MODELLING FUTURE CO_2 EMISSIONS FROM ROAD FREIGHT TRANSPORT – THE CASE OF GREAT BRITAIN

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ABSTRACT

The transport sector is responsible for around a quarter of world energy-related greenhouse gas emissions. Globally, road freight transport has been growing more rapidly than road passenger transport and this is expected to continue for the foreseeable future (Kahn Ribeiro et al., 2007). As a result of this growth the energy used by trucks is expected to increase by nearly 150% by 2050, as compared to 2000 level (WBCSD, 2004). This causes a great deal of concern about future growth in CO_2 emissions from road freight transport, particularly in the light of the recently announced UK and European targets to reduce carbon emissions by 80% compared to 1990 level, by the year 2050.

In order to achieve these ambitious targets it is important to have a reliable baseline forecast of CO_2 emissions from road freight transport, i.e. a so-called business-as-usual (BAU) scenario, as well as a good understanding of factors influencing the level of emissions. Typically, forecasting studies assume close relationships between Gross Domestic Product (GDP) and tonne-kms and between tonne-kms and CO_2 emissions and produce macro-level forecasts with limited disaggregation of results.

This paper presents an alternative approach to the forecasting of future CO_2 emissions from road freight transport. Based on an analytical framework linking economic growth and CO_2 emissions through a series of key logistics variables and ratios, a spreadsheet forecasting model was developed and operationalised with data for Great Britain. Projections of future changes in the key logistics and freight transport parameters derived from a large-scale Delphi survey were used to produce the BAU forecast for the period 2007-2020. The input values of the key parameters were then varied to model a range of scenarios representing different policy options and technological developments. By assessing the sensitivity of future CO_2 emissions to policy initiatives and technological changes, it was possible to identify the most effective measures to decarbonise carbon emissions in the road freight

sector and provide valuable decision-making support for the design of transport policies at both macro and corporate levels.

Keywords: CO_2 emissions, road freight transport, Great Britain, modelling, 2020

INTRODUCTION

Freight transport is vital to economic prosperity and growth. Raw materials, components and final products flow in vast quantities through complex supply chain systems to satisfy the demands of consumers. Although crucial to ensuring economic prosperity, freight transport also poses a large burden on the physical environment and society. Externalities such as air pollution, noise and vibrations, impact on land use and biodiversity, congestion, accidents or visual pollution, are typically not taken into account in a decision making process but can, in the longer-term, cause irreversible environmental damage and significantly compromise the quality of life. The environmental problems associated with freight transport are well researched in the literature (e.g. Kroon et al., 1991, Holman, 1996, Worsford and Blair, 1996) and legislation is in place to limit the external impacts (e.g. Euro emission standards, noise limits and regulations on the maximum weight and size of vehicles, etc.). Nevertheless, the true extent to which freight-related externalities can be minimised depends on the preparedness of individual businesses to recognise, acknowledge and mitigate the impacts of their transport activities.

Climate change and its potentially catastrophic consequences are now at the top of political agendas. As a result of burning fossil fuels, CO_2 concentrations in the atmosphere have increased by over one third since pre-industrial times (around 1750) and now stand at 387 part per million (ppm) (Stern, 2006). The increasing concentrations of GHGs are leading to the gradual warming of the Earth's atmosphere. This is likely to cause a range of negative impacts on food and water supply, ecosystems, weather conditions, etc. (Stern, 2006). In recognition of the major environmental threat posed by rising CO_2 and other GHG levels, governments are taking action at global, national and local levels to address the problem.

In the UK, road is the dominant freight transport mode carrying 65% of the total tonne-kms and 82% of tonnes lifted in 2008 (Department for Transport, 2009a). This creates a large environmental problem as road is the second most energy intensive mode of freight transport (after air). At present, emissions from HGVs account for around 5-6% of total domestic CO_2 emissions (McKinnon, 2007a). Given the geographical attributes of the country and the high service quality and economic efficiency offered by road freight operators, road is expected to maintain its leading position in the UK freight transport market. Thus, while shifting more freight to less carbon intensive transport modes is an important policy option, efforts should be focused on maximising the efficiency of goods movements by road. Also, unlike air pollutants and many other environmental impacts, CO_2 emissions from road freight transport still remain unregulated. What is more, they may further increase as a result of tighter emission controls on other pollutants (e.g. introduction of Euro 6 emission standard in 2013).

