Transport and mobility choices in 2050.

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The transport sustainability challenge

Transport is possibly the most problematic area with regard to achieving a low carbon society. It is the UK's fastest-growing source of CO_2 emissions, with domestic transport contributing 27.5 per cent of the UK CO_2 emissions (Department for Transport, 2007, Table 3.8). The 2006 UK Stern report (Stern, 2006) noted that between 1990 and 2002, transport was the fastest growing source of carbon emissions in OECD countries (a growth of 25 per cent) and the second fastest growing sector in non-OECD countries (36 per cent growth). Rather than declining over the next 40 years, the trend is for transport CO_2 emissions to grow, particularly in non-OECD countries, where their share of global emissions is anticipated to grow from one third to one half by 2030.

Over 90 per cent of the UK's transport CO_2 emissions come from road transport (Table 1). Passenger cars remain the biggest source of CO_2, but road freight emissions are significant and have risen by 23 per cent over the last ten years compared with roughly static emissions from passenger cars. Rail produces only 1.6 per cent of transport's CO_2 emissions, despite recent substantial rises in passenger-kilometres and freight carried.

Table 1: UK CO_2 emissions by source

Source	2005 Million tonnes of carbon dioxide	Per cent of all UK domestic transport emissions	per cent of all UK domestic emissions
Passenger Cars	69.9	54.2	12.6
Light duty vehicles (vans etc)	16.8	13.0	3.0
Buses	3.6	2.8	0.6
Heavy Goods Vehicles	28.6	22.2	5.2
Mopeds and motorcycles	0.4	0.3	0.1
Other road transport	0.6	0.5	0.1
ALL ROAD	**(119.9)**	**(92.9)**	**(21.6)**
Railways	2.0	1.6	0.4
Domestic aviation	2.5	1.9	0.4
Domestic shipping/navigation	4.2	3.3	0.8
TOTAL DOMESTIC	129.0	100.0	100.0
International aviation	35.0		
International shipping	1.4		
TOTAL ALL	**165.4**		

Source: Department for Transport, 2007 Table 3.8

CO_2 emissions from aviation have also grown rapidly in the last decade, up by 60 per cent. If international aviation is included, it accounts for nearly a quarter of all transport's CO_2 emissions. The 2004 Transport Policy White Paper (Department for Transport 2004) noted that because emissions at altitude have a greater global warming effect, these now represent 11 per cent of the UK's total climate change impact. At currently predicted growth rates the aviation sector will constitute about 33 per cent of total UK climate change impact by 2050. So, even if all other sectors meet government CO_2 reduction targets, air travel is a key environmental issue for the twenty-first century (Bishop and Grayling, 2003).

Given this situation, how might we achieve a low carbon transport future? A list of greener transport initiatives is not difficult to compile. 'Low carbon' vehicles and fuels are particularly attracting attention. The comprehensive E4tech report for the UK Department for Transport (E4tech, 2006), reviewed a range of vehicle technologies (including battery-electric, hybrid electric and fuel cells) and a range of related fuels (gasoline, diesel, bioethanol, biodiesel and hydrogen). This study concluded that, compared to conventional petrol and diesel-engined cars, hybrid cars can cut carbon emissions by around 20 per cent. The use of low carbon fuels offers greater improvements; bioethanol can cut CO_2 emissions per vehicle kilometre by 25 per cent, biodiesel by 45 per cent and hydrogen by 40 per cent or more. However, these improvements very much depend on the production methods used. But, crucially, almost all these technologies appear to fall short of the 60 per cent (or more) cut in all transport's CO_2 emissions that would be needed to achieve a 2050 low carbon society.

International studies (e.g. EUCAR et al, 2005) have produced similar results. In 2002, the UK Government has set a target that low carbon cars should represent 10 per cent of all car sales by 2012 (DfT, 2002) and in 2005 announced the Renewable Transport Fuels Obligation, requiring suppliers to source 5 per cent of transport fuel sales from renewable sources by 2010/11. This formed a major part of transport's contribution to the 2006 Energy Review (DTI, 2006). It is notable that the commitment to low-carbon battery electric cars was the one transport policy measure to feature in the 2010 Conservative/Liberal Democrat Coalition pact.

