



TRAVELLING LIGHT

The roles of behavioural change and technical innovation in achieving sustainable transport

Keynote paper for the 2006 Shell Eco-marathon

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STEPPING STONES TO SUSTAINABILITY

Numerous ways are advocated to reduce the environmental impacts of personal transport system. Those taking part in the Eco-marathon are particularly well informed on sustainable mobility issues and the survey of the participating teams produced a set of excellent suggestions. These include increased use of biofuels and speeding up the introduction of hydrogen fuel cell cars, more car clubs, better public transport, developing bike rentals, plus high taxes on fuel inefficient cars as well as better public education and EU/national policies to support the development and use of cleaner transport technologies and modes.

It is recognised that each individual measure will not constitute 'sustainable' transport, but any could represent a 'stepping stone' towards 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 behavioural change approaches that, although they may produce results quickly, have inadequate potential to deliver sustainability.

This paper undertakes a macro-level 'backcasting' exercise starting from a definition of sustainability for the personal transport sector, and then exploring various combinations of changes to transport technology and behavioural changes 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 2007) and in stakeholder meetings to evaluate transport policy development.

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. The Shell Eco-marathon very much concentrates on global sustainability issues and hence the issue of global warming is of key importance.

Following the protracted ratification of the 1997 Kyoto climate change conference, most developed nations now have a legally-binding obligation to reduce carbon dioxide (CO₂) emissions. Of all CO₂ 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 CO₂ emissions come from private cars, 23% from goods vehicles and under 2% from buses and coaches.

Even though the Kyoto goals are proving hard to achieve, the longer term the situation is even more challenging. Successive reports of the Intergovernmental Panel on Climate Change (for example, Houghton et al 1990 and Watson et al, 2001) indicate that a 60 % cut on 1990 CO₂ 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 CO₂ 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 CO₂ 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 and the developing world, oil production is set to peak (the latest estimate is by around 2011) 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 the 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 starting to emerge as well.

POTENTIAL OF TECHNOLOGY AND INNOVATION

Two of the 'thematic pillars' of the Shell Eco-marathon are (1) the role of technology and innovation and (2) behavioural change in making transport sustainable. The third pillar is decision makers' policies. First this section explores the potential of technical measures and innovations to achieve a sustainable transport target and then moves on to look at the role of behavioural change.

In terms of technology, 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 CO₂ to an average of 120 grams per kilometre for new cars by 2005. This represents an equivalent to a fuel consumption of 5 litres per 100km for new petrol-cars and 4.5 l/100km. for new diesel cars. Although there has been an improvement in the test fuel consumption and CO₂ emissions of new cars sold in Europe, this target has failed to be met.

As participants in the Eco-marathon will know, technically there is considerable scope for improved fuel economy. 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) notes that electronic engine management, transmission design improvements, lean burn engine designs and weight reduction represent 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 within 10 years. Yet today there are no cars on the market that achieve anywhere near this technically possible performance.

Even a shift to more economical cars currently available could yield significant gains. Again this has been possible for a long time. As far back as 1992, Holman listed eight cars with a composite official fuel consumption better than the EU target of 5 litres per 100km. 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. Amory Lovins' highly influential work has shown that existing materials and technologies are capable of being used to produce ultra-lightweight, highly fuel efficient cars. With a hybrid engine, such a vehicle would be capable of 1.6 l/100km (180 mpg). Cousins and Sears (1997) 'E-Auto' study 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 fuel economy potential of internal combustion engine cars is only now beginning to be properly explored. At the moment, the on-road fuel economy of cars in Europe average around 9 litres/100km, varying from 9.8 in Sweden, 9.1 in the UK, to 8.4 in France, 8.1 in the Netherlands and 7.7 in Denmark. The application of best current practice could reduce this figure to around an average of 6 litres/100km with the best cars achieving 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.

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 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 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.

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. For electric vehicles, CO₂ emissions in generating the electricity is important; Gover et al. (1996) calculate that two-thirds of the primary fuel used by electric vehicles is consumed in the generation, transmission and battery storage process. In general, if the primary fuel used for generation is coal then, in global terms, electric vehicles are dirtier than petrol-driven ones. If the fuel is nuclear, little CO₂ is emitted, but different sorts of pollutants are involved by way of the thorny issue of nuclear waste. For the UK, calculations vary from those of the SMMT, that suggest CO₂ emissions are broadly similar for comparable electric and petrol-engined vehicles, although other sources suggest up to a 20% reduction.

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.

Backcasting Targets

Even if technical improvements to vehicles were widespread, how far would they take us towards sustainability? 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 measures eventually need to reach? There is no real consensus on defining ‘sustainability’. This paper therefore takes a robust and pragmatic approach by concentrating upon the key environmental impact of CO₂ emissions, and the IPCC targets for CO₂ 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 sum 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. At a 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:

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 values simply to stop global environmental impacts getting worse.