Recently, the UK government has committed to reduce emissions of GHGs to at least 80% below 1990 levels by 2050. In the light of this legally binding GHG reduction target, there is a need for new policies and measures focusing on the transport sector. Road freight transport is one of the industry segments where further improvements are needed. However, to be able to assess the full consequences of new policies, it is crucial to have a baseline against which the anticipated policy benefits could be benchmarked. Hence, there is a need for a reliable forecast of future CO_2 emissions from road freight transport in the absence of new policy interventions. Most currently available transport forecasts focus on passenger traffic. Where available, forecasts of road freight volumes and related externalities are typically linked to trends in economic activity, ignoring changes in the nature of logistics and supply chain systems over the medium to long term. This research on the prediction of future trends in HGV-related CO_2 emissions from business perspective is therefore particularly timely.

ENVIRONMENTAL IMPACT OF ROAD FREIGHT TRANSPORT – ASSESSMENT FRAMEWORK

CO_2 emissions from road freight transport are directly related to the type and amount of energy used by HGVs (Piecyk, 2010, Leonardi et al., 2006). As virtually all HGVs are diesel powered, the energy use equals the amount of diesel fuel consumed. For every litre of diesel burnt 2.6391 kilograms of CO_2 are emitted to the atmosphere (DEFRA, 2009). Energy use, in turn, is driven by the demand for road freight transport, which in the past has been quite closely related to the economic growth (Sorrell et al., 2009, Tapio, 2005, McKinnon, 2007b). Thus, at a macro-level, the trend in CO_2 emissions is underpinned by the relationship between the volume of road freight movement and economic growth.

The underlying rationale used to explain the relationship between economic growth and transport volumes often refers to the fact that transport is generated by other economic activities and, as such, can be described as ‘a second-order activity’ or a derived demand (Ruijgrok, 2001, Pastowski, 1997). Thus, changes in production and consumption of goods and services will determine the demand for freight transport. Numerous attempts have been made to explain or predict freight demand using various economic and industrial indices based on an assumption that changes in freight volumes will most likely lag behind and be attributable to changes in one or more such indices (e.g. Fite et al., 2002, Lyk - Jensen et al., 2005, Kveiborg and Fosgerau, 2007, Lu et al., 2007, Sorrell et al., 2009). A cross-sectional study of a sample of thirty-three countries at different stages of development undertaken by the World Bank using 1989 data found that differences in Gross Domestic Product (GDP) explained 89% of the variation in road tonne-kms (Bennathan et al., 1992). While economic growth increases the welfare of a country, externalities associated with road freight transport reduce that welfare. Thus, the question of how a country can experience economic growth without facing the negative side effects of transport growth is receiving increasing attention (Ballingall et al., 2003). This highly desired ability of an economy to grow without a corresponding increase in road freight transport activity is commonly referred to as ‘decoupling’.

A number of studies have investigated the degree of decoupling of GDP and transport growth in Europe (e.g. Meersman and Van de Voorde, 2002, Tapio, 2005, Leonardi et al., 2006, Tapio et al., 2007, Verny, 2007), in the US (Banister and Stead, 2002), New Zealand (Ballingall et al., 2003) and Asia (Lu et al., 2007). The predominance of the European perspective on the problem can be explained by the fact that while there are significant signs of the decoupling in the US (Banister and Stead, 2002), in the EU road freight traffic continues to grow at a much faster rate than GDP (McKinnon, 2007b), creating the need for further investigation into opportunities to reverse this relationship.

Irrespectively of the EU-wide situation, in the UK the signs of decoupling are already visible. However, there is still a great deal of uncertainty of their long-term durability and magnitude (McKinnon et al., 2008). As freight transport continues to grow, even at a slower pace, the associated environmental problems become more severe. Schleicher-Tappeser et al. (1998) indicate two solutions to this problem: technological improvements and the deceleration of transport growth. They also believe that current technological approaches are not sufficient to mitigate unacceptable environmental impacts, thus the emphasis should be put on preventing a further increase of transport volumes. Similarly, Stead (2001) suggests "the current rate of increase in transport volumes is outstripping the rate of improvement in environmental technology for transport, resulting in increasing environmental problems in the transport sector. There is therefore an increasingly strong environmental argument to increase transport intensity (i.e. GDP per tonne-km) in order to reduce pollution, resource use and waste" (p.29). It is worth emphasising here that Stead's definition of transport intensity is the opposite of that presented by other authors (e.g. Peake, 1994, Lakshmanan and Han, 1997 or Ahman, 2004), thus increasing transport intensity is a desirable development in this case, contradictory to the intuitive understanding of the concept.