An alternative approach to low carbon fuels is to use fuel more efficiently. This is actually how hybrid cars cut carbon emissions, but there is a greater potential than the 20 percent improvements they achieve. Well over a decade ago, Wemyss (1996) in his technological review considered that advances in vehicle technologies should allow cars to achieve 1.9 litres/100km (150 mpg) within 10 years. Yet, despite some progress in the fuel economy of new vehicles, there are still no cars on the market that achieve anywhere near this technically possible performance.

A separate range of measures involve more of a systems approach, advocating modal shift from cars to more energy efficient forms of transport including light rail and innovative public transport systems, public shared bicycle schemes, car pooling, car clubs and telecommuting. This is often coupled with proposals for planning controls to produce settlement patterns and conditions that will favour sustainable modes and disadvantage car use. In his comprehensive review of this and other approaches, Banister (2005, Chapter 6) cites case studies of cities that have achieved a ten per cent cut in car use through approaches utilising planning controls and public transport development.

A further systems approach is that of pricing mechanisms. Economists have long argued that the core problem is the under-pricing of the environmental costs of road and air transport and that marginal cost pricing should be adopted (Maddison et al, 1996; ECMT 1997; Glaister and Graham, 2003). The arguments and evidence for a tax neutral programme of green fiscal reform was presented by the 2009 report of the UK Green Fiscal Commission, including a detailed briefing paper on transport taxation (Green Fiscal Commission, 2009).

Each of above approaches to vehicle technologies, modal split, planning and fiscal reform could represent part of moving towards a 2050 vision of a low carbon transport, but what might be the relative roles of each of these components? This chapter takes surface transport (which covers a major part of UK transport's carbon emissions) and undertakes a macro-level analysis exploring what sort of strategic approaches could deliver a genuinely low carbon transport future. The intention is to set a specification and provide a framework to identify targets and strategies for development and deployment. In doing this, although technical and policy viability are necessarily taken into account, they are not the paper's main focus. This is a 'backcasting' exercise starting from a definition of a 2050 low carbon personal transport sector, and then exploring if various combinations of transport technologies and changes in travel can take us from our current position to one of sustainability. The process uses a simple equation model. This is purposely simple in order to provide a tool to develop understanding by anyone wanting to explore transport's sustainability challenges. This tool has been used in Open University environment courses (Potter and Warren 2006 and Potter 2007) and in stakeholder meetings to evaluate transport policy development.

Exploring the issue

At the moment, cars in the UK car fleet averages 9.1 litres/100km with the best performing cars returning under 6 litres/100km. Technically, the application of best current practice could improve fuel economy to an average of around 6 litres/100km with the best being 4 litres/100km. However, in practice, despite such designs being available for the last 15 years, only marginal improvements have arisen. The simple fact is that new cars are sold on their power, top speed, acceleration, style and equipment. An industry regime has emerged around these design features which uses improvements in fuel efficiency mainly to enhance performance rather than cut fuel consumption.

Alternative fuelled vehicles originally emerged in response to air quality concerns, particularly in the USA. These include designs for vehicles powered by electricity, compressed natural gas (CNG), liquid petroleum gas and hybrids, which combine electric and internal combustion drives. Although these fuels offer significant reductions in the emission of local air pollutants, in terms of carbon it is a mixed picture. As was noted above, E4tech (2006), estimated such technologies to produce between 20 per cent and 40 per cent less CO_2 compared to conventional petrol and diesel-engined cars.

In the long term, for some time virtually all commentators consider the use of hydrogen fuel cells linked to renewable energy generation as the ultimate ideal clean traction method for transport. Lane (2004) reviews the actual and anticipated performance of fuel cell cars and notes that using natural gas as a feedstock for a fuel cell would produce between 12 and 43 per cent less emissions compared to using natural gas in an internal combustion engine - itself cleaner than the best petrol or diesel technologies. However, fuel cell efficiencies vary considerably and improvement in emissions may be less than is widely claimed. In addition building a supply infrastructure for hydrogen vehicles would be a massive task (Berridge 2009).

