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Exploring strategic approaches towards a sustainable transport system

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Exploring strategic approaches towards a sustainable transport system

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Note: This paper is based upon Potter (2007a, 2007b) and Potter and Warren (2007)

Abstract

This paper undertakes a 'backcasting' analysis exploring strategic approaches for overall systems sustainability in personal transport. Starting from a robust definition of sustainability for the personal transport sector, the research examines the impact of combinations of transport technologies and changes in travel behaviour in reducing CO_2 emissions towards a sustainable level. In doing this a simple equation model is used. This is purposely simple to provide a tool developing understanding by anyone exploring transport's sustainability challenges. It is concluded that technical measures in isolation are likely to be ineffective and politically problematic. Equally, even substantial modal shift from car to public transport cannot on its own attain the sustainability target. A combined strategy of both technical improvements and demand management addressing trip length, trip generation and modal share can deliver the necessary improvement, although the implementation of such a package remains politically challenging.

1. Stepping stones to sustainability

Numerous ways are advocated to reduce the environmental impacts of personal transport systems. In the 1980s and 1990s, new fuel formulation and exhaust system technologies were introduced to cut emissions of air pollutants. Today, although some air quality problems remain, the focus has shifted to cutting carbon emissions. Many 'Low carbon' vehicles and fuels are 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). They concluded that, compared to conventional petrol and diesel-engined cars, hybrid cars can cut carbon emissions by around 20%, bioethanol by 25%, biodiesel by 45% and hydrogen by 40% or more (depending on the production methods used). International studies (e.g. EUCAR et al, 2005) have produced similar results. The UK Government has set a target that low carbon cars should represent 10% of all car sales by 2012 (DfT, 2002) and in 2005 announced the Renewable Transport Fuels Obligation, requiring suppliers to source 5% of transport fuel sales from renewable sources by 2010/11. This has formed a major part of transport's contribution to the 2006 UK Energy Review (DTI, 2006).

Rather than switching to low carbon fuels, an alternative approach is to use fuel more efficiently. Of the fuel consumed by a car, 75% is lost in the engine, another 15% in the transmission and only 10% actually turns the wheels (Melde et al 1989). Holman (1992, p.51) noted that electronic engine management, transmission design improvements, lean burn engine designs and weight reduction were the design areas with the greatest potential, all yielding up to a 15% improvement over current designs. A shift to direct injection, high speed

diesel engines would yield up to a 30% improvement, due to the more efficient combustion processes involved. 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[1]) within 10 years. Yet, although there has been 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 modal shift from cars to more energy efficient forms of transport including light rail and innovative public transport systems, public shared bicycle schemes (as introduced in Paris in 2007),car trip sharing, 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. Such an approach is perhaps epitomised by the series of reports by Newman and Kenworthy who argue for high density cities structured around public transport systems to reduce car use (Newman and Kenworthy, 1999). In his comprehensive review of this and other approaches, Banister (2005, Chapter 6) cites case studies of cities that have achieved a 10% 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 (Pearce, 1993; Maddison et al, 1996; ECMT 1997; Glaister and Graham, 2003). Correct pricing would stimulate the use of alternative fuels and energy efficient vehicles, optimise the use of modes and, in the long term, lead to adjustments in land use patterns to reflect true transport costs. However, practically charging individual transport users according to marginal emissions, congestion and other environmental impacts for each part of separate journeys is not currently possible, even were it politically acceptable. Thus pragmatic moves involved changes to taxes and charges on vehicle purchase, ownership, fuel, and parking, plus some road toll initiatives. These are rarely structured according to the principles of environmental economics, but some are moving in this direction, including the Dutch restructuring of vehicle purchase taxes, differential fuel duties in several countries and the UK's CO_2 graded company car and Vehicle Excise Duty (Potter and Parkhurst, 2005).There are also the beginnings of area charging in cities such as Singapore, Bergen, Oslo, Rome, London and Durham (Ison, 2004; Ieromonachou, 2006). Oregon will soon introduce a state-wide distance charge, but this is not intended to address environmental impacts. The proposed UK national congestion charge (Department for Transport, 2004) seems to be a genuine attempt to introduce marginal cost pricing for congestion, but not other environmental impacts such as CO_2 emissions. This will require GPS-based instrumentation to be fitted to all vehicles, and in practical terms could be complex and costly.