At the same time, it is argued that explaining the growth in road freight transport and related CO_2 emissions solely in terms of underlying economic growth or other industrial indices is not sufficient to be able to target the problem effectively. There is a need for a framework providing an understanding of how changes in logistics systems can help to break the link between economic growth and road freight transport-related CO_2 emissions (Voordijk, 1999). Drewes-Nielsen et al. (2003) also suggest that the structure of freight transport growth in Europe has changed in the last decades and this change relates to "the logistically induced demand for transport, especially the increase in flexibility of the production and distribution structures" (p.295). Thus, there is a strong need to disaggregate the relationship between GDP and road tonne-kms into a series of logistical variables to enable an in-depth analysis of the underlying causes of freight traffic growth (McKinnon and Woodburn, 1996, McKinnon, 1998).

The first attempt to express the relationship between economic growth and road freight transport demand in terms of a number of key ratios is presented by McKinnon and Woodburn (1996). Using as an example the food and drink sector, the authors present the relationship between the real value of products consumed and exported and the amount of vehicle kms generated by the industry. This framework was further developed in the European Commission-funded REDEFINE (Relationship between Demand for Freight

Transport and Industrial Effects) project. The purpose of the REDEFINE project was to examine the relationship between economic growth and the demand for road freight transport in five European countries (France, Germany, the Netherlands, Sweden and the UK). This relationship is determined by seven key ratios, i.e. value density, modal split, handling factor, average length of haul, vehicle carrying capacity, load factor and empty running. These key ratios link road freight traffic aggregates such as road tonnes lifted, tonne-kms or vehicle kms in a way that, "if each of these ratios remained stable, road freight traffic would be perfectly correlated with changes in the value of goods produced. In practice, each of these ratios can vary independently. By estimating changes in each of the key ratios through time, it should be possible to establish how much of the growth of lorry traffic is a function of economic growth and how much is attributable to logistical changes" (REDEFINE, 1999, p.2). The framework was subsequently adapted in other European projects e.g. Trilateral Logistics Study (TRILOG, 1999), and the Analysis of the Effects on Transport of Trends in Logistics and Supply Chain Management (SULOGTRA, 2000) and, at a micro-level, applied in case study research (Voordijk, 1999).

In a similar vein, Schleicher-Tappeser et al. (1998) identified a range of key factors for developing decoupling strategies, namely the material intensity of the economy, the spatial structure of production, distribution and consumption, the handling requirements of goods and the organisation of transport. On this basis, three strategies for achieving the decoupling are developed, that is "dematerialisation of the economy", "reducing the spatial range of material flows" and "optimisation of transport organisation". This is consistent with the framework discussed above.

Fosgerau and Kveiborg (2004) use a model similar to the one presented by McKinnon and Woodburn (1996). The starting point is production activity measured in terms of output value expressed in fixed prices. It is then chained by a number of conversion factors to transport flows measured in vehicle kms. The model is then presented in a more elaborated form in Kveiborg and Fosgerau (2007). The authors link a number of 'observables' (such as production output value by sector, production output value by commodity, production output weight by commodity, transport tonnage by commodity, vehicle size and ownership and vehicle kms by commodity, vehicle size and ownership) through a series of 'transformation factors' (i.e. commodity mix, value density, distribution of vehicles by size and ownership, average load and average length of haul). The changes in the transformation factors will cause changes in the observables and, eventually, contribute to the reduction or growth in freight traffic volumes. In their model, Kveiborg and Fosgerau use industry production values instead of GDP as the economic measure, as "the GDP of an industry is the value of its production less the value of inputs other than capital and labour. Thus GDP is a poor measure of the volume of goods transported, since the whole product is transported, not just that is added by the industry" (p.41). Lehtonen (2006) supports this view arguing that "while GDP is by far the most commonly used measure of economic well-being and the most often used variable to measure decoupling, it is the growth of goods output- not GDP per se- that drives growth in road freight demand" (p.7).

Cooper et al. (1998) introduce a framework linking GDP and vehicle kms in a similar manner to that proposed by McKinnon and Woodburn (1996), but it is then extended to include the environmental effects of HGV activity. It is achieved by linking vehicle kilometres and environmental impacts (defined in terms of CO_2 and other air pollutant emissions) through a series of what the authors call ‘compounding factors’ such as fuel consumption, engine technology and vehicle mix. Although rather crude, this was the first attempt to link economic growth, demand for freight transport and associated atmospheric emissions.

Ahman (2004) does not present a formal framework but suggests that in order to achieve the decoupling of economic growth and CO_2 emissions from road freight transport, the following measures should be used:

- Shifting to non-carbon fuels
- Promoting modal shift to less carbon-intense modes
- Use of more energy efficient vehicles
- More efficient logistics systems
- Shifting to less transport intensive economic growth.

