both to existing users of public transport systems, and those diverted from other modes), and in operating costs. Specifically in relation to energy usage, these comprise:

(a) Reduced ‘stop-start’ operations (resulting from fewer stops per km for all purposes), with significant gain in kpl. For busways, effects may be more marked if a wider passenger stop spacing is adopted (e.g. 1 stop per km).
(b) Ability to attract higher passenger loads due to generation of trips and modal transfer. For most on-street bus priorities likely to be modest – say, 5% - and may be mainly from walk or newly-generated (but with *pro rata* increase in average loads and passenger-km per litre). In some cases, very much larger gains in ridership have been reported (see Brighton example below). For busways, the higher speed and reliability may stimulate substantial car diversion (see Cambridge case below). For example, if we assume a 25% growth in ridership on a busway service, and all due to car diversion, bus pax-km per litre would go up by 25% (assuming same service level), but substantial gain in total energy use would also be attained by removing car vehicle-km. For example, if car use were diverted at the peak average load of 1.2 occupants per car, for each bus-km run a further 0.2 litres (approx) would be saved as a result of the car travel no longer made (assuming that the car trip length were the same as the passenger trip length by bus).

7. Case study: Cambridgeshire guided busway

The Cambridgeshire busway is the longest in Britain, and indeed the longest guided busway in the world. Over a total of about 25 km, it provides a link from St Ives to Cambridge through the rural region north-west of the city, and also a short link south of the city to Addenbrookes Hospital and Trumpington Park & Ride. Through services operate beyond St Ives to Huntingdon, forming a trunk route to Cambridge, and other through workings also operate into rural areas north and west of the busway. Within the city, use is made of existing street sections, benefitting from bus priority, especially in access to the city centre. Much of the St Ives - Cambridge alignment is over the former rail link, but the busway provides much better access to the core city central area, in comparison to the location of the city's rail station. Services are provided by two operators, the great majority of operation being by the local subsidiary of Stagecoach (routes A and B) with more limited operations (service C & D) by Whippett, a long-established local independent, now a subsidiary of Tower Transit.

The ex-ante BCR (as quoted at the public enquiry into authorisation of the busway) was 2.26 including allowance for operating costs of additional vehicles, etc.)[13], but an ex-post figure is not available. Given the rapid growth in ridership and large diversion from car (see below) it is likely that out-turn benefits would at least equal the forecast.

A large-scale user survey was undertaken about one year after opening by the Atkins consultancy[14], and a further account, including developments subsequent to the survey, is provided by Brett and Menzies[15]. Busway users were also the subject of an attitudinal survey by (the then) Passenger Focus, published March 2013[16] : this study also examined the South Hants service, and a range of conventional bus services in other regions which may be used as comparators.

A strong growth in busway usage was reported from the outset with year 2 monthly ridership forecasts attained in the first three months. Data from the main operator indicates an approximate percentage growth in ridership of about 10% between 2012-13 and 2014-15[17]. In particular, a large component of growth has been attracted from car users, especially through park and ride sites such as that at St Ives. It is likely that these display a higher average trip length than traditional bus users who walk to the nearest stop, and would include movements within Cambridge city itself.

The high proportion of those with cars available clearly indicates substantial diversion from that mode. It would not be reasonable to assume that all those with a car available are newly-diverted, since a substantial element of such users can be found on other bus services. However, the difference in the proportion is very striking. For example the Passenger Focus survey indicates that 44% of respondents had 'easy access' to private transport (compared with 28% for the South Hants busway surveyed at the same time) and about 25% for bus users in areas outside larger conurbations covered in the same survey[18]. A much younger age profile was found than is typical of bus use, 55% on the sample (aged 16 upward) being aged 16 to 34. Overall satisfaction levels were generally high at 87% (the combined percentages 'satisfied' or 'very satisfied') but somewhat lower for certain factors such as distance of the bus stop from the journey start (74%) - although this itself may of course reflect the attraction of users from a wider catchment than is normal for a bus service. One issue with such satisfaction surveys that attracting new users with a wider mode choice, especially for peak journeys, may lead to lower satisfaction being reported than from traditional bus users – for example, the younger age groups (16-34) had a lower overall satisfaction rate at 71%, than the sample as a whole. This needs to be borne in mind when comparing with other areas.