Each of above approaches to vehicle technologies, modal split, planning and fiscal reform could represent a 'stepping stone' towards transport sustainability. However, what happens if the stepping stones only get you halfway or less across a river? There is a danger of locking into particular technical or social approaches that, although they may produce results quickly, have inadequate potential to deliver sustainability. All this does is provide a false hope followed by disillusionment. An example is the faith placed in the catalytic converter in the USA which was expected to 'fix' the air quality problem. In practice it only bought time before the growth in car use reduced air quality in major cities back to unacceptable levels.

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[1] UK gallons

Having provided a glimpse of the benefits of sustainability on the other side of the river, this set of stepping stones petered out midstream. So, what is needed to get right across to the other side?

This paper undertakes a macro-level analysis exploring what sort of strategic approaches could achieve overall sustainability for ground personal transport systems. 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 sustainability for the personal transport sector, and then explores various combinations of transport technologies and changes in travel behaviour to explore if they 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 2007b) and in stakeholder meetings to evaluate transport policy development.

2. Transport's environmental impacts

A backcasting exercise first requires defining a future desired state. Only then can an exploration of paths to that state be undertaken. Defining what constitutes sustainability for personal transport, and hence the level of improvement being sought, is in itself problematic and often controversial. It is therefore useful to first review the environmental impacts of the personal transport system. Four geographical levels of environmental impacts can be identified (see Table 1).

Table 1. Transport's environmental impacts and sources

Level of impact	Sources
Local, e.g. smell, air quality, health effects, accidents and noise	Particulates, volatile organic compounds, carbon monoxide, sulphur dioxide, ozone, vehicle noise
Regional, e.g. land use and waste disposal	Land take of infrastructure; stimulates urban sprawl; disposal of scrap tyres, engine oil, chemicals etc.
Continental, e.g. acid rain	Vehicle exhaust emissions – nitrogen oxides, sulphur dioxide
Global, e.g. climate change, ozone depletion	Vehicle exhaust emissions – carbon dioxide, CFCs in air conditioning

Source: Potter and Warren (2006)

These impacts are upon humans and also entire ecosystem. Local and regional effects upon ecosystems may include the displacement and disruption of habitat (for example the coastal location of an airport may have a serious impact on the breeding habitat of seabirds) through to air pollution impacts upon plant species (Manning and Feder, 1980). Continental impacts include deforestation caused by acid rain and global impacts include habitat loss and desertification caused by climate change.

In addition to the environmental impacts, sight should not be lost of other transport impacts, such as its contribution to social exclusion, lifestyle and economic effects as well as the traditionally acknowledged problems of traffic casualties.

2.1 Health effects

In recent years there has been a growing awareness of road traffic's detrimental health effects. Small particulates, associated with diesel emissions are associated with aggravating child asthma, cancer, heart disease and premature deaths (The Committee on the Medical Effects of Air Pollution (COMEAP), 1995). The 1998 UK Transport Policy White Paper (DETR, 1998), quoting the COMEAP work, noted that
"up to 24,000 vulnerable people are estimated to die prematurely each year (in the UK), and a similar number are admitted to hospital, because of exposure to air pollution, much of which is due to road traffic."

This death toll is over six times the number killed in road traffic accidents. A European Commission study (Bjerrgarrd et al 1996) that notes deaths, hospitalisation, work sick leave and other health effects attributable to traffic pollution amounts to at least 0.4% of GDP.

The progressive tightening of European emissions standards (including the introduction of catalytic converters and associated fuel quality standards) has resulted in a significant reduction in local air pollutants from road transport (Cleaner Vehicles Task Force 1999). The 2004 UK Transport Policy White Paper (Department for Transport 2004, p 23) notes a reduction of over 40% in NOx and particulate emissions since 1990. However this has been insufficient to meet the 2005 target for urban air quality. Technical measures have yielded significant improvement but in practice are not quite making the standards needed for some key pollutants.