Even if more efficient vehicles were built and cleaner fuels used, would this be enough to achieve carbon sustainability by 2050? Cleaner technologies may be emerging, but whether they have sufficient scope is another question. One method is explore combinations of measures to cut environmental impacts is a simple environmental impact formula. Such a formula was originally developed by Paul and Anne Ehrlich (1990) and refined by Ekins et al (1992), who uses the equation that environmental impacts are the product of:

Population (P) X Consumption (C) X Technology (T)

Environmental impacts are the sum of the number of people, how much each person consumes and the technology used in the goods and services they consume. This simple equation assumes that P, C and T are independent variables. In practice they do exert some influence upon each other; for example, increased wealth, expressed as consumption (C), can and does influence population growth; equally improvements to technology that reduce cost will stimulate more consumption (sometimes called the 'rebound effect' - see Herring and Roy, 2007). However, this criticism, although statistically valid, misses the point of such an approach, which is to explore at a very basic level, the implications of alternative scenarios in these three key variables. For example, at global level, it could be assumed that population grows by a third by 2050 and eventually stabilise at twice its current level. Global consumption might also double in this period. If we take the current situation as an index (i.e. everything is currently 1.0) and assume that technologies do not get any environmentally cleaner this results in:

Equation 1:

Current position:	P x C x T =	Impacts
	1 x 1 x 1 =	1
In 50 years:	1.3 x 2 x 1 =	2.6

On this basis, environmental impacts will rise to 2.6 times current levels, so simply in order to stop them from worsening, the figure for 'Technology' has to drop to an index of 0.38. This simple little bit of mathematics suggests that the CO_2 impact of all goods and services need to be cut over the next 40 years to around a third of current levels simply to stop global environmental impacts getting worse. Indeed, if we were to allow for the rebound effect of improved technology further increasing consumption, then the Technology index would need to drop even further.

This environmental impacts formula approach has been developed by the author (Potter and Warren, 2006) and others (Including Kwon and Preston, 2005) to analyse transport's carbon dioxide emissions. In this adaptation, 'Consumption" becomes a function of the number of car journeys per person and journey length. Technology can be expressed in terms of the CO_2 emissions produced per vehicle kilometre (which is a combination of the fuel economy of the vehicle and the carbon content of the fuel used). Thus the environmental impacts from motorised vehicles would be:

Population x Car journeys per person x Length x Emissions per Vehicle Kilometre

The baseline emissions situation expressed as an index would be:

Equation 2:

Population	X	Car Journeys	x	Length	x	Emissions per vehicle kilometre	=	Total Pollution
1	X	1	x	1	x	1	=	1

Again, this approach assumes independence between the variables, which is not entirely so. Improved fuel consumption (part of 'emissions per vehicle km.') would reduce cost and therefore lead to some increase in the number of car journeys and their length. However this is a relatively minor impact on overall costs and, for the level of detail explored, the independence of variables is a reasonable simplifying assumption.

From this a 'business as usual' scenario can be developed. Here, a 20 year scenario is used rather than 40 years to 2050. The shorter timescale is used as it allows us to explore technologies and policies that can be more realistically assessed. However this work will use a CO_2 reduction target that represents a convergence path to a 60-80 per cent cut by 2050. It thus relates to a path leading to the full 2050 target.

The current situation and trends for the UK car fleet are shown in Table 2. For fuel economy, a greater improvement than historically achieved has been assumed reflecting tightening EU standards and as increasing oil prices take effect.

Table 2: Indices of Transport Trends

	Index in 20 years
About a 5 per cent increase in population	1.05
Car journeys average about 630 per year (currently rising by 6-7 per year)	1.2
Journey length averages 11.1km (rising at 0.15km a year)	1.3
Fuel use averages 9.1 litres per 100km across the car fleet (improving by 0.2 per cent a year assumed to improve to 8 litres per 100km)	0.88

Sources: Noble and Potter (1998) and Department for Transport (2007)

The 'business as usual' scenario for 20 years time would result in the equation becoming:

Equation 3:

Population	x	Journeys	x	Length	x	CO_2 per vehicle km.	=	Total Pollution
1.05	x	1.2	x	1.3	x	0.88	=	1.44

So, despite an improvement in fuel economy, CO_2 emissions increase by 44 per cent over the next 20 years.

