The potential of the railway to reduce greenhouse gas emissions

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Abstract
Concerns about Climate Change have led to a need to reduce Greenhouse Gas (GHG) emissions significantly, and the transport sector is not excluded from this. To meet emissions reduction targets it is likely that consideration will need to be given to changing individual travel behaviour, which may include encouraging modal shift towards modes with a lower environmental impact.

Carbon dioxide (CO_2) forms the bulk of GHG emissions from the transport sector. Operationally, electric trains typically produce less CO_2 per passenger km travelled than cars or short-haul aeroplanes. In theory, therefore, the railway can offer a relatively high level of environmental performance, making it a good target for modal shift.

However, it is important to take a holistic view and note that emissions from a transport system stem from more than the movement of passengers or freight between two points. Emissions from the construction and maintenance of both vehicles and infrastructure are potentially significant and analysis of the whole life-cycle should be undertaken.

Sources of electricity generation are a key variable when determining the emissions from electric trains. Additionally, the load factors attained by the different modes of transport have a big effect on the environmental impact per passenger. It is also important to challenge the assumption that a shift in passengers from road or air to rail will automatically lead to a reduction in car journeys or flights.

A simple illustrative model is used to demonstrate the possibility of a net reduction in emissions if a new railway is built and modal shift from road and air occurs. Building on a basic consideration of operational emissions the model is expanded to include wider life-cycle impacts and it is shown that the railway may retain an environmental advantage. The illustrative model is then used to examine the possible effects of some of the other influencing factors.

Reference is made to ways of maximising the potential benefits, and a discussion is included on how to encourage modal shift of passengers from road and air. Very brief reference is also made to freight transport (for which the railway also has a potential advantage over road transport).

Introduction
The railway is one of the oldest mechanised modes of transport. Railways exist in a variety of different forms ranging from urban light rail, such as the San Fransisco Bay Area Rapid Transit, through to long distance High Speed networks, such as those found in France (the TGV). The dominant position once held by rail transport has been ceded to road and air transport; in the UK, for example, rail's share of passenger journeys above 50 miles is just 12 % (Department for Transport, 2009a, Table NTS0317).

Current concerns about climate change and global warming may lead to a necessary change in travel habits and the railway could once again see increased prominence. In October 2006 Sir Nicholas Stern, Head of the Government Economic Service, presented a report to the British Prime Minister and the Chancellor of the Exchequer about the Economics of Climate Change. Stern states that "the risks of the worst impacts of

climate change can be substantially reduced if greenhouse gas levels in the atmosphere can be stabilised between 450 and 550 ppm CO_2 equivalent (CO_2e)" (Stern, 2006). To achieve such stabilisation, annual emissions need to be reduced by as much as 80 % of current levels and the transport sector needs to play its role in this. Banister (2010) notes that a reduction in energy use and emissions in the transport sector is "proving extraordinarily difficult to achieve," especially given that in the EU there has been a steady increase in travel since 1990. He goes on to note that although technological innovation could help towards achieving a reduction in emissions, it will not on its own be able to help meet the targets set. Indeed, he claims that "significant reductions of CO_2 emissions in transport in the EU can only be achieved through behavioural change."

In light of this, encouraging modal shift towards the railway is a potentially attractive option. As Armstrong & Preston (2010) put it, "rail's specific strengths in the context of climate change include its general environmental friendliness relative to competing modes." The basis for this includes the fact that for steel wheels running on steel rails there is comparatively little rolling resistance which results in greater energy efficiency.

Despite high levels of operational efficiency it cannot be assumed that an increase in rail patronage will result in a net reduction of Greenhouse Gas (GHG) emissions. This paper will look at factors which affect the environmental performance of the railway and consider the circumstances under which it has the potential to contribute to a reduction of emissions, by using a very simple illustrative model It will consider first a comparison of the emissions produced by vehicle operation before looking at the effects of considering the whole life-cycle of each transport system. Then it will review other important variables which affect relative environmental performance and suggest ways in which the potential environmental benefits of the railway can be maximised.

Although rail travel is fairly unique as a mode of public transport, in that it caters for both short and long distance-journeys, this paper will primarily focus on longer distance travel (journeys above 50 miles). It is this segment of the market in which rail begins to compete with short-haul aviation, and the potential here for reducing emissions by modal shift is theoretically quite high. It is also the segment of the market occupied by High Speed Rail – a concept which is currently gaining popularity across the world.

Emissions from different modes of transport

Even when simply considering the movement of passengers or freight between two points it can be difficult to make meaningful comparisons of emissions levels between different modes of transport. One reason for this is that data is often presented in different forms for different modes – for example figures for cars are typically given in terms of emissions per vehicle-kilometre (vkm), and figures for trains are typically given in terms of emissions per seat-kilometre (seat-km).