2.2 Noise pollution

Road traffic noise is the most widespread form of noise disturbance, followed by aircraft (BRE, 1993 and Department for Transport, 2005, section 8). In the 1999/2000 BRE survey 30% of people reported being adversely affected by road traffic noise compared with 17% by aircraft and 4% by trains. Traffic noise contributes to stress-related problems such as raised blood pressure, minor psychiatric illnesses, and may be an aggravating factor in mental illness (WHO, 1995). The WHO study sees sleep interference as significant. Up to 63% of dwellings are exposed to a level of night-time noise high enough to interfere with sleep. The main effect of exposure is a reduction of REM sleep and disturbed sleep can alter mood and performance of intellectual and mechanical tasks (Jones, 1990).

2.3 Lifestyle health impacts

As noted by Davis (1996), in addition to the direct health impacts of pollution and noise, it is now recognised that transport's impact on health also involves subtle and cumulative processes. These include behavioural and lifestyle changes such as reductions in independent mobility as traffic levels rise. Transport inequalities are now recognised as a major source of social exclusion (Social Exclusion Unit 2003).

An important health issue that has now grown to be a major concern is the role of transport trends in obesity and poor fitness among both children and adults. The House of Commons Select Committee on Health (2004) pulled together a considerable amount of evidence on the subject, noting a 400% increase in obese people over the last 25 years. The report noted that a

mix of poor diet and inactive lifestyles were the root causes. Although a range of possible measures were identified, travel behaviour was particularly singled out.

2.4 Land use effects

The direct land take of transport infrastructure by roads, parking, airports, railways, stations and ports is relatively insignificant when compared to indirect, second-order, land take effects. Metropolitan decentralisation was initially stimulated by developments in rail, buses and trams, accelerated with the arrival of mass car ownership. This is typified by the low density urban and semi-urban developments in California, Australia and South Africa which, at a somewhat more muted level, can be seen in urban fringe housing and retail developments in Britain. Such developments are highly car dependant and represent highly hostile conditions for public transport operations or access by foot and bicycle. This trend is reflected in data on travel behaviour that provides key insights. Travel surveys in Britain show that the average number of trips per person and the time spent travelling has not altered. The volume of travel has increased because journeys have lengthened - reflecting the changes in activity patterns and land uses. In the 20 years to 2003, the average trip length in the UK increased by 50% (Department for Transport (2005).

Although such land use effects are widely acknowledged, there are more subtle effects beyond the developed economies. An example is the globalisation of production leading to, for example, unsustainable agricultural practices in the developing world in order to provide 'out of season' crops to the developed economies of the 'north'.

2.5 Climate change

Emerging policies and technical measures to reduce transport's local air quality impacts still leaves global environmental issues unaddressed. One area of particular concern is the contribution of carbon dioxide (CO_2) emissions to global warming.

Following ratification of the 1997 Kyoto climate change conference, the UK, along with most developed nations, has a legally-binding obligation to reduce CO_2 emissions. The UK's target is to reduce emissions to below 1990 levels by 2008-12. The transport sector, the fastest-growing source of CO_2 emissions, is by far the greatest cause for concern. CO_2 emissions from transport have risen from 80 million tonnes of carbon in 1970 to 130 million tonnes in 2000 and are continuing to rise. Current projections, contained in the 2004 Transport Policy White Paper (Department for Transport 2004, p 23) are for road transport emissions to rise to 15% above 1990 levels by 2010 and possibly return to about 1990 levels by 2025.

Of all CO_2 emissions from transport sources in the European Union, 80% are from road vehicles (with most of the rest being from air transport). Just over half of road transport's CO_2 emissions come from private cars, 23% from goods vehicles and under 2% from buses and coaches.

Despite the rise in transport emissions, the UK is set to meet its Kyoto obligation as emissions from the domestic, industry and commercial sectors are declining. This is largely due to a shift in fuel from coal to gas in Britain's power stations. This use of a fuel with a lower carbon content and more efficient generation means that CO_2 emissions for electricity

production are dropping. Thus, for the moment at least, the pressure is off the transport sector, but the UK cannot indefinitely rely on other energy sectors cutting their emissions to permit those from transport to continue growing into the indefinite future.