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[13] Communication from Alan Brett of Atkins Consultancy August 2015

[14] Cambridgeshire Guided busway. Post-opening User Research. Cambridgeshire County Council/Atkins. Final Report September 2012.

[15] Alan Brett and Bob Menzies 'Cambridgeshire guided busway, UK – an analysis of usage' Proceedings of the Institution of Civil Engineers, Vol 167, issue TR3 (Transport) June 2014, pp 124-133.

[16] Passenger Focus (now Transport Focus): Bus Passenger Survey March 2013.

[17] Personal communication August 2015.

[18] An unweighted average of Devon, Essex, Kent, Milton Keynes, Northumberland, Nottinghamshire, Oxford and Suffolk (estimate by author)

The analysis of the Atkins passenger surveys[10,11] also indicates a user profile closer to that for rail users in terms of income, mode choice available, and age.

One would thus expect a busway such as Cambridge to attain a higher-than-average output in terms of passenger-km per litre of fuel used, due to high load factors being attained, and for further benefits to be provided through diversion of car trips to bus via the P&R sites, producing a net reduction in litres of fuel used. Although detailed, the surveys of Cambridge busway passengers do not directly enable an estimate of average trip length to be made. However, calculations by the author in section 10 illustrate a case broadly equivalent to Cambridgeshire.

8. Benefits of bus lanes – Brighton and Hove case study

The City of Brighton and Hove is well-known as an example of strong growth in bus use in recent years, and very high per capita ridership. A number of factors lie behind these, including extensive provision of bus lanes[19].

During the mid-1990s bus lanes were introduced through the city centre, followed by a very significant length of bus lane in 2008 on the Coast Road notable for being a joint project between Brighton & Hove City Council and East Sussex County Council, bypassing long regular traffic queues that still exist. Then a couple of years later a southbound bus lane was introduced on the main A23 road into the city, and finally a bus lane on the A270 road which serves the city's two universities (Sussex University and Brighton University) in 2013.

The city centre bus lanes had the desirable effect of removing private traffic from the main roads served by buses in the area, but the most dramatic effects have been seen on the Coast Road where the reason for the bus lane was to by-pass regular queueing traffic.

Between 2007, before the bus lane was introduced, and 2015 the operator has doubled the number of peak hour journeys on the two main routes using that road (routes 12 and 14). Before the bus lane was introduced not only was the bus journey time much longer but it was also unpredictable. Since the bus lane has been introduced not only are bus journey times shorter but they are much more predictable. As soon as the bus lane opened the operator introduced new limited-stop journeys numbered 12X and a typical peak-period journey from Peacehaven to Brighton which previously had a scheduled time of 44 minutes (but in practice could be up to 10 minutes longer on a bad day) now takes 26 minutes. Time savings in other periods are somewhat less, around 5 minutes.

In 2012 the operator carried out a simple survey on the Coast Road by counting the number of vehicles and the number of occupants in each during the morning peak and found that buses made up 2% of the number of vehicles but carried 45% of the people.

The number of passengers on the main route to use the bus lane, route 12 (and variants 12A etc) has increased by 63% between 2007 and 2015, although data is not available on the extent of diversion from other modes[20]. The catalyst for this growth has been the bus lane but a virtuous circle has developed and the operator have been able to grow the service levels at all times of the day and

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[19] Data and commentary shown were provided by Martin Harris (Managing Director) and Mike Best (Commercial Director) of the Bus & Hove Bus Company.

[20] If it were assumed that 25% of the new bus passengers were diverted from car then corresponding gains might be obtained by reduction in car-km at the peak average load of 1.2 : see further discussion in section 9.

week. On summer Sundays for example there are now six buses per hour on the 12 group, compared to three per hour in 2007, another example of doubling the frequency.

In the evenings the increase is even more marked, with eight departures from Brighton on route 12 after 7pm in 2007 compared with no fewer than 24 departures now, including a commercial night service six nights a week.

Although the effects of the Coast Road bus lane are the most marked, all the bus lanes in the city have contributed to the success of the bus network. The city centre bus lanes in particular benefit all services and have been a factor in bus ridership per head being the highest in the UK outside London[21].