Technical fix scenario

If there were a purely technical approach, affecting only the last part of the equation, then simply to stop emissions getting worse would require reducing the index for CO_2 per vehicle km to be 0.61. If current fuels are used this would mean improving average on road fuel consumption from the present 9.1 to 5.5 litres per 100km. Even allowing for actual on-road fuel economy being some 20 per cent poorer than test figures, present high fuel economy designs could hit this target. However, such vehicles would have to be in very widespread use.

But such an improvement in vehicle fuel consumption would do no more than stop CO_2 emissions getting worse. If we are looking to a 60 – 80 per cent reduction in UK CO_2 emissions by 2050, then we need at least a 40 per cent cut in the next 20 years (which fits into the trajectory of the EU 2010 Copenhagen target for a 20 per cent cut in 10 years time on a 1990 emissions baseline).

A sustainability target for this formula model that is consistent with a 2050 low carbon society would be for a 20 year target of a reduction of 40 per cent in transport's 1990 CO_2 level. In Britain, CO_2 from transport has already risen by 10 per cent since 1990, so the index target needs to be adjusted down to 0.36 rather than 0.40. If we are to hit this target by using technical measures alone, it is a simple matter of working through the equation. The mathematics are that, if the travel growth parts of the formula were not altered, the 'CO_2 per vehicle km.' index figure would need to be 0.22 in order to hit an overall index target of 0.36 for the personal transport system as a whole.

If this were to be achieved by fuel economy alone, then the UK car fleet would need to achieve an average fuel economy of 2 litres per 100km. This is a very ambitious technical target and is getting close to the best claimed for small, lightweight hybrid-engined cars. Such fuel economy might be achieved by some cars, but getting the entire car fleet to average this figure is another matter. An alternative would be to combine fuel economy with the development of low carbon fuels. So if fuel economy could improve to around a fleet average of 5 litres/100km and low carbon fuels introduced that cut the carbon intensity of road fuels by 60 per cent, this would hit the target. Equation 4 shows this result, which splits out CO_2 per vehicle km into fuel use/km and Carbon Intensity/km.

Equation 4:

Population	x	Journeys	x	Length	x	Fuel use/vehicle km	x	Carbon Intensity	=	Total
1.05	x	1.2	x	1.3	x	0.55	x	0.4	=	0.36

Overall, this exercise suggests that, on their own, it is hard to envisage that either ultra-fuel efficient cars or the widespread adoption of low carbon and renewable fuels could in 20 years deliver a sufficient improvement in CO_2 emissions. In particular, the current emphasis on low carbon fuels represents a danger of just replacing petrol of diesel gas guzzlers with electric or hydrogen guzzlers. That will not get us on track for transport sustainability. A shift to lower carbon fuels needs to be combined with substantial improvements in fuel economy. But even if this were to be the case, the pace of technological improvement would need to rapidly increase and looks beyond that envisaged as achievable in this timescale. This is not to decry technological improvements. It is just that on their own they cannot realistically hit the sustainability target, even though they do offer a substantial reduction in CO_2 compared with current vehicles.

Modal shift scenario

If it looks like fuel and vehicle technology would require unrealistic improvements to deliver sustainability, what about moving to another part of the CO_2 - generation equation and explore the possible behavioural change policies, such as shifting a substantial amount of travel to public transport - a much advocated response to transport’s environmental impacts. This could be through a variety of investment, planning, land use and fiscal measures.

With modal shift, a key question is by how much energy use and CO_2 emissions are reduced when people travel by transport modes other than the private car. For cycling, emissions are effectively zero, but for public transport, emissions depend strongly on the occupancy of trains and buses, which varies considerably. Figures are often quoted in terms of the seats in vehicles. Table 3 shows that in terms of seat kilometres, bus and rail have a 1.5 - 4 times improvement in energy efficiency over cars. However, this drops to only a 0 - 2 times improvement when current occupancy is taken into account. Furthermore, the relative performance of car and public transport varies with journey purpose. For example for commuting, car occupancy is low and public transport vehicle occupancy very high, resulting in the average car commuting trip using over five times the energy of public transport (Potter, 2004). However for all trip purposes, the gap is narrower. A realistic assumption is that a transfer to public transport would increase vehicle occupancy and hence improve fuel efficiency per passenger kilometre, but overall more than a 3 fold improvement compared to car is unlikely.