In the longer term the situation becomes even more challenging. Successive reports of the Intergovernmental Panel on Climate Change (for example, Houghton 2004 and Watson et al, 2001) indicate that a 60 % cut on 1990 CO_2 emissions is needed to mitigate the effects of climate change. If transport's emissions continue to grow, to meet such a 'sustainability' target would require cutting CO_2 emissions from the domestic, industry and commercial sectors by some 90%. Such figures border on the ludicrous. Failing to get transport to take its fair share in cutting CO_2 emissions may work in the short term, but creates a worsening crisis for future generations. This is another route that peters out long before sustainability is reached.

Furthermore, security and economic issues are now starting to support, rather than conflict with environmental actions. It seems likely that just as car use is taking off in Eastern Europe, India and China, oil production is set to peak and start to decline. It is difficult to see how a growth in the numbers of cars of current technologies and fuel consumption can be maintained for very much longer. Possibly, when oil production fails to meet growing demands, developing countries will be priced out as developed countries secure their supplies. It is not just environmental impacts and emissions of pollutants that are unsustainable: the availability of oil supplies to maintain current travel growth trends is also in question. Overall growth in car use seems to be both economically and environmentally unsustainable, with additional social, developmental and political implications all beginning to emerge as well.

This paper concentrates on the issue of CO_2 emissions as being the most problematic environmental impact of transport, although CO_2 emissions do act as a reasonable proxy indicator for a number of transport's other environmental effects.

3. Cutting emissions

3.1 Technical improvements

The traditional response to growing traffic demand has been, wherever possible, to increase road capacity and facilitate traffic growth. Demand was taken as given and any detrimental consequences accommodated within this. A result of this approach has been an emphasis on reducing emissions by vehicle design or cleaner fuels. The focus of transport's environmental impacts relate to the private car, with air travel being an emerging concern. At the moment, the world's car fleet averages about 10 litres per 100km. In June 1996 the European Union Environment Council agreed a target reduction of CO_2 to an average of 120 grams per kilometre for new cars by 2005, equivalent to a fuel consumption of 5 litres per 100km (56 mpg) for new petrol-cars and 4.5 l/100km. for new diesel cars. This target has failed to be met, although there has been an improvement in the test fuel consumption and CO_2 emissions of new cars sold in Europe.

Even a shift to more economical cars currently available could yield significant gains. Again this has been possible for a long time. Fifteen years ago, Holman (1992) listed eight cars with a composite official fuel consumption better than the EU target of 5 litres per 100km (56

mpg). However, in practice, actual fuel consumption is poorer than the official test figures by about 20%, but even allowing for this, such existing cars are a third better than the current UK average of 9.1. Cranfield University's now dated 'E-Auto' study (Cousin and Sears 1997) indicated the viability of a petrol-engined vehicle capable of 2.5 l/100km (113 mpg), essentially similar to a family car of today.

The technology for better fuel economy has existed for well over a decade, and demonstrates that the fuel economy potential of internal combustion engine cars has not been properly explored. At the moment, cars in the UK average 9.1 litres/100km with the best performers returning under 6 litres/100km. Technically, the application of best current practice could reduce this figure to around an average of 6 with the best being 4. The ultra-fuel efficient new technologies suggest that the average could be cut to as low as 3, with the best returning 1 litre/100km.

Figure 1. The hydrogen-powered Esstin vehicle. This was the winner of the 2006 UK Shell Ecomarathon, which managed 11,634mpg. Although this is a tiny, non-road vehicle, such trails show the potential for a substantial improvement in fuel economy.

The EU target of an average for new vehicles of 5 litres per 100km for petrol cars and 4.5 l/100km for diesel cars is certainly technically achievable, even though it was not met as planned by 2005. Indeed a target of 3.5 l/100km for new cars might well be in order. 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. Indeed, for important segments of the car market, the trend is towards worsening fuel economy - in particular the fashion for jeeps and sports utility vehicles. Although there are some indications of positive change at the margins, (e.g. new super-mini designs), fuel economy is a niche and not a central competitive or profitable factor in the global automotive industry.