Levels of GHGs referred to by Stern are in terms of equivalent CO_2 (CO_2e) which includes additional factors to take in to account the effects of other GHGs such as methane (CH_4) and nitrous oxides (NO_x) but at this point there is more raw data available in terms of CO_2. Hence the decision is taken to use CO_2 per passenger-kilometre (CO_2 per pkm) as a standard for comparison. This decision is also justified by the fact that for the transport sector, almost all GHG emissions are from CO_2 (Department for Transport, 2009b). Whereas this is a good basis from which to make broad comparisons between different modes, the effect of other GHGs should not be ignored when assessing progress towards Stern's targets.

Another reason that it is difficult to make comparisons is that there are many variables which affect emissions data. When working in terms of passenger-km, load factor is a crucial variable. The load factor is a measure of the occupancy of a vehicle and is often calculated in terms of the fraction of seats occupied (to allow for standees, it can be greater than 1). It is also important to remember that in reality there is no such thing as the 'average journey' and factors which affect emissions levels can include journey type, congestion, cold starting (for cars) and the source of electricity (where appropriate).

Despite these limitations, it is possible to get a general idea of the relative environmental performance of each mode. Tables 1 and 2 show some sample operational emissions and load factor data for different long distance transport modes.

By combining the data in each table, it is possible to get a set of average emissions figures in terms of grams of CO_2 per passenger km. Where more than one source exists for each mode listed, a mean was taken, and the results are graphed in Figure 1.

In terms of reducing GHG emissions, travelling on an electric train does indeed appear to be better than travelling by car or by plane. Diesel trains have higher operational emissions and may not offer any advantage over road transport as the car fleet becomes more efficient. Indeed, the most efficient 5-seat car on sale in the UK today (a Skoda Fabia) emits just 89g CO_2 per vehicle km (ACT ON CO2, 2010), which is already significantly ahead of the target for the average new car from 2012. The lifespan of a train is much longer than that of a car, and so the relative efficiency of the car fleet is set to improve in the next few years. On the other hand, electric trains have the advantage that as the electricity grid becomes 'decarbonised' their environmental performance will be further improved.

An illustrative model

A BASIC MODEL

A simple illustrative model can be developed to demonstrate the ability of the railway to contribute to a reduction of CO_2 emissions. The scenario chosen for the model is a new High Speed (HS) line, and the initial data used will be based on that for HS2 in the UK, between London and Birmingham. An HS line between these two cities would compete directly with existing road and, interestingly, conventional rail links. Although there are currently no direct flights on this route, there may be some air passengers who switch to using the new HS link as part of a longer journey between (for example) London and Manchester. By 2033, forecasts suggest that HS2 will be carrying 145,000 passengers per day between London and Birmingham. Of this, 57 % of trips would be as a result of switching from classic rail, 8 % would be from air, 8 % from car and 27 % would be generated (Preston, 2010).

Table 1 – Sample operational emissions data for different forms of long distance transport.

Mode		Data Source	CO_2 per vkm (g)	kWh per seat km	CO_2 per seat km (g)	CO_2 per pkm (g)	Notes
Car	2009 UK New Car Average	SMMT (2010)	149.5		*29.9*	*93.4*	Assumes a 5-Seat Car with an average of 1.6 occupants
	2012 EU Target	RSSB (2007)	120		*24.0*	*75*	
Rail	Defra Average	DEFRA (2010)				56.5	
	Class 221 (Diesel)	RSSB (2007)			*31.8*		1.2 litres of fuel per 100-seat km, with 1 litre/100km emitting 26.5g CO2
	Class 91 (Electric)	RSSB (2007)		0.032	*16.1*		Assumes 14% coasting
	Class 91 (Electric)	RSSB (2007)		0.038	*19.1*		Does not allow for coasting
	Class 91 (Electric)	Network Rail (2009)		0.035	*17.6*		
	Pendolino (Electric)	Network Rail (2009)		0.033	*16.6*		
High Speed Rail	Class 373 Eurostar	RSSB (2007)		0.055	*27.6*		
	Class 373 Eurostar	Network Rail (2009)		0.041	*20.6*		
	Alstom AGV	Network Rail (2009)		0.033	*16.6*		Representative of stock planned for use on new UK Route (HS2)
Short Haul Air	UK Domestic Average	DEFRA (2010)				171.0	Does not include Uplift Factor

Electricity Emissions (g CO_2 per kWh) at the point of generation	502.49	(DEFRA, 2010)

The values in italics have been calculated from the raw data.

A basic idea of the reduction in operational emissions between London and Birmingham resulting from HS2 could be calculated as follows:

$$\text{\% Change in Emissions} = \text{\% Trip Generation x HS Emissions} - \Sigma\ (\text{\% Modal Shift x Reduction in Emissions})$$

The simplifying assumption is made that the journey distance is the same across all modes.

Using data from Tables 1 and 2, the emissions from the Alstom AGV assumed to be used on the new HS line are calculated as 39.5g CO_2 per passenger km.

