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Enabling technologies for demand management: Transport ☆

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ABSTRACT

Rising transport demand is likely to be the biggest hurdle to reducing our greenhouse gas emissions. Globally and nationally, transport is consuming an ever increasing share of our total energy use. Furthermore, the bulk of energy used in transport comes from the burning of petroleum products. This brief paper summarises options arising from the two routes to reduce energy demand in transport: improved and more efficient use of existing and possible new transport modes, and the reduction of transport demand. In both areas, the prospects in the immediate and longer-term future are hedged with difficulties. Automobiles and aircraft have improved considerably in recent decades, but future improvements are likely to be incremental. The introduction of hydrogen as a fuel is appealing, but there are technical problems to be solved. Active reduction of demand for transport will require a decoupling of the link between demand and growth in gross domestic product. Globally, this will be very difficult to achieve. Various modes of public transport exist that are efficient in terms of their energy use per passenger kilometre. But they need large investments to make them more attractive than the automobile. However, population concentration in mega-cities, allied with congestion, will make such innovation essential. Policy measures can be assisted in their implementation by new technology, but will remain politically problematic.

'The only function of economic forecasting is to make astrology look respectable,' J.K. Galbraith, 1908–2006

1. Key challenges

Rising transport demand is likely to be the biggest hurdle to reducing our greenhouse gas emissions.[1] Transport is consuming an ever increasing proportion of our total energy use. Furthermore, the bulk of energy used in transport comes from burning petroleum products.

For example, in the UK, greenhouse gas emissions from industry have fallen from 20.5 MtC in 1990 to 11.8 MtC in 2000 and are projected to decrease further to 11.1 MtC by 2020. By contrast, the figures for transport were 40.3 MtC in 1990, 43 MtC in 2000 and projected to increase to 47.8 MtC in 2020. Therefore, industry's share of total greenhouse gas emissions will have fallen from 10% in 1990 to 7% by 2020, while transport will have risen from 19% in 1990 to 29% in 2020. The situation is similar in all developed economies, and transport demand in developing counties is frequently growing by 10% or more per annum. Transport took a 42.3% share of world energy consumption in 1973. By 2003, its share had risen to 57%.

Transport's final energy use has risen by 62% since 1980 (Fig. 1), while its share of petroleum product consumption has risen from 32% in 1980 to 70% in 2004 (Department of Business Enterprise & Regulatory Reform, 2008). In 2006 transport consumed 74% of our oil (Department of Trade and Industry, 2006). Worldwide, there is a very strong link between propensity to travel and gross national product (GNP), although in the UK there has been a small decoupling of this link in recent years. Furthermore, people's daily travel-time budget is remarkably insensitive to GNP, meaning people travel by faster modes of transport as they become richer, and faster modes of transport consume more energy per passenger unit distance transported.

Here then is the nub of the problem. We, that is, the world economies, desire to grow GNP. It is likely that this will cause an equivalent growth in transport demand. There is a growing realisation that this is an unsustainable goal, which has prompted a debate about improving our quality of life. Such arguments are unlikely to persuade the developing economies that progress means anything other than producing more and selling more. Developed economies are also increasingly reliant on goods produced elsewhere. Many would argue that we need to increase transport provision in order to grow the economy. Certainly, the inefficiencies caused by congestion and inconveniently long door-to-door journey

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[1] The level of CO_2 emissions worldwide is now about 20% higher than when the Kyoto protocol was signed in 1997. The two largest factors are increased coal burn in China and rising transport demand worldwide.