3.2 Alternative fuels

Alternative fuelled vehicles have 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 combining electric and internal combustion drives. Although these fuels offer significant reductions in the emission of local air pollutants, in terms of other environmental impacts it is a mixed picture. As was noted in section 1 of this paper, E4tech (2006), estimated such technologies to produce between 20% and 40% 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 (e.g. Serfas, et al 1991). Lane (2004) reviews the actual and anticipated performance of fuel cell cars and notes that even using natural gas as a feedstock for a fuel cell would produce 12 - 43% 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.

Even if more efficient vehicles were built and cleaner fuels used, would this be of a magnitude to represent 'sustainability'? Cleaner technologies may be emerging, but whether they have sufficient scope is another question.

4. Where the stepping stones have to go…
4.1 Backcasting targets

Even if technical improvements to vehicles were widespread, how far would they take us towards sustainability, particularly if other factors generating the volume of travel continue to counterbalance them? To answer this requires identifying the amount of environmental improvement that is needed. What is the 'transport sustainability shore' on the far side of the river that our stepping stones of incremental policy measures eventually need to reach? This brings us into the thorny issue of defining sustainability. There is no real consensus on a sufficiently precise definition for the purpose of developing transport policies. This paper therefore takes a robust and pragmatic approach by concentrating upon a single key environmental impact, CO_2 emissions, and the IPCC targets for CO_2 reductions to minimise the impact of global warming.

In terms of developing a backcasting analysis, one method is to express environmental impacts as the result of 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 are consuming. This simple equation assumes that P, C and T are independent variables. In practice they do exert an 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'), and therefore indirectly also affect population. 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 of changes in these three key variables. For example, at global level, population is expected to grow by about a third by 2025 and eventually stabilise at twice its current level. Assuming a 3% annual growth in economic output, then global consumption will double in 25 years. 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 25 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 environmental impact of all goods and services need to be cut over the next 25 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 probably need to drop even further.

This environmental impacts formula approach has been developed by the author (Potter, 2001, Potter and Warren, 2006, 2007, Potter 2007b) and others (Including Kwon and Preston, 2005) to analyse transport's environmental impacts. The intention has been to provide a simple transport model to identify key factors generating the total volume of travel with environmental impacts being represented by Carbon Dioxide emissions. Consequently 'Consumption" becomes a function of the number of car journeys per person and journey length. Technology can be expressed in terms of the 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 overall, for the level of detail explored in this paper, the independence of variables is a reasonable simplifying assumption.

From this a 'business as usual' scenario can be developed. 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% 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% a year assumed to improve to 8 litres per 100km)	0.88

Sources: Noble and Potter (1998) and Department for Transport (2005)

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

Equation 3:

Population x Journeys x Length x Emissions per vehicle km. = Total Pollution

    1.05   x   1.2   x   1.3 x   0.88   =   1.44

So, despite a substantial improvement in fuel economy, CO_2 emissions will increase by 44%.

4.2 Technical approaches

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 'pollution per vehicle' to 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 at least 20% poorer than test figures, present high fuel economy designs could hit this target. However, such vehicles would have to be in widespread use.

But a 39% improvement in vehicle fuel consumption would do no more than *stop* CO_2 emissions *getting worse*. Sustainability requires a reduction in CO_2 emissions. A sustainability target for this formula model could be to use the IPCC targets for global CO_2 emission reduction and assume that transport should take a proportionate share. The IPCC estimate that global CO_2 emissions need to be cut to 40% of their 1990 level. In Britain, CO_2 from transport has already risen by 10% since 1990, so the index target needs to be 0.36 rather than 0.40.

This allows us to identify a sustainability target. This is that, if travel growth were not altered, the 'Emissions per vehicle km.' index would need to be 0.22 in order to hit an overall index of 0.36 for the personal transport system as a whole.

That means fuel economy for the UK car fleet would have to improve to an average 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 is another matter. The approach of vehicle technical improvements alone looks increasingly unrealistic.

This, of course, is referring to Britain alone. Traffic levels per capita of the developing world are growing much faster than in Britain. Ekins (1992) used the growth in motor vehicles as a particular example, pointing to the global growth rate of 5.1% per annum for trucks and buses and 4.7% for cars. This means that the global vehicle stock doubles every fifteen years.