Similar calculations for the other modes, and the resulting effects of modal shift are shown in Table 4. The DEFRA average figure is used for classic rail, because as well as the West Coast Mainline (WCML) which uses electric trains, passengers may also shift from the Chiltern line, which uses diesel multiple units. It is worth noting from Table 1, however, that the Pendolinos on the WCML have the same environmental performance as the Alstom AGV and that the reduction in emissions resulting from a shift from classic rail may be overstated.

Hence from (1): % Change in Emissions = (0.27 x 39.5) – (9.7 + 5.2 + 10.5) = -14.7%

It is necessary to remember that there are many limitations to such a basic model and this is not an accurate 'real world' result. However, it does serve as a good starting point from which to illustrate the effects of considering additional factors, and changing key variables.

VEHICLE TRIP CANCELLATION

Any potential emissions savings tend not to occur at the point one passenger switches modes, but at the point when enough passengers switch to warrant the cancellation of the trip. This is summarised in a 2006 report on High Speed Rail and GHG Emissions in the US (Center for Clean Air Policy, 2006). This is

Table 2 – Example average load factors on long distance transport.

Mode		Data Source	Average Load Factor	Notes
Car		RSSB (2007)	32%	1.6 passengers in a 5 seat car
Classic Rail	Average	RSSB (2007)	31%	
	InterCity Average	RSSB (2007)	40%	
High Speed Rail	Eurostar: London - Paris	Network Rail (2009)	64%	
	French TGV: Paris - Strasbourg	Network Rail (2009)	88%	Standard Class
	UK High Speed 2	Network Rail (2009)	42%	Predicted figure for all services
Domestic Air		RSSB (2007)	70%	
		Department for Transport (2009c)	64%	

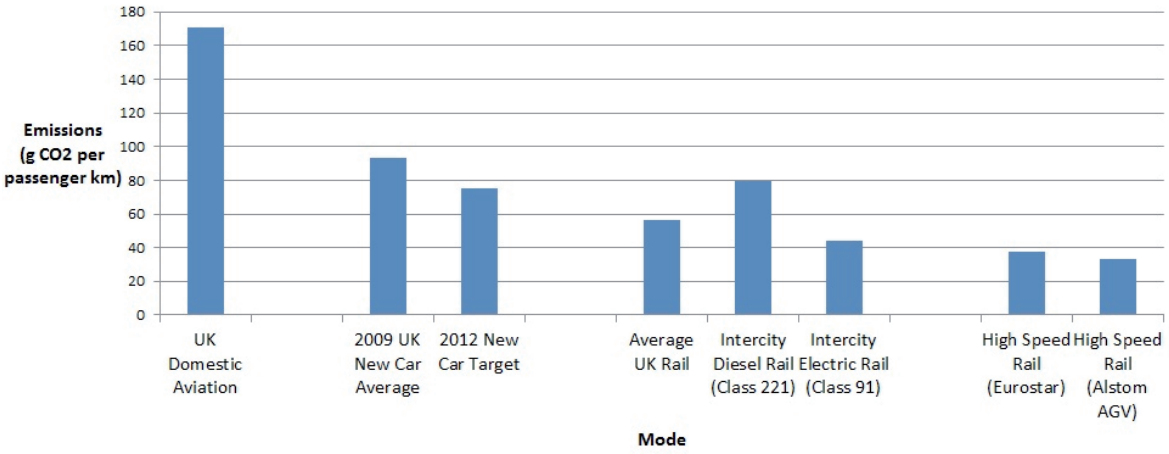


Figure 1 – A comparison of operational CO_2 emissions for different long distance modes.

Table 3 – Emissions Data used to demonstrate the basic model.

Mode	Emissions (gCO2 per pkm)	Reduction in Emissions from switching to HS instead (gCO2 per pkm)	% of HS Journeys resulting from Modal Shift	% Modal Shift to HS x Reduction in Emissions
Classic Rail (DEFRA average)	56.5	17.0	57%	9.7
Car (current average)	104.4	64.9	8%	5.2
Domestic Aviation	171.0	131.5	8%	10.5

not necessarily hugely significant when considering modal shift away from the car, because if the driver chooses an alternative mode of transport then the car journey is not made; although there is the potential for indirect trip generation. If modal shift from road to rail results in reduced road congestion then some people may choose to make car journeys which were previously unattractive.

Vehicle Trip Cancellation is a much more important factor when assessing the overall benefits of modal shift from air to rail. There is evidence to suggest that where High Speed Rail lines are built along domestic aviation corridors, enough modal shift does occur to warrant a reduction in the number of flights - French domestic air traffic is said to have declined 7 % between 2000 and 2007, largely due to the increased availability of TGV connections (OECD, 2009, Footnotes on Page 20). However, Section 5 of the same report notes that the shift from air to rail freed up scarce capacity. In other words, the airline slots could have been reallocated elsewhere, and a reduction in domestic aviation does not necessarily result in a reduction in aviation overall. In the UK, slots at some of the major airports are so valuable that airlines have been criticised for running empty flights to protect them during periods of low demand (Nugent, 2008). If High Speed Rail were to permanently reduce demand on a particular corridor (for example London-Edinburgh), airlines may simply serve other destinations instead. Without any sort of intervention to prevent this, the benefits of modal shift from air to rail would be substantially weakened.