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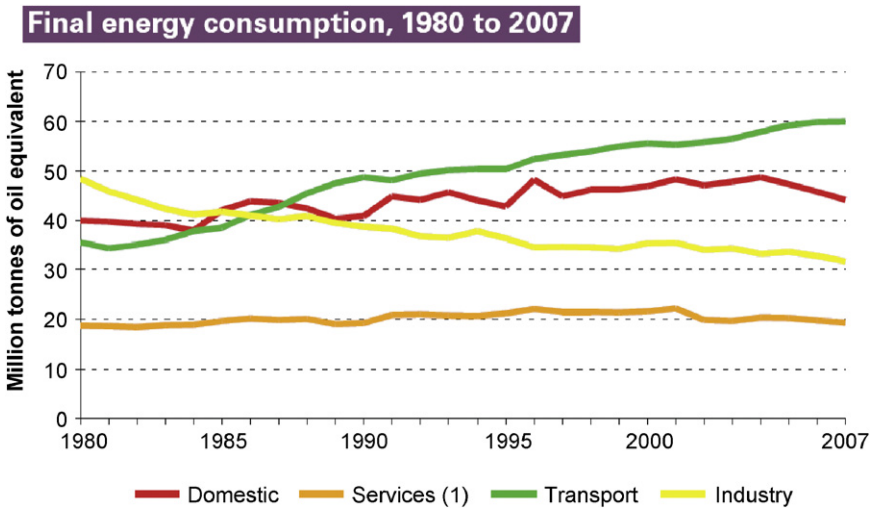

Fig. 1. Changes in final energy use, by sector, 1980–2007 (Department of Business Enterprise & Regulatory Reform, 2008).

times cannot be assisting economic growth. Can we reduce transport demand or, failing this, can we use technology to reduce or contain the growth of emissions arising from transport?

The past 50 years have seen relatively small changes in our domestic transport scene. The rise of the automobile has seen a significant switch from public transport modes. Use of the train has remained constant and, because of rising overall demand, its mode share has fallen. Motorways have made long-distance journeys much quicker, so overall journey times match or beat rail journeys. Although motorways are only 1% of road length, they carry 19% of the total traffic.[2] Transport into and within large cities, particularly London, depends strongly on rail. The most significant rise has been the use of aircraft for both domestic and international travel. The jet engine has served to 'democratise' air travel; fares have significantly reduced in real terms. New technologies have not been commercially successful—e.g. Concorde, the hovercraft—and have had little significance. The development of high-speed trains for journeys up to about 4 h has been significant in many other countries. The role of technology has largely been to reduce costs and therefore to stimulate demand. Congestion is becoming a major obstacle to economic growth, with current losses estimated to be in the order of £20 billion a year. Because cars are stationary for approximately 96% of their life, they are singularly inefficient as transport machines. Parking is a major problem, which suggests that schemes for vehicle sharing should be pursued with vigour.

These issues are shared by most developed countries. The sharp rise in automobile traffic in developing economies gives cause for concern if global emissions are to be contained.

Transport's central role in the economy and its pervasive influence on daily life make rapid changes in this sector difficult to achieve. Its relatively weak sensitivity to energy price movements and the long time constants associated with infrastructure change make it difficult for governments to implement measures to improve sustainability. Some possible measures include:

- improving vehicle and systems energy efficiency,
- increasing the use of renewable and other low-carbon energy sources and expanding world access to cleaner and more efficient transport technologies, coupled with a more rapid development and deployment of advanced technologies,
- developing politically acceptable, but aggressive, policies to shift the direction of transport to a more sustainable path.

2. Improving vehicle and system energy efficiency

Because cars so dominate the transport market, it is appropriate to consider this sector first. Harmful emissions have been significantly reduced by catalyst exhaust systems. The situation with CO_2 is not as good because, while potential fuel economy has been improved, this has largely been offset by increased car mass, with safety and comfort systems such as air conditioning. There is little scope for further significant improvement of conventional engines, but hybrids show promise and have been successfully introduced. The weakness remains the life of batteries and their poor energy-density characteristics. Some, but not major, advances are possible.

Many claims are made for hydrogen-powered cars. The major obstacles to implementation remain the need for energy-efficient and greenhouse-gas-free methods for the production of hydrogen, suitable storage devices and the development of a new infrastructure for distribution. It is unlikely that a significant switch can be made in the next decade or so, but the prospects for 25–50 years look promising.

Similar prospects arise for buses and coaches, which, given high load factors, are currently considerably more efficient per passenger kilometre than cars, but have the advantage of being refuelled from a localised and limited infrastructure.