So shifting to a global level, it is necessary to allow for the fact that the vehicle population, and consequently car journey, growth is much higher than in Britain. This would produce a journeys index of 2.3 for a 20 year period. Furthermore population growth is higher than in the UK. In doing this, the journeys and length factors for the UK, have been retained. This is clearly are not valid as developing countries are starting from a much lower level of car use and shorter trip lengths. Thus the growth in these factors will be much higher than in the UK. However, such data are not readily available and it is worthwhile retaining the lower, UK-based, figures for the moment simply to explore the overall effect. This is shown below:

Equation 4:

Population x Journeys x Length x Emissions per vehicle km = Total Pollution

   1.3   x   2.3   x   1.3 x   0.093   =   0.36

Even assuming that the growth of car ownership in the developing 'south' nations will only lead to modest trip lengthening, to hit the CO_2 reduction target means that emissions per vehicle needs to be around 9% of current levels. To achieve this using fossil fuels would require a global average fuel consumption of 0.8 litres per 100 km in 20 years, and (assuming population and car growth continues) around 0.5 by 2030. Such technical performance, although achieved by tiny single-seater trails vehicles running no faster than 40 kph (25 mph), is impossible for practical transport purposes. Alternatively, this average would be possible if 85% of the global car fleet used totally renewable energy sources and the remaining 15% achieved 3 l/100km (100mpg), which is also an extremely unlikely outcome.

Overall, these calculations provide a consistent message. On their own both ultra-fuel efficient cars and even the use of low carbon and renewable fuels cannot deliver a sufficient improvement to reduce CO_2 emissions from personal transport to a sustainable level. 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 practice.

4.3 Modal shift
If vehicle technology cannot deliver sustainability (and even getting part way would require considerable changes), it is possible to move to another part of the equation and explore the effect of possible behavioural change policies. One such policy could be shifting a substantial amount of travel to public transport, which is a much advocated response to transport's environmental impacts. This could be through the investment, planning, land use and fiscal measures mentioned in section 1 of this paper. To examine a modal shift scenario requires using information on travel behaviour and other specific factors and so this analysis needs to be undertaken at a national/regional level. The following uses the UK situation, where data are readily available, and is reasonably typical for a developed economy.

With modal shift, reductions in energy use and CO_2 emissions depend strongly on the occupancy of trains and buses, which vary considerably. Table 3 shows that in terms of seat kilometres, bus and rail have a 1.5 - 4 times improvement in energy efficiency over cars, but only a 0 - 2 times improvement when current occupancy is taken into account. This does vary with journey purpose. For example for commuting, car occupancy is lower 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. It could be assumed 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. (at 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); Potter and Warren (2006)

At the moment in Britain, according to the National Travel Survey (Department for Transport, 2005), car use accounts for 64% of trips, walking 25%, bicycle 1%, bus 6% and train 2% (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% share, with bus at 10% and train at 2%.

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 per vehicle km x modal share = total pollution

Car: 1 x   1 x   1   x   1.1   x   0.88

Bus: 1 x   1 x   1   x   0.5   x   0.10   } = **1**

Train: 1 x   1 x   1   x   0.5   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% of current fuel used), together with policies to produce a modal shift resulting in the share for bus rising to 25% and train to 10% with car is dropping to 65%. These are the targets adopted in some planning studies and suggested by the Royal Commission on Environmental Pollution (RCEP, 1994).

Equation 6:

Population x Journeys x Length x Emissions per vehicle km x modal share = total pollution

Car: 1.05 x   1.2 x   1.3   x   (1.1 x 0.88)   x   0.65 (car)

Bus: 1.05 x   1.2 x   1.3   x   (0.5 x 0.88)   x   0.25 (bus)   } = **1.3**

Train: 1.05 x   1.2 x   1.3   x   (0.6 x 0.88)   x   0.10 (train)

Even with this large modal shift CO_2 emission rise by 30%. This may be a substantial improvement from the 50% rise under the 'business as usual' scenario, but it is still a 30% increase. So, just the same way that vehicle technical improvements *on their own* will fail to provide a sufficient environmental improvement, so also would the sole use of modal shift policies.