If no flights are cancelled, the model should not include a reduction in emissions due to shift from aviation. In the basic scenario modelled here, excluding aviation reductions means the change in operational emissions would be just -4.2 %. On a route where abstraction from air travel was higher, the reduction in emissions would be smaller still, and there may even be a net increase instead. If the flights are cancelled, but the slots are used for longer routes instead, an increase in emissions may also be expected.

The particular scenario considered in this case also has a high level of shift from the classic rail network to the new High Speed line. Indeed, it is suggested that HS2 would have a higher level of abstraction from rail and a lower level of abstraction from road and, particularly, air than other HSR schemes (Preston, 2010). If the abstraction results in classic rail services being cancelled, then a reduction in emissions would be expected. However, if the services still run, then the model should not include any reductions due to modal shift from classic rail. The exception would be if the services on the classic rail network also attracted new modal shift from road or air (perhaps as a result of more capacity, or of improved service timings). This modal shift would be expected to contribute to a reduction in emissions, and would need to be calculated separately.

THE IMPORTANCE OF LIFE-CYCLE ANALYSIS

Although the actual movement of passengers or freight accounts for a large share of the emissions from the transport sector, there are many other sources of emissions to take into account, including the manufacturing, maintenance and disposal of vehicles, and the building, running and maintenance of the infrastructure. Vehicle operations alone can additionally include idling and running empty to/from a depot. It is therefore important to take a more holistic viewpoint and consider the whole life-cycle.

For rail, life-cycle emissions beyond passenger carrying operation may be comparatively high because there is a relatively large amount of supporting infrastructure. At the other end of the scale, aircraft have the largest operational to total life-cycle energy ratios due to their high fuel consumption and relatively limited fixed infrastructure.

Preston and Armstrong (2010) make the point that railways may have a comparatively higher carbon cost of construction than roads "owing to the inflexibility of alignment options, and the need for associated earthworks, tunnelling and viaducts," but this is of course dependent on the specific situation. The production of concrete in particular is known to be very energy intensive and releases CO_2 in cement production from both fossil fuel use for kilns in clinker production and the calcination of limestone (Chester & Horvath, 2010). Although construction is an important component, life-cycle analysis should not be restricted to new systems. Existing systems require maintainence and still generate additional emissions beyond passenger carrying operation.

To demonstrate the effect of life-cycle analysis, the emissions data in Table 3 was scaled up according to analysis done by Chester and Horvath (Chester & Horvath, 2009, Section 3.2). They suggest that for GHG emissions, the life-cycle components result in total road emissions being 1.4–1.6 times larger, total rail emissions being 1.8–2.5 larger, and total aviation emissons being 1.2–1.3 times larger than the operational components alone. For road and domestic air-travel, the "worst case" multipliers of 1.6 and 1.3 were used here respectively.

For the railway systems, it would not be appropriate to use the worst-case figures from Chester & Horvath's analysis, because they apply to an urban system, which can require more in the way of infrastructure than an inter-city railway (on a per-distance basis). For the classic rail system, it was therefore decided to use a multiplier of 1.8.

The Life-cyle Multiplier used for HS rail in this case was varied upwards from 1.8, to take in to account the fact that unlike the existing classic rail system it requires new (and possibly more energy intensive) infrastructure. The results are shown in Figure 2.

It can be seen that if the life-cycle costs become high enough, there is the potential for a new railway to result in a net increase in emissions, rather than a reduction. The costs will vary according to the specific scenario, but the importance of including life-cycle analysis should not be underestimated. To maximise the environmental performance of a railway system, therefore, the life-cycle costs need to be minimised.

THE ELECTRICITY GENERATION MIX

It should be noted that the factor used in Table 1 for CO_2 emissions from electricity generation is comparatively high – especially since it is taken at the point of generation and does not include losses. The RSSB (2007) use an alternative figure for the UK of 455 g of CO_2 per kWh (again, excluding losses) and go on to predict that it could be reduced further to 320g/kWh over the next 15 years. Furthermore, compared with some countries, the UK still relies quite heavily on fossil fuels for electricity generation, and for those countries who use rela-

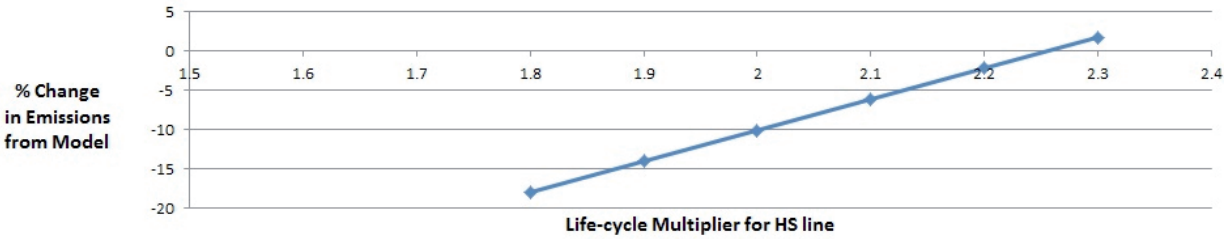


Figure 2 – The effect of life-cycle costs on emissions.