Table 3: Current Energy Use of Transport Modes (megajoules)

Mode	MJ per seat km.	MJ per passenger km. (average occupancy in UK)
Small Petrol Car	0.6	1.4
Medium Petrol Car	1.0	2.2
Large Petrol Car	1.3	2.9
Motorcycle	0.9	1.6
Bus	0.3	1.4
Rail	0.4	1.4

Source: Potter, 2004 and Potter and Warren 2006

At the moment in Britain, according to the National Travel Survey (Department for Transport, 2008), car use accounts for 64 per cent of trips, walking 25 per cent, bicycle 1 per cent, bus 6 per cent and train 2 per cent (with motorbike, air, taxi and other minor modes making up the balance). However, our interest is in motorised trips (which produce carbon dioxide); for these the car has an 88 per cent share, with bus at 10 per cent and train at 2 per cent.

The environmental impacts equation can be adapted to proportionately cover all motorised passenger travel. Allowing for the relative energy efficiencies of the car, bus and train, Britain’s baseline situation would be:

Equation 5:

	Population	x	Journeys	x	Length	x	Emissions/vehicle km	x	modal share	= Total
Car:	1	x	1	x	1	x	1.1	x	0.88	= 1
Bus:	1	x	1	x	1	x	0.3	x	0.10	
Train:	1	x	1	x	1	x	0.4	x	0.02	

If, as before, the first stage in exploring this policy option is to assume an historical improvement in energy efficiency (to 88 per cent of current fuel used), together with policies to produce a modal shift resulting in the share for bus rising to 25 per cent and train to 10 per cent with car is dropping to 65 per cent. These are the targets adopted in some planning studies and suggested by the Royal Commission on Environmental Pollution (RCEP, 1994). This is shown in equation 6

Equation 6:

	Population	x	Journeys	x	Length	x	Emissions/vehicle km	x	modal share	= Total
Car:	1.05	x	1.2	x	1.3	x	(1.1 x 0.88)	x	0.65 (car)	= 1.2
Bus:	1.05	x	1.2	x	1.3	x	(0.3 x 0.88)	x	0.25 (bus)	
Train:	1.05	x	1.2	x	1.3	x	(0.4 x 0.88)	x	0.10 (train)	

So, even with this large modal shift, CO_2 emissions rise by 20 per cent. This may be a substantial improvement from the 50 per cent rise under the 'business as usual' scenario, but it is still an increase by a fifth. It would require an heroic change in travel behaviour to stabilise, let alone cut CO_2 emissions. So, just the same way that, on their own, vehicle technical improvements will fail to provide a sufficient environmental improvement, so also would the sole use of modal shift policies.

A fusion solution

If on their own neither behavioural changes nor technical improvements can viably hit the sustainability target, then what about fusing together the two? Equation 7 includes the modal shift figures and a large, but technically possible, improvement in the fuel emissions of all modes (through a combination of efficiency and switch to low carbon fuels). This is represented in the fourth column of Equation 7. For cars a reduction to 30 per cent of current CO_2 emissions per vehicle kilometre is assumed. Although energy efficiency technologies would also benefit public transport as well as cars, there are some constraints. For example, light-weighting is less viable especially in rail vehicles, but switching to low carbon fuels in fleets is possibly more immediately viable than for cars. Overall the model assumes improvements are slightly less for buses than for cars, and rail slightly less than this.