This environmental impacts formula approach has been developed by the author (Potter, 2001 and Potter and Warren, 2006) and others (Including Kwon, 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, journey length and how well a vehicle is occupied. Technology can be expressed in terms of the emissions produced per vehicle kilometre. Thus the environmental impacts from motorised vehicles would be:

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

The baseline emissions situation expressed as an index would be:

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

From this a ‘business as usual’ scenario can be developed. The current situation and trends, in terms of the UK car fleet are as shown in Table 1. The figures for other European nations would be similar, with the UK being close to the EU average for car fuel economy.

Table 1: Indices of Transport Trends

	<u>Index in 20 years</u>
Car journeys average about 630 per year (currently rising by 6-7 per year)	1.2
Journey length averages 11.1km (rising @ 0.15km a year)	1.3
Occupancy averages 1.6 (declining by 0.3% per year)	1.1
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)

With population being roughly stable, this can be left out of consideration. Thus the ‘business as usual’ scenario for 20 years time would result in the equation becoming:

$$\text{Journeys} \times \text{Length} \times \text{Occupation} \times \text{Pollution per vehicle} = \text{Total Pollution}$$

$$1.2 \quad \times \quad 1.3 \quad \times \quad 1.1 \quad \times \quad 0.88 \quad = \quad 1.5$$

So, CO2 emissions will increase to 1.5 times their current level.

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 0.58. If current fuels are used this would mean improving average on road vehicle fuel consumption from the present 9.1 to 5.3 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 - so the challenge is not so much technical as one of acceptance by users and government/EU policies to promote fuel efficiency. Pricing mechanisms probably have an important part to play. Targeting these on key decision making points could be important - for example varying car purchase or VAT and also circulation taxes by CO₂ emissions. It is notable that the EU countries with the best fuel economy (Denmark, Netherlands and Italy) have graded purchase and circulation taxes (Potter and Parkhurst, 2005). Alternative fuels can further be promoted through lower fuel taxes. In the Netherlands car purchase tax is 45.2 percent. This may seem high (although at 105 percent Denmark’s is higher), but there are counterbalancing fixed allowances of €1540 for petrol and LPG cars, €580 for diesel cars and other allowances for cleaner vehicles. This fixed allowance cuts the charge significantly for smaller and more fuel-efficient cars and raises the price of larger and less fuel-efficient vehicles. For circulation taxes, the UK and Germany have both adopted a CO₂ emission-based system, but the charge is too low to have much impact. Italy’s highly graded engine size system, with very high tax for large cars, is far more effective.

But even if such measures did result in a 42% improvement in vehicle fuel consumption, this does no more than *stop* CO₂ emissions *getting worse*. Sustainability requires a reduction in CO₂ emissions. A pragmatic way to identify a sustainability target for this formula model is to use the IPCC targets for global CO₂ emission reduction and assume that transport should take a proportionate share. The IPCC estimate that global CO₂ emissions need to be cut to 40% of their 1990 level. In Britain, CO₂ 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 ‘Pollution per vehicle’ index would need to be 0.18 in order to hit an overall index of 0.36 for the personal transport system as a whole.

That means fuel economy would have to improve to an average of less than 1.6 litres per 100km. This is a very ambitious technical target and is getting close to the best claimed for small, lightweight hybrid-engined cars. One idea from the Eco-marathon participants was for a car manufacturers' Eco-marathon. This is an excellent idea. Perhaps for 2007 Shell could offer a fuel economy or lowest carbon emissions per kilometre trophy.

But even if 1.6 litres per 100km were achieved by some cars, getting the *entire* car fleet to average this is another matter. The use of more low carbon fuels would mean that a less difficult fuel economy target could be set. Unfortunately, at the moment alternative fuelled cars have rather poor fuel economy. Overall, the approach of vehicle technical improvements alone is looks increasingly unrealistic.

This, of course, is referring to the situation in a developed country. Traffic levels per capita of the developing world are growing much faster. 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 it is necessary to add back in population growth. In doing this, the journeys, length and occupation 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 is 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:

$$\text{Population} \times \text{Journeys} \times \text{Length} \times \text{Occupation} \times \text{Pollution per vehicle} = \text{Total Pollution}$$

$$1.3 \quad \times \quad 2.3 \quad \times \quad 1.3 \quad \times \quad 1.1 \quad \times \quad 0.084 \quad = \quad 0.36$$

Even assuming that the growth of car ownership in the developing 'south' nations will only lead to modest trip lengthening, to hit the CO₂ reduction target means that emissions per vehicle needs to be around 8% of current levels. To achieve this using fossil fuels would require a global average fuel consumption of 0.6 litres per 100 km in 20 years, and (assuming population and car growth continues) around 0.4 by 2030. This is an Eco-marathon technical performance - but virtually impossible for production cars. Alternatively, this average would be possible if 85% of the global car fleet used totally renewable energy sources and the remaining 15% achieved 2.8 l/100km, 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 CO₂ 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 CO₂ compared with current practice.