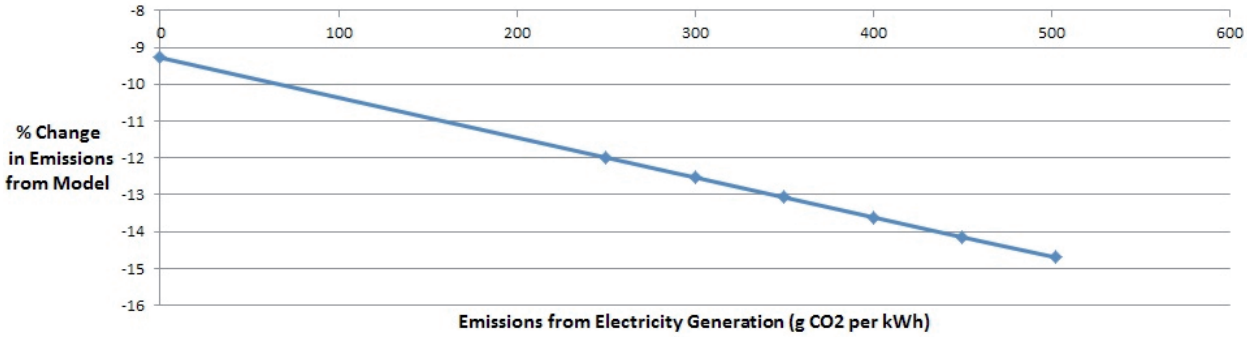


Figure 3 – The effects of grid decarbonisation.

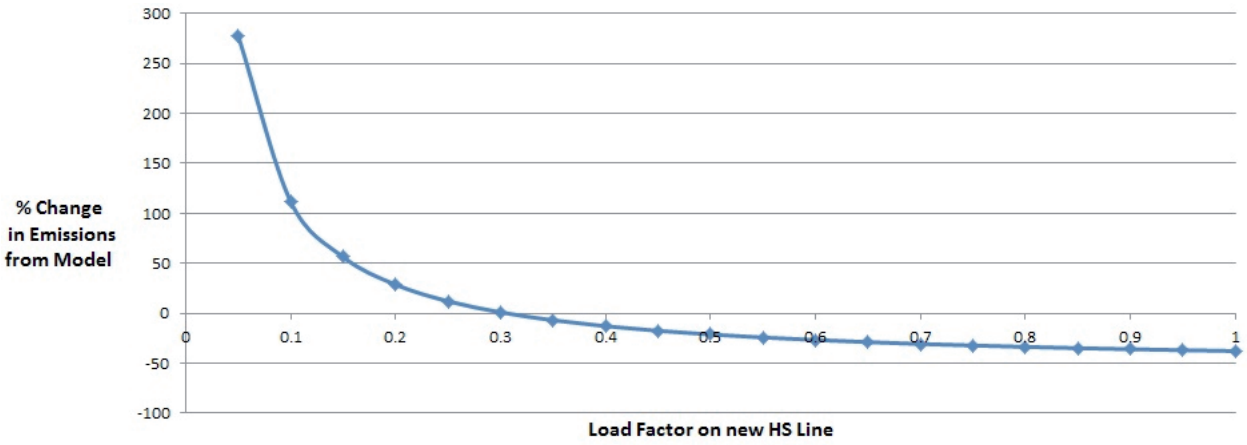


Figure 4 – Change in emissions with load factor.

tively large amounts of renewable or nuclear energy then this figure will be lower still.

Because the new HS line modelled here is electrified, its emissions would be expected to decrease as the electricity grid was decarbonised. For the purposes of this simple model, the classic rail emissions are also assumed to decrease, but at half the rate to take in to account the fact a lot of the UK network is not currently electrified. The effects of grid decarbonisation on the overall reduction in emissions in this scenario is shown in Figure 3.

The results may appear somewhat surprising, because the benefit of HS in terms of reduced emissions appears to diminish as a result of decarbonisation. The reason for this is the high percentage of passengers who have come from classic rail, and the fact that the benefits of shifting diminish as the grid is decarbonised. Using an alternative scenario, with much more modal shift from road and air, and less from classic rail does demonstrate what would more conventionally be expected – namely that the relative environmental benefits of shifting from road and air to rail do increase as the grid is decarbonised. However, there is still the caveat that no account has been taken of likely improvements in both automative and aeroplane efficiences and any benefit of decarbonisation that is seen is likely to be offset to some extent by this.