9.Other busways in Britain

A substantial diversion from a car to bus has also been reported for the Fastrack service in the Dartford/Gravesend area of North Kent. A survey in 2006 shortly after opening showed that 25% of users had the use of a car, but chose to use Fastrack, and 19% would have made their journey by car before Fastrack opened[22]. No further surveys of Fastrack users to identify modal shift have taken place since 2006, but the catchment area served by the busway has developed as new housing has been constructed, and extensions to the busway opened.

The element of car diversion is slightly lower in the case of the two busways examined in detail in the study by KPMG undertaken in parallel with this report[11] - in the case of Fastway, a passenger survey in 2008 indicated that 8% of its users surveyed had previously travelled by car; on the Eclipse services a December 2012 passenger survey indicated that 14% of users had previously travelled by car.

In some other cases, busways have been less successful. The Luton busway, opened in September 2013, is carrying traffic well below forecast (no specific data is available on diversion from car) – possible factors include the state of the local economy, and a somewhat fragmented service pattern, split between three operators.

10. An Illustrative example of the impacts of a major busway scheme

As an example of the favourable outcomes that may emerge from a successful scheme, the following data illustrates such a case. It is based broadly on the reported outcomes of the Cambridgeshire busway, with some supplementary working assumptions, notably re energy consumption and passenger trip length. It should not, therefore, be taken as a direct representation of that case, but one within a similar range of outcomes which are known to be plausible from the Cambridgeshire experience. The following assumptions have been made by the author:

- Service operated comprises a core route of 37.5 km, of which about 25 km is on a fully-segregated busway, the rest on conventional roads with on-street priorities within urban centres

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[21] An average of 167 trips per head per annum, in 2013/14 (DfT, Annual Bus Statistics: England 2013/14, page 8)

[22] FDE (Fastrack Delivery Executive) 'The first six months', covering the period from opening in March 2006'(8pp)

- About 2.8 million passengers per year are carried
- A high frequency of service is operated, with a ten-minute headway for most of the day (lower evenings and Sundays), and augmented at peaks. Total bus-km run per annum 13.6 million.
- Buses average 30 kph[23] (an average of somewhat higher speeds on the busway section, and lower on conventional roads). Average fuel consumption is 2.5 kpl (derived from WebTAG guidance for 'PSVs' at 30 kph, as above)
- Total bus fuel consumption p.a. is thus approximately 550,000 litres.
- Following enhanced services, 25% of the bus users formerly travelled by car, with a corresponding reduction in car vehicle-km run (the Atkins study indicates a diversion of 24%, plus a further 13% formerly using lifts or car-sharing. As a cautious assumption, the effect of reduced energy consumption from the latter group is regarded as negligible).
- The average trip length for all passengers on the busway service is 15 km (this is close to an average estimate from the O&D pattern shown in the Atkins survey, table 12, with assumptions about section lengths by the author. This is specific to the Cambridgeshire busway case, and is considerably longer than typical local bus use in Britain).
- Total bus passenger-km per annum thus equals 42 million, with an average load of about 31 passengers. Average bus passenger-km per litre of fuel used is thus about 75.
- For car user trips diverted on to the busway services, an average trip length on the busway service of 18.5 km is assumed – this is close to an average for all passenger trips between the two P&R sites (St Ives and Longstanton) and all other points on the busway inferred from the Atkins survey (as above). A somewhat higher average that that for all bus passengers as a whole is plausible given that existing bus users accommodated on the busway service within urban areas will be accessing stops mainly on foot, whereas P&R sites by definition are attracting car users. In reality, the situation is somewhat more complex – some car users who live close to busway stops may walk to the nearest stop, whereas some P&R access may be by non-car modes.
- It is also assumed that the average length of the car vehicular trips diverted on to the busway is also 18.5km, i.e. the destination point is, on average, as close to a busway stop as where the car was previously parked. It is not assumed that the whole length of car vehicle trips is diverted onto busway services, as those using P&R sites will have an access leg made by car. It is implicitly assumed that the car trip would have travelled past, or close to, the P&R site (for example to access the A14) prior to diversion[24].
- Average car occupancy is 1.25 (i.e. mainly peak journeys)

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[23] Brett and Menzies report a St Ives – Cambridge rail station scheduled timing of 45 minutes. Given a distance of about 24 km this corresponds to 32 kph.