Equation 7:

	Population		Journeys		Length		Emissions/vehicle km		modal share	= Total
Car:	1.05	x	1.2	x	1.3	x	(1.1 x 0.3)	x	0.65 (car)	= 0.43
Bus:	1.05	x	1.2	x	1.3	x	(0.3 x 0.4)	x	0.25 (bus)	
Train:	1.05	x	1.2	x	1.3	x	(0.4 x 0.5)	x	0.10 (train)	

The result is getting close to the sustainability goal. This has an important policy lesson; whereas separately neither technical measures (low carbon and fuel efficient technologies) nor behavioural (modal shift) can provide an adequate improvement in CO_2 emissions, the combined effect is powerful. However, despite managing to get close to the sustainability goal, this still assumes very substantial technical and fuel switch improvements as well as a substantial model shift. Both could be eased if changes were made to yet other parts of the equation. These are parts that policy has tended to sideline. In particular, policies to promote public transport rarely consider journey numbers and length. It seems to be assumed that any increase in public transport use must be beneficial. This is not necessarily so. If an increase in public transport simply adds to transport intensity, then this is environmentally damaging.

A scenario can be explored assuming:

- trip lengthening is halted for bus and car journeys
- rail trip length rises, to substitute for longer car journeys
- a small rise in the number of motorised journeys
- a less ambitious fuel economy improvement for cars and buses

These final adjustments result in hitting the sustainability target in a more robust way as shown in Equation 8:

Equation 8:

Population x Journeys x Length	x	Emissions/vehicle km	x	modal share	= Total
Car: 1.05 x 1.1 x 1.0	x	(1.1 x 0.35)	x	0.65 (car)	= 0.35
Bus: 1.05 x 1.1 x 1.0	x	(0.3 x 0.45)	x	0.25 (bus)	
Train: 1.05 x 1.1 x 1.2	x	(0.4 x 0.5)	x	0.10 (train)	

Overall, in developing anything like a viable approach to hitting transport's sustainability goal, there needs to be a fusion of the role of increased fuel efficiency, modal shift and trip length reduction. This is consistent with the conclusions of an OECD/G8 study (EPA, 1998) exploring the reduction of all environmentally damaging emissions from transport to sustainable levels by 2030. This study concluded that a third of the reduction could be achieved by technical measures and two-thirds by demand management.

How quickly such a target might be achieved remains a further question. The above changes clearly cannot be achieved within a short timescale. With strong political will and social acceptance, it might be possible in 20 years, but a 30-year or more timescale seems more likely.

Conclusions

This exercise shows that, to fulfil the needs of sustainability, technical measures in isolation are likely to be ineffective and politically and socially very hard to achieve. Equally even substantial modal shift to public transport cannot attain the sustainability target and will also be politically and socially hard to achieve. Trip length in particular is neglected as a focus for demand management measures.

A combined strategy, seeking to optimise technical improvements with demand management addressing trip length, trip generation and modal share can deliver the necessary improvement. This is in a realistic, though still tough, package. A real danger is that it may be politically easier to develop some technical measures (e.g. fuel switch) more readily than demand management. There would be a danger of the success of technical measures resulting in the neglect or abandoning of demand management policies. This backcasting exercise shows that if everything depends on one group of measures, then sustainable transport become unattainable even if technical improvements are pushed to unrealistic extremes. While ‘quick wins’ are being implemented, the foundations of longer term and more tricky measures need to be put into place.

Transport policies at the local, national and international level need to blend technical improvements to vehicles with modal shift and also reduce the growth in journey lengths. Transport’s environmental challenge is of such a magnitude that, unless substantial progress is made on all these fronts, we will inevitably fail to get on track for transport sustainability. This approach also highlights a fundamental weakness in the approach of transport policy, which assumes only slight adaptations in systems and behaviours. Measures to cut travel through increasing command and control regulation and the manipulation of people and societies run counter to our modern society. Regulation, fiscal and planning measures must play a part, but cannot be carried through to extremes. In terms of policy responses a ‘fusion’ approach seems also to be necessary. Traditional transport and planning policy measures need to be combined with other initiatives. Indeed, the key to transport sustainability may lie in finding alliances with social and economic trends towards the information society leading to the reinvention of how access is achieved. This has major implications for the nature of transport planning, which needs to shift towards a focus on service development, delivery and social marking. Indeed very concept of transport planning may cease to have much meaning in a low carbon society.

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