Because rail has a low mode share, despite its energy efficiency, it is unable to significantly contribute to future energy savings unless there is a large mode switch for which additional capacity would be needed. There are currently some indications that, in the UK, a capacity deficit has been reached that is being managed by raising fares, which in turn may only serve to increase road use. In terms of intercity transport, the development of new infrastructure (either rail or maglev) could, as has been demonstrated elsewhere, provide this capacity, with good energy efficiency even at speeds of 300–350 kph. Such an infrastructure could ease overheating in the south east. It would be arranged to allow easy access to car users and would enable airports to be developed in the regions. Additionally, the capacity freed on conventional lines could be used for freight.

[2] There are approximately 8 million cars per 1000 km of motorway in the UK, compared with an EU average of 3.5 million (European Road Federation, European Road Statistics, 2007).

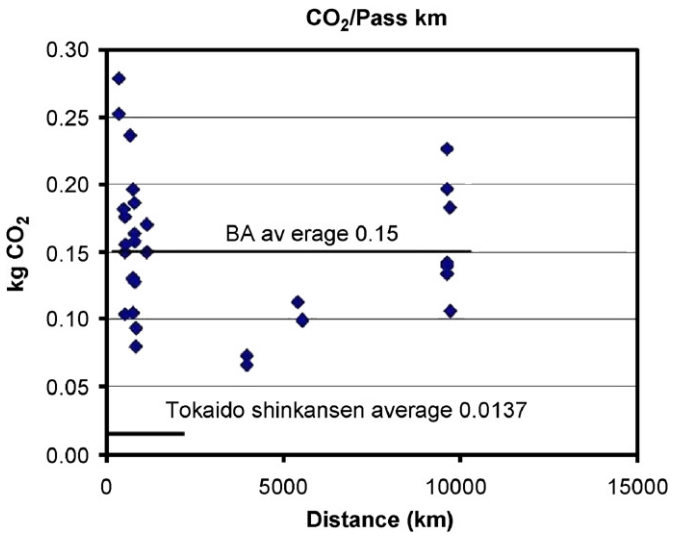

Fig. 2. Actual energy use for aircraft (Smith, personal data collection).

For existing rail, the obvious decarbonisation route is, through further electrification, to benefit from renewable or nuclear electricity supply.[3] The fixed and controlled infrastructure of the railways is well placed to exploit these sources. Electrification could also enable energy savings through regenerative braking. The use of diesel fuel for trains is a weakness in rail's environmental credentials, which may be improved by stringent particulate emission reduction legislation now on the statue book. The position of lightly used rural routes is questionable: they made some social contribution, but little effective overall contribution to our transport system. Hybrid trains for local lines are under development in Japan, but limited battery or flywheel capabilities currently render these trains unsuitable for more intensive use. It is worth noting that the time constant of change of rail rolling stock is in the order of 40 years, whilst the whole fleet of cars can be replaced in, say, 10 years. This cuts two ways: because of the extremely high levels of productivity of rolling stock, high capital investment for replacement with more energy-efficient stock becomes easier to justify.

Aircraft are a difficult problem.[4] Extrapolations of current mode share indicate that, unless something changes, more passenger kilometres will be by air than by train in the UK in about 20 years' time. The use of aircraft for short-haul flights is particularly inefficient, because of the high proportion of the flight taken up by taxiing, waiting, climb and approach (see Fig. 2).

Distances are great circle between airports. Load factors vary, 1 kg fuel burned = 3 kg CO_2. British Airways' average taken from their Social and Environmental Report, 2003/4: 103,092 million passenger kilometres produced 15.4 million tonne CO_2. Average figures on similar basis from the Tokaido shinkansen, J.R. Tokai. The environmental case for high-speed rail for journeys up to approximately 800 km is eloquently made by this comparison.

The considerable improvement to jet engine fuel efficiency made over the last 50 years will not be matched in future decades. Indeed, there is evidence that the rate of improvement is now very low. There are no obvious technical switches of fuel on the horizon, and CO_2 emissions at altitude are perhaps two to three times more damaging than equivalent emissions at ground level. Some energy savings can be made by weight reductions, using, for example, more carbon fibres and aluminium–lithium alloys.[5] This provides further support for the development of a new high-speed infrastructure for internal transport. It is worth recording that the recent *Energy Review* makes little mention of growing aircraft use and the associated emissions, save a reference to 'expand the EU Emissions Trading Scheme to include aviation' (Department of Trade and Industry, 2006).