[24] Evidence from a number of studies indicates that additional car-km may be generated by bus-based P&R schemes, due primarily to additional car-km originating in rural areas, where driving to a P&R site becomes more attractive than using low-frequency conventional bus services. However, such additional car-km may create little external impact (being made largely on uncongested rural roads, with low fuel consumption), whereas the car-km diverted within built-up areas may impose much higher external costs and operate at lower fuel efficiency. Monetising such impacts may lead to a net economic benefit even where a net increase in car-km has occurred (see unpublished paper 'Further Analysis of bus-based Park and Ride Impacts' by by Mateer, G.; Mills, G.; and White, P.R. at Universities' Transport Studies Group Annual Conference, University of Aberdeen January 2012). In the absence of specific evidence from the Cambridgeshire busway case, this factor is not considered further here.

- If 25% of the bus trips comprise those diverted from car, then 700,000 such trips are made each year. Applying an average trip length of 18.5 km and car occupancy of 1.25, car vehicle-km diverted each year total 10.35 million. Car average speed over the section diverted to the busway is assumed to be 30 kph (i.e. the same as buses) – in practice, this will vary, and if under peak conditions the busway offered faster speeds than a congested parallel road, this would be a high figure. Applying WebTAG guidance, car kpl at 30 kph is 13.5 for petrol cars, and 16 for diesel. Assuming a 50/50 mix for petrol and diesel cars, average car occupant-km per litre used on the travel diverted to bus would be about 16.9 (compared with 75 for all passengers on the busway service, above).

Outcomes:

As indicated above, the average bus load of about 31 produces a passenger-km per litre of about 75, vastly better than current average figures estimated earlier in this report.

In absolute terms, a total of about 700,000 litres of fuel per annum would be saved from diversion of the car trips. However the enhancement of bus services *vis a vis* the previous service level would incur some additional fuel consumption (albeit the enhanced services will of course benefit existing bus users and newly-generated trips). As a rough working assumption, some 150,000 litres of additional bus diesel fuel is assumed to be consumed (i.e. the bus service was enhanced by about 375,000 km per annum). However, this would still create a net fuel saving of about 550,000 litres per annum. A pro rata reduction in CO_2 may be assumed[25].

An alternative way of expressing such changes is that, given a bus occupancy of 31 passengers, each bus passenger would use about one quarter of the fuel, and produce about one quarter of the emissions, of car journeys over the equivalent section of route.

In terms of pollution effects on health, these are less clear-cut. However, in respect of diesel fuel, it would be reasonable to assume that the net reduction obtained through transfer from car to bus (approx 170,000 litres p.a.) would provide corresponding reductions in diesel-related pollutant emissions. However, this would not apply in the case of diversion from petrol cars.

Bear in mind that the Cambridge outcome may represent the most favourable case in Britain to date, and insofar as these calculations reflect a similar case, it would be at the upper end of the realistic range.

Concluding observations

Where substantial improvements to bus service quality have taken place, notably through major busway schemes such as that in Cambridgeshire, the resultant attraction of additional bus usage,

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[25] See, for example, 'Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles - Lot 1: Strategy' Final report by AEA-Ricardo to European Commission – DG Climate Action, February 2011, section 4. Accessed 20 August 2015 at: http://ec.europa.eu/clima/policies/transport/vehicles/docs/ec_hdv_ghg_strategy_en.pdf

notably through diversion from car, may result in a very much higher output in terms of person-km per litre of fuel used than is typical of bus services at present, and also much higher than for car usage as such. Environmental benefits through reduced emissions of CO_2 and localised pollutants may also be produced.

It is also evident in the process of carrying out this work that considerable scope exists for more precise calculation of fuel consumption within the bus industry. At present, relatively simple fleet-wide or area-wide averages for kpl or mpg are produced, but these may conceal a wide range of variation associated with vehicle type and operating conditions. Introduction of telematics systems to encourage improved driving generates large amount of data at the level of each vehicle run made, which could be sampled to produce estimates of variations by vehicle type and operating conditions.

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