It is also worth bearing in mind that the improved environmental performance of electric trains resulting from using lower carbon sources is not necessarily a good reason to further encourage an increase in electric rail. It could be argued that if the railway did not utilise electricity from 'low carbon' sources, then these sources could be used instead to replace other conventional power stations, such as those which burn lignite (RSSB, 2007).

THE EFFECT OF LOAD FACTOR

As already noted, the load factor of a given mode of transport is a key variable in determining emissions on a per-passenger basis. The data in the earlier section about emissions can be used to illustrate this, particularly when High Speed Rail is compared with conventional electric rail. On a per-seat basis, conventional Class 91 electric train uses less energy (and hence produces fewer emissions) than any of the High Speed alternatives considered. However, the fact that the High Speed services considered have a higher average load factor than the conventional UK inter-city services means that per passenger they produce fewer emissions.

Any advantage rail may have in terms of contributing to a reduction in GHG emissions is dependent on being able to maintain a high enough load factor. Indeed, as Chester & Horvath (2010) observe, "while one mode may outperform the other at their average occupancies, there are many ridership levels where this may not be the case." Figure 4 shows how the change in emissions may be expected to vary with load factor on the new HS line modelled here. The assumption is made that the relative amounts of modal shift and journey creation remain the same.

It can be seen that there is a minimum load factor which must be maintained in order for the new railway to have any environmental benefit. Below this point, the adverse effects could be quite serious. The minimum load factor will vary according to the specific scenario, and according to the proportion of passengers who have shifted from other modes compared with those who are undertaking new journeys.

Modal Shift and Journey Creation

When considering a new transport system, the environmental benefits of a high load factor will only be realised if it is a result of modal shift from more polluting modes rather than from journeys which would not otherwise have been made. Any journey creation will not contribute to a reduction in emissions. Network Rail (2009, Section 3.1) deal with the impact of journey creation by "effectively removing these passengers from the equation, thereby decreasing the overall percentage occupancy levels." This may not go far enough, however, because in the case of rail there could be an additional environmental impact of getting to and from the station. To maximise the environmental performance of any rail system (new or otherwise), modal shift from both aviation and road transport needs to be encouraged (assuming average or below-average car and plane occupancy levels). Some rail routes will more naturally compete with aviation, whereas driving will be the main competitor for others.

As has been seen here, new High Speed railways also have the potential to compete directly with and draw from existing classic rail systems, which can affect the overall environmental impact. It has also been seen that the environmental costs of building a new railway can reduce the benefits of modal shift. However, existing rail capacity may not allow much scope for modal shift, especially when considering the fact that the dominance of road transport means that even a modest amount of modal shift can have a large impact on rail passenger numbers. For example, the Independent Transport Comission (ITC) suggest that a shift of just 2.5 % of car travellers to rail will increase existing rail demand by 15 %. (Independent Transport Commission, 2010). According to a recent report, much of the southern part of the WCML already has "minimal or no capacity for growth," or is at the stage where "growth may be difficult to accommodate without affecting performance" (Network Rail, 2010a, Figure 3.9). Hence if large-scale modal shift to rail is to be possible, the construction of new railways will in some cases be essential. The challenge is to ensure that any capacity which is created is utilised primarily for modal shift whilst keeping new journey creation to a minimum.

ENCOURAGING MODAL SHIFT FROM THE CAR

In both Europe and the USA the car is very much the dominant mode of travel. Blainey and Preston (2010) suggest that the reasons for car travel being so much more prevalent than rail travel include "the ability of the car to offer a seamless door-to-door journey from origin to destination and the greater flexibility offered by the car when visiting multiple destinations," which stands to reason given the limitations of the railway infrastructure and the fact that many destinations are not directly accessible by train. When it comes to barriers which prevent modal shift to rail. "Network limitations" and "the inherent unsuitability of [some] trips for rail" are two examples of 'hard' barriers which have been identified (Blainey, Hickford, & Preston, 2009). Although increasing the coverage of the rail network would help to reduce some of these issues, it would be optimistic to assume that rail could ever be a viable alternative to every car journey.

However in some cases – especially for longer distance journeys – rail can be a viable alternative to driving, and may even be able to offer benefits which outweigh some of the limitations (such as a lack of seamless door-to-door journey). Possible benefits include shorter journey times, cheaper travel and the ability to work on the train/avoid the stress of driving. If modal shift is to be encouraged, these benefits must be maximised.

When it comes to journey times, studies have shown that long journey times by rail are a barrier to modal shift (Blainey, Hickford, & Preston, 2009, Section 2.1) and it is thought that for long distance travel, car users are comparatively sensitive to journey time (Independent Transport Commission, 2010, Section 5). Blainey et al. (2009) therefore suggest that reducing journey times on existing lines or constructing new lines to reduce journey times could be one way of encouraging modal shift.