BEHAVIOURAL CHANGE

If vehicle technology alone 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 changes to the second pillar of sustainability - behavioural change. One behavioural change 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 include better rail services, the development of new tram and metro systems or innovative bus services (like the magnetically guided Phileas bus/tram in the Netherlands). To examine this requires using information on travel behaviour and other specific factors and so this analysis needs to be undertaken at the national/regional level. Again, the following uses the UK situation, where data are readily available and which is reasonably representative of the European situation.

With modal shift, reductions in energy use and CO₂ emission depend strongly on the occupancy of trains and buses, which vary considerably. Table 2 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. It could be assumed that a transfer to public transport would increase occupancy rates, but more than a 3 fold improvement compared to car is unlikely.

Table 2: 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
Bus	0.3	1.4
Rail	0.4	1.4

Source: Potter, 1997 and 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 environmental impacts); 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:

$$\text{Journeys} \times \text{Length} \times \text{Occupation} \times \text{Pollution per vehicle} \times \text{modal share} = \text{total pollution}$$

Car:	1	x	1	x	1	x	1.1	x	0.88	} = 1
Bus:	1	x	1	x	1	x	0.5	x	0.10	
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 that the current improvement in fuel economy continues (to 88% of current fuel used), but to this is added 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 sort of targets adopted in UK planning studies and suggested by the Royal Commission on Environmental Pollution (RCEP, 1994). Such a shift is likely to stop car occupancy declining and probably an improvement in occupancy of public transport vehicles. The result is as follows:

$$\text{Journeys} \times \text{Length} \times \text{Occupation} \times \text{Pollution per vehicle} \times \text{modal share} = \text{total pollution}$$

Car:	1.2	x	1.3	x	1.1	x	(1.1 x 0.88)	x	0.65 (car)	} = 1.28
Bus:	1.2	x	1.3	x	0.8	x	(0.5 x 0.88)	x	0.25 (bus)	
Train:	1.2	x	1.3	x	0.8	x	(0.6 x 0.88)	x	0.10 (train)	

Even with this large modal shift CO₂ emission rise by 28%. This may be a substantial improvement from the 50% rise under the ‘business as usual’ scenario, but it is still a 28% 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.

A COMBINED STRATEGY

Whereas on their own, both technological and behavioural change strategies push improvements beyond what appears feasible, combining the two looks more hopeful. If, as well as modal shift, a large, but more realistic, four-fold improvement in the fuel efficiency of all modes is included the results come out as follows:

Journeys x Length x Occupation x Pollution per vehicle x modal share = total

Car:	1.2	x	1.3	x	1	x	(1.1 x 0.25)	x	.65 (car)	} = 0.37
Bus:	1.2	x	1.3	x	0.8	x	(0.5 x 0.4)	x	.25 (bus)	
Train:	1.2	x	1.3	x	0.8	x	(0.6 x 0.5)	x	.10 (train)	

Although it can be assumed that 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.

This result is getting very close to our sustainability goal. Whereas separately, neither technical measures (low carbon and fuel efficient technologies) nor behavioural (modal shift) can provide an adequate improvement in CO₂ 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 behavioural change measures. Both could be eased if changes were made to other parts of the equation. Policies to promote public transport or cut the environmental impacts of cars rarely consider journey numbers and length. These are key factors that transport policy has tended to sideline. This includes the impact of trip lengthening. A scenario could 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

This fully combined strategy would require measures that do more than just making alternatives to the car attractive. It requires more advanced measures that represent a reinvention of how we obtain access and mobility. Car Clubs are an example of this, whereby the system of obtaining car access is more resource and energy efficient. There are also more innovative public transport systems - for example demand responsive bus services that provide much better access than ordinary buses ever can. Enhancing access for less mobility is also an advanced strategy. This might include teleworking and trip substituting technologies, but also land use planning to enhance walking and cycle access, plus road pricing to provide fiscal signals.

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

Journeys x Length x Occupation x Pollution per vehicle x modal share = total pollution

Car:	1.1	x	1.0	x	1.0	x	(1.1 x 0.35)	x	0.65 (car)	} = 0.35
Bus:	1.1	x	1.0	x	0.8	x	(0.5 x 0.4)	x	0.25 (bus)	
Train:	1.1	x	1.2	x	0.8	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 improve fuel economy, 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. With strong political will and social acceptance, it might be possible in 20 years.

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. Trip length in particular needs to be 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 in what could be a realistic, though tough, package. It is worthwhile examining carefully what measures are needed for each of the approaches. A real danger is that it may be easier to develop some technical measures more readily than demand management. There is nothing wrong in this, but the danger is if the success of technical measures results in the neglect or abandoning of demand management policies. As this simple modelling exercise has shown, if everything depends on one group of measures then sustainable transport become unattainable even if improvements are pushed to ridiculous extremes. While the '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 our stepping stones will end well short the shorelines of sustainability.

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This paper is has been developed from an invited contribution by the author to the *International Journal of Sustainable Transportation*, to be published later in 2006.