3. Shifting to alternative fuels

Of the several possible alternative fuels that may displace petroleum, many in practice offer only small CO_2 reductions on a life-cycle or well-to-wheel basis. Only four options can provide greater than 50% reduction in CO_2 equivalent emissions per kilometre of driving. These are

- alcohol derived from cellulose biomass, using biomass as the process fuel,
- bio-diesel from oil crops,
- hydrogen produced from a low-greenhouse-gas source (e.g. renewable electricity), used to power fuel cell vehicles,
- low-greenhouse-gas electricity itself when used with electric cars.

These options are all relatively expensive and the latter two would need large investments in new types of vehicles and refuelling infrastructure. Crops for fuel require considerable water for irrigation. This may prove an important limitation. They are not therefore short-term candidates and require substantial and risky long-term investments. Support for continuing research and development may change this situation in the longer term.

4. Transport demand management

There is understandable scepticism that transport demand can be reduced by changing people's attitudes and behaviour. The car was originally seen as the great liberator and, if its appeal is being tarnished in developed societies, it is because of its very ubiquity, while, in developing economies, car ownership is a badge of success and progress. Nevertheless, attitudes can be changed. There are successful examples: drinking and driving, the use of seat belts and the diminution of smoking.

Before turning to transport demand management measures, it is worth mentioning the possibilities of information technology for reducing the need for travel. The indications so far are less than persuasive that any real reductions have taken place. Indeed, the opposite could be argued. It is now so easy to plan and book travel without leaving one's desk that demand may well have increased. There may be a role to play for increased flexible working, both in terms of hours and from home, and this may serve to ameliorate the commuting peaks that cause problems with transport into cities.

Many transport demand management measures have been suggested and are summarised in Table 1. The role of technology here is both direct and indirect. Many of these schemes require organisation, monitoring and control, which are relatively

[3] Former French President Chirac has announced that SNCF and RATP 'should not consume a drop of oil in 20 years' time,' (*The Times*, 6 January 2006), possible because of French nuclear power. Because of a switch back from gas to coal caused by rising gas prices and security of supply considerations, the need to reduce emissions from power generation is pressing. Carbon capture and storage may play a part (see Fells and Horlock, 2006).

[4] In 2005, 2.08 trillion litres of jet fuel were burned worldwide at a cost of €127 billion, more than double the cost reported for 2003.

[5] Virgin Atlantic estimate a fuel cost reduction of $43,000/plane/year for a 0.5 tonne weight saving (*Observer*, 11 June 2006).

Table 1
Examples of transport demand management strategies (Hensher and Button, 2003[a])

Improve transportation options	Incentives to reduce driving	Parking and land-use management	Policy reforms and programmes
Alternative work schedules	Walking and cycling encouragement	Bicycle parking	Access management
Bicycle improvements	Commuter financial incentives	Car-free districts and pedestrianised streets	Campus transport
Bike/train transit integration	Congestion pricing	Clustered land use	Car-free planning
Car sharing	Distance-based pricing	Location-efficient development	Commute trip reduction programmes
Flextime	Fuel taxes	New urbanism	Comprehensive market reforms
Guaranteed ride home	High-occupancy vehicle priority	Parking management	Context-sensitive design
Individual actions for efficient transport	Parking pricing	Parking solutions	Freight transport management
Park and ride	Pay-as-you-drive vehicle insurance	Parking evaluation	Institutional reforms
Pedestrian improvements	Road pricing	Shared parking	Least-cost planning
Ride sharing	Speed reductions	Smart growth planning and policy reforms	Regulatory reform
Shuttle services	Street reclaiming	Transit-oriented development	School transport management
Small-wheeled transport	Vehicle-use restrictions		Special event management
Taxi service improvements			Transport demand management marketing
Telework			Tourist transport management
Traffic calming			Transportation management associations
Transit improvements			
Universal design			

[a] This collection of papers over 827 pages is a source of considerable material and reference lists of key information in this area.

straightforward electronic tasks, requiring mere development of existing technologies and opportunistic use of newly developed techniques. The original intended uses may be far removed from transport, but parasitic opportunities will arise. The use of technology, for example, to enforce speed limits and hence increase capacity, to monitor and collect payments for road-charging schemes, to provide better real-time information for public transport, is already in place and is relatively cheap. Improved technologies will undoubtedly emerge, and so technology will not be a barrier to the implementation of transport demand management schemes.