The cost of rail travel is often seen as one of the largest barriers to modal shift (Blainey et al. 2009, Section 2.6), although this may partly result from misconceptions, and the fact that expenditure on rail travel is often viewed as a luxury (compared to car travel, which is more often viewed as a necessity). Suggestions therefore include making rail travel cheaper, increasing awareness of cheap fares and providing incentives such as discounted season tickets for new commuters. The effect of travel costs is shown by the ITC, whose model suggests that holding the cost of rail constant until 2030 will double the predicted increase in demand for long distance rail travel (Independent Transport Commission 2010, Figure 9). However, the corresponding reduction in demand for car travel is comparatively low, suggesting that cheaper rail fares alone may lead to journey creation as well as modal shift. The ITC model also considers options for increasing the cost of driving (including Road User Charging) and in these scenarios the potential for modal shift is much more promising.

Other solutions suggested by Blainey et al. (2009) for encouraging modal shift to rail include:

- Increasing the reliability of the rail service
- Increasing train operating frequencies and hours of operation
- Adjusting timetables to fit with passenger requirements
- Operating more direct services
- Improving interchanges and access/egress from stations

Additionally, focus on improving train comfort and onboard facilities to allow passengers to use the time on board productively may prove an important attraction for modal shift. Some of the ways of encouraging modal shift will also carry an environmental penalty – such as the construction of new lines or the running of extra services. Careful analysis should therefore be undertaken to ensure that the resulting modal shift does lead to a net reduction in emissions.

ENCOURAGING MODAL SHIFT FROM AIR TRAVEL

Like rail travel, flying does not offer the flexibility of a car and is therefore not an option for many journeys. However it provides real competition to the railway over longer distances, when it can offer faster journey times.

On some corridors High Speed Rail can offer fast enough journey times to encourage modal shift. However, on routes with a high-proportion of interconnecting air traffic (interlining), reduced rail journey times alone may not be enough and if rail is going to be a true alternative to an interconnecting flight it must offer as seamless a travel experience as possible. Ideally this would mean that the railway serves the airport directly, and through ticketing is offered. Connecting airports with HSR has the potential to attract interlining passengers, and reduce domestic flying; however, using HSR to make an airport more generally accessible is not without its disadvantages. A key concern is that flying in general could become more attractive for some, and a level of trip generation (across both HSR and longer haul aviation) could result.

Many of Blainey et al's suggestions for encouraging modal shift to rail apply as much to air travel as they do to car travel. In the case of air travel, the potential for modal shift could possibly be further increased if some of the benefits of rail travel, such as the ability to work on the train, were promoted in contrast to the 'hassle-factor' involved in flying (such as having to queue for security).

Further issues surrounding overall environmental performance

LINE-HAUL DISTANCE AND OVERALL DISTANCE TRAVELLED

It is very rare for a journey to be made which begins and ends at a railway station. Hence when travelling by rail, a journey will usually comprise more than the actual travelling on the train itself (the "line-haul element"). Transport Watch UK suggest that for journeys whose main mode is rail the average distance travelled is about 7.5 miles more than the line-haul distance (Transport Watch UK, 2006). Where journeys to and from the station are made on foot, bicycle, or by existing public transport, it would reasonably be expected that the environmental impact would be negligible. The worst-case scenario would perhaps be if a traveller received a lift in a car to and from the station, which would necessitate an extra return car journey at each end of the trip. When considering a new station, the impact of developing a new bus network or other public transport system to provide accessibility should also not be underestimated.

On the other hand, rail journeys can often be more direct point to point than travelling by road can. Data from the Transport Direct website (Transport Direct, 2011), for example, suggests that a journey from Central London (Oxford Circus) to Central Edinburgh (Scots Memorial) is 40 miles (64 km) shorter by rail than by road.

One of the major limitations with the basic model used in this paper is the assumption that the journey length is not dependent on mode. It could be argued that the more direct routing of some railway lines offsets the impact of the additional non-line haul element, but the model would need further development to be of any use in a real-world situation.

FREIGHT TRANSPORT

Although this paper has so far focussed on passenger transport, rail also plays an important role in the transport of freight, particularly when it comes to moving bulk goods over long distances. In recent years, the containerisation of freight services has also provided rail with a significant advantage in the Intermodal market, as it is very well-suited to the movement of large numbers of containers between ports and their hinterlands (Armstrong & Preston, 2010). Although the development of road transport eroded rail's dominance in the freight market, the amount carried by rail has risen again in recent years (Department for Transport, 2009c, data from Section 4). However, rail freight suffers from the same limitations as passenger rail – namely that it cannot offer a comprehensive point to point service.

According to The Economist (2010), the best freight railway network in the world is in North America. The Economist notes that "America's railways are the mirror image of Europe's" with much less focus on passenger rail, but a much more successful freight offering. Data shows that coal is the dominant commodity carried by weight (Association of American Railroads, 2010, Type of Freight Carried for Year 2009) and a possible reason for the fact that rail freight has such a large market share in the US is that rail is particularly suited to the overland movement of bulk goods across long distances.