5. A combined scenario

If on their own neither behavioural changes nor technical improvements can viable hit the sustainability target, then combining the two now needs considering. Equation 7 includes the modal shift figures and a large, but technically possible, four-fold improvement in the fuel

efficiency of all modes. This is represented in the fourth column of Equation 7. For cars a reduction to 25% of current emissions per vehicle kilometre is assumed. Although energy efficiency technologies would also benefit public transport as well as cars, there are some constraints (e.g. lightweighting is less viable especially in rail vehicles) so it is assumed improvements are less than for cars.

Equation 7:

Population x Journeys x Length x Emissions per vehicle km x modal share = total pollution

Car: 1.05 x 1.2 x 1.3 x (1.1 x 0.25) x 0.65 (car) ⎤
Bus: 1.05 x 1.2 x 1.3 x (0.5 x 0.4) x 0.25 (bus) ⎬ = **0.42**
Train: 1.05 x 1.2 x 1.3 x (0.6 x 0.5) x 0.10 (train) ⎦

This is getting close to the sustainability goal. 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, although managing to get close to the sustainability goal, this does assume very substantial technical improvements as well as radical model shift measures. Both could be eased if changes were made to other parts of the equation. These are parts that policy has tended to sideline, particularly the impact of trip lengthening. Policies to promote public transport rarely consider journey numbers and length. It tends 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. For example, the Eurostar train may be more fuel efficient than aircraft, but because it has stimulated so much growth on the London-Paris market, total energy use has risen.

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

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 per vehicle km x modal share = total pollution

Car: 1.05 x 1.1 x 1.0 x (1.1 x 0.3) x 0.65 (car) ⎤
Bus: 1.05 x 1.1 x 1.0 x (0.5 x 0.4) x 0.25 (bus) ⎬ = **0.35**
Train: 1.05 x 1.1 x 1.2 x (0.6 x 0.5) x 0.10 (train) ⎦

Overall, in developing anything like a viable approach to hitting transport's sustainability goal, the best approach seems to be a three-way split between 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.

6. Backcasting from sustainability

The approach of this paper has been to start with a 'backcasting' exercise to identify what sort of overall strategic approach is needed to meet transport's energy challenge. The backcasting model reported here concludes that to have any hope of achieving a sustainable transport system it is necessary to combine technical and behavioural change approaches. Other backcasting scenario studies (e.g. Hickman and Banister, 2006 and 'Visions for the future' in Banister, 2005) have come to the same conclusion.

How quickly such a target might be achieved remains a further question. With strong political will and social acceptance, it might be possible in 20 years, but a 30-year or more timescale seems more likely. The backcasting model can be represented as paths on a diagram. Figure 2 shows the general approach diagrammatically. 'A' is where we are now, with the curve up to this point representing the growth in transport's environmental impacts to date. We are already well above the sustainability zone. The top curve represents current 'business as usual' trends, whereas the lower curve is the sort of path needed to return to a sustainable level of environmental impacts. This has year 'C' set for achieving a sustainability target, with an interim target by year 'B'.

Figure 2: Backcasting for sustainability

Source: Potter and Warren, 2007 p 155

Figure 3 maps onto the backcasting graph the UK's actual transport CO_2 emissions and three projections for future trends. A similar general pattern might be expected for any other industrialised nation. The sustainability zone is the target based on the various IPCC reports (summarised in Houghton, 2004). The curve to date is actual CO_2 emissions from transport in the UK and the top line is the government's 'business as usual' projection. The bottom projection is the anticipated effect of policies included in the 2004 UK Transport White Paper. It is notable that this projection would only return transport CO_2 emissions to their 1990 levels by 2030. Already one key element of meeting this projection, the European Commission's motor industry voluntary agreement to improve fuel economy and CO_2 emissions, has failed. The 2006 UK Energy Review provides a less optimistic projection and anticipates emissions from transport continuing to grow to 2015 and thereafter to fall. This is the middle 'fuel switch' projection.