5. Freight transport

The transport of freight deserves a separate discussion. By far the greatest tonnage of the world's freight is carried by ships. Operating at relatively low and constant speeds, diesel-engined ships are extremely energy-efficient per tonne kilometre carried. The huge increase in the size of ships over the last 50 years has contributed to this efficiency. It is unlikely that there will be significant developments in this area.

However, an increasing proportion of freight is carried by aircraft. A significant proportion of air freight is driven by customer choice in supermarkets. The question arises as to whether it is sensible, for example, to carry strawberries, largely composed of water, around the globe? This is a matter of policy not technology.

Within countries, with few exceptions, of which the USA is the most interesting, most freight is carried by road, with adverse environmental and congestion effects. This has been caused by a reduction in heavy industry in developed countries, with particularly large declines in coal and steel products that were 'naturals' for rail. It has also been driven by the economics of 'just-in-time' stock delivery both for industry and supermarkets. Only significant policy changes will make inroads into this situation.

Some technically easy enhancements could improve rail freight ability and capacity. These include enlarging of the loading gauge to enable through-freight transfer from the continent and from ports, with the simultaneous ability to handle standard-size containers. Telematics will play a role in tracking consignments. The freeing of capacity on conventional rail tracks with the introduction of new high-speed train systems has already been mentioned.

6. The 50-year horizon

Looking further forward to the 2050 horizon, one is tempted to say 'your guess is as good as mine'. It is also worth bearing in mind the quotation which introduced this paper. The past 50 years have not produced radically different modes of transport, and no significant new possibilities are available to tantalise us. It is probable that the hydrogen economy will have been sufficiently developed to make a significant contribution to overall energy demand. We are told that fusion will be developed practically, but its role will be electricity production, which will only feed into transport through the hydrogen production route, battery storage for cars and electrification of trains. It is possible that developments of carbon capture and storage will reduce CO_2 emissions, but this will only be useful for vehicles through electricity use in various forms. The most worrying sector is that of aircraft where no significant breakthroughs are evidencing themselves and demand is rising quickly.[6] Although the link between transport demand and gross domestic product may weaken somewhat in developed economies, in the developing economies where demand is growing fastest this is unlikely.

Perhaps a major possibility is to make cars more like trains. A major part of the energy saving of trains, and to a large part, their superior safety, stems from the convoy principle. Development in electronics and telematics mean that the electronic coupling of cars is a distinct possibility. This could, in one go, enhance both speed and capacity on major highways, improve safety and reduce fuel use through the maintenance of constant

[6] The rapid expansion of budget airlines is particularly worrying. Fares such as £75 London to Hong Kong (*Metro*, 5 July 2006) are economically and environmentally unsustainable.

speeds. Much greater efforts than are currently being made in this area may well reap large rewards.

The Energy Review (Department of Trade and Industry, 2006) suggests that

> Although emissions form this (the transport) sector have increased since 1990, growth in emissions is slowing down, and is not expected to grow as strongly in the future. Emissions from transport are projected to reach a peak around 2015 and thereafter fall. This is on the basis of projections that growth in demand for transport moderates, fuel efficiency in transport continues to improve and lower-carbon fuels, especially biofuels, increase in their market share.

This appears to be a very optimistic view. While in the UK, it may conceivably prove to be true, it is not apparent that the new technologies needed or the changes in our past habits will be forthcoming. Globally, our efforts will be swamped with increasing transport demand. Perhaps the biggest challenge will be the need to influence, inform and change social attitudes.

References

Department of Business Enterprise & Regulatory Reform, 2008. Energy in Brief. Department of Business Enterprise & Regulatory Reform, London, UK.

Department of Trade and Industry, 2006. The energy challenge. Energy Review. A Report. Department of Trade and Industry, London.

European Road Federation, European Road Statistics, 2007.

Fells, I., Horlock, J., 2006. Carbon capture and storage. Ingenia, 27 June.

Hensher, D.A., Button, K.J. (Eds.), 2003. Handbook of Transport and the Environment. Elsevier, Oxford.