In theory, encouraging a modal shift of freight from road to rail brings huge potential for the reduction of GHG emissions. Network Rail (2010, Section 4.4) claim that per tonne of cargo conveyed, rail freight produces 76 % less carbon dioxide than road freight. However, when looking to the future, the question arises as to whether the movement of some goods will be sustainable at all. Coal, for example, is a finite resource, for which long term demand can only reduce as alternatives to fossil fuels are sought. The role of rail may therefore be challenged in the future if it continues to focus on this section of the bulk market.

The Intermodal sector has the potential to fare a bit better. According to the Association of American Railroads (2008),

the Intermodal sector has been the fastest growing rail traffic segment for many years; intermodal freight currently accounts for around 22 % of rail revenue and in 2006/7, 12 million containers were carried by rail, up from 3 million in 1980. Of course, if this is all new demand (rather than modal shift) then it is not contributing at all to a reduction in GHG emissions; but if the containers would otherwise be moved by road then it is worth promoting rail as an alternative.

It is important to realise that there is a potential conflict between running passenger and freight services on the same line, as they have different running speeds and stopping patterns. Additionally, in America, the regularity of InterCity passenger services does not sit well with the current way of running variable freight services at short notice to meet demand, and choices may have to be made. Similar choices are likely to be faced in Europe, especially when considering how best to use existing classic rail infrastructure which loses its InterCity services to new HS lines. The emissions savings per tonne of freight are much more significant than those saved per passenger, but the supporting infrastructure and level of service offered will affect levels of demand for both passenger and freight transport.

Conclusions

In the right circumstances, it can be seen that the railway can indeed play a role in reducing GHG emissions. Although diesel trains may not offer better operational environmental performance than other modes, especially in the future, electric trains have the potential to offer much lower emissions per passenger than road or air transport. Decarbonisation of the electricity grid will improve the environmental performance of electric rail further, but the relative benefits may be offset by improvements in other modes.

Use of a simple model has shown, that encouraging modal shift to rail does not guarantee that lower operational emissions will result in a net benefit – especially if new rail infrastructure is needed to provide services and cater for demand. Lifecycle costs are important, and potentially contribute more to emissions from rail than alternative modes of transport, due to the high level of supporting infrastructure. There will be cases where the environmental costs of construction are not paid off within a reasonable period of time, if at all, and each new development should be carefully thought through.

The level of vehicle trip cancellation is an important factor, because if other modes continue to operate the same level of service then any benefit of modal shift is negated. Indeed, when other factors (such as travel to and from the station) are then taken in to account, the overall effect could be negative. To maximise the abilitly of the railway to reduce GHG emissions, mechanisms need to be implemented which ensure that the modal shift of passengers results in the cancellation of flights and a reduction in car journeys.

Load factor is another important variable, and rail services need to maintain sufficient loadings to realise environmental benefits. The minimum load factor will vary for each specific situation and is heavily dependent on the amount of modal shift relative to new journey creation. Some thoughts on how to maximise modal shift from road and air transport have been given. The data used here has also illustrated the possible effects of abstraction from classic rail to new High Speed lines; unless the capacity released on classic lines is also utilised for modal shift from road and air, this has the potential to be a negative phenomenon overall compared with modal shift which comes from road or air.

In its current form, the model is very limited, and does not take in to account journey distances and travelling to and from a railway station (or other public transport hub). The impact of these factors is again very much dependent on each individual scenario, but they should be fully assessed – especially when any reduction in emissions is predicted to be marginal.

The analysis in this paper has focussed on a very specific scenario, using demand forecasts for the proposed new High Speed line in the UK (HS2) as inputs to the model, and the results need to be seen in context. One of the interesting factors at play in this particular scenario is the high level of abstraction from an existing classic rail system, and the results for other High Speed systems could differ accordingly. For other types of rail system, the results could be very different – for example, an urban light rail system could not expect to reap the benefits of modal shift from domestic aviation, whilst Chester & Horvath's analysis suggests that overall life-cycle costs could be higher.

Many of the principles will nonetheless apply generally - for example the need to take a holistic view and consider the whole life-cycle impact, the need to maintain a minimum load factor and the need to encourage modal shift over trip generation if benefits are to be realised. In this sense, despite the limitations, the model used is useful for heightening awareness of the important factors.

Rail freight should also not be ignored, as it has the potential to offer huge savings in emissions over transporting goods by road. Once again, the benefits realised in practice are dependent on the specific situation. Where passenger and freight flows are in conflict, careful analysis needs to be done to ascertain which the railway should focus on, balancing the potential for modal shift and the associated benefits against the potential for new demand creation.

In conclusion, rail performs well environmentally relative to other modes, and could indeed be used to help meet environmental targets. Many factors affect the environmental performance of a transport system however. The simple model here outlines where caution needs to be taken, and how the benefits of rail travel can be maximised, but there is plenty of scope for more detailed work.

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