Figure 3: UK Ground transport carbon dioxide emissions 1970–2004 and projections to 2030

Source: Potter and Warren, 2007 p 156

This analysis shows that the sort of policies currently being pursued might, at the very best, return transport's CO_2 emissions to near 1990 levels, but they fall hopelessly short of even the short-term sustainability target. This indicates the limitations of policies concentrating on technologies that do not challenge the current car culture of power, acceleration and performance. These projections are for a future of 'low carbon fuel guzzlers'. Emissions arising from increases in the volume of travel more than counterbalance the shift to low-carbon fuels. It may be politically astute to concentrate upon policies for technologies that do not require a change in motorists' attitudes and behaviour, but these alone will not get anywhere close to a sustainable transport system.

If, as well as switching to low carbon fuels, significant improvements to fuel economy were achieved, then a move could be made closer towards sustainability. The combination explored involved, as well as a 20% reduction in carbon intensity through fuel switching, something like a 50% improvement in car fuel economy (plus a 40%-50% improvement to bus and train fuel economy). If this were done over 20 years it would get us significantly towards a sustainable level of transport CO_2 emissions, at least for the short term. Figure 4 maps such a combined fuel switch and fuel economy trajectory onto the backcasting graph.

Figure 4: UK Ground transport carbon dioxide emissions 1970–2004 and projections to 2030

Source: Potter and Warren, 2007 p 157

But this still fails to achieve sustainability. Adding in transport demand management is also needed. Many factors both influence travel and are influenced by it. Figure 5 presents a number of these factors. To the top left of the diagram are economic factors, and mobility management measures here might include taxes on fuel, on vehicle purchase and ownership. These could be designed in particular to influence vehicle choice (e.g. tax concessions or subsidies on low-carbon vehicles) or be more general to try to influence modal choice or the volume/length of trips (e.g. a general fuel tax). User charges, such as for parking, city Congestion Charging (as in Singapore and London) or road and bridge tolls, tend to be more specific and focus mainly upon trip numbers and modal choice rather than vehicle type. To the bottom left are factors around the way in which settlement patterns, density and transport infrastructure affect the amount of car and public transport use (and walking and cycling as well), and also the level of congestion. At the top right of the diagram are cultural attitudes and perceptions, which are moulded and influenced by a whole host of factors, only some of which are mentioned here. Informational measures may be used here, for example linking travel behaviour to health and children's well-being.

Some travel-determining factors, like income and economic aspects, are more independent and some are more amenable to policy influence than others. For example, central and local government have strong control over the provision of transport infrastructure (roads, metro lines or cycle paths) but only a moderate influence over settlement patterns through planning and development control functions. Transport taxation can affect part, but not all, of the costs of travelling. Here, targeted incentives can be important, such as tax breaks to help consumers purchase new technologies such as hybrids or fuel cell vehicles. Overall, the potential for influence varies considerably and, because this system is extremely dynamic with numerous feedback effects, only concerted, linked action across several factors is likely to be effective.

Figure 5: Factors contributing to travel demand

Source: Potter and Warren, 2007 p 158

A combined strategy of complementary policies and actions can get us to transport sustainability (Figure 6). This involves roughly equal contributions coming from fuel switching, fuel economy improvements and TDM measures such as modal shift and trip length reduction.

Figure 6: UK Ground transport carbon dioxide emissions 1970–2004 and projections to 2030

Source: Potter and Warren, 2007 p 161

7. Conclusions

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. A more comprehensive demand management strategy is required involving an understanding of the range of factors determining the volume and length of trips.

A combined strategy, seeking to optimise technical improvements with demand management addressing trip length, trip generation and modal share can deliver the necessary improvement in what could be a realistic, though tough, package. A real danger is that it may be politically easier to develop some technical measures more readily than demand management. There is nothing wrong in this as such, but the danger is if the success of technical measures results in the neglect or abandoning of transport demand management policies. As this simple backcasting exercise has shown, if everything depends on one group of measures then sustainable transport become unattainable even if technical improvements are pushed to ridiculous extremes. While the 'quick wins' are being implemented, the foundations of longer term and more challenging 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, our stepping stones will end well short the shorelines of sustainability.

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