In focusing on these specific areas, Ahman’s approach is similar to the framework presented by Cooper et al. (1998).

Piecyk and McKinnon (2009) extend and modify the frameworks presented in REDEFINE (1999) and Cooper et al. (1998) to include energy requirements of road freight transport and related CO_2 emissions (Figure 1). This framework is largely based on the one applied in the REDEFINE project (upper part of the figure). In the bottom part, it draws on the idea presented initially by Cooper et al. (1998) to link the demand for road freight transport to environmental impacts associated with that demand. However, instead of factors such as fuel consumption, engine technology and vehicle mix, two variables, i.e. fuel efficiency and carbon intensity of fuel are introduced.

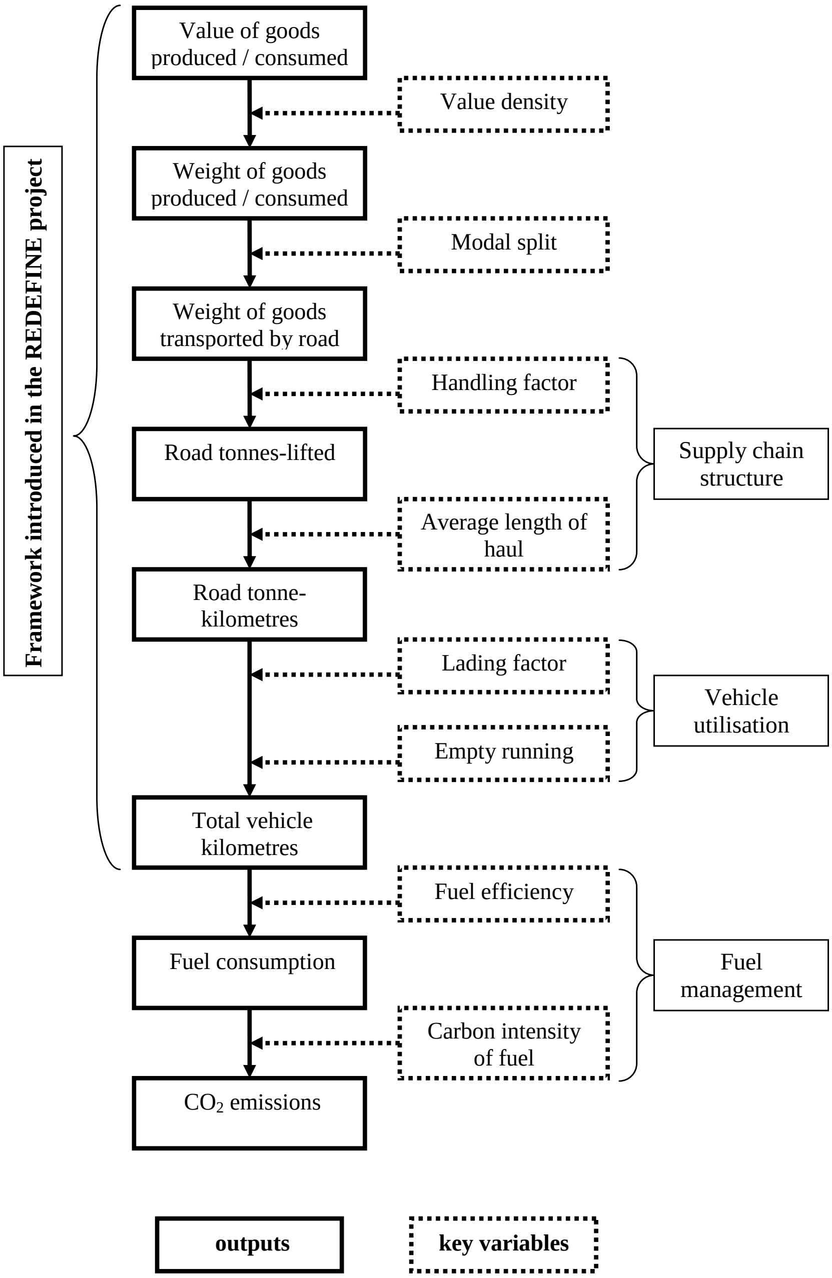

Figure 1. Framework linking economic activity, road freight traffic and CO_2 emissions (Adapted from: REDEFINE, 1999, Cooper et al. 1998)

The key variables in the framework can be defined as follows (REDEFINE, 1999, Department for Transport, 2009b):

- **Value density –** this is a ratio used to convert the value data on economic output / consumption into a weight based measure. It is expressed as value per weight unit of a product (e.g. £/tonne).
- **Modal split** – represents the division of the tonnes-lifted or tonne-kms between different modes of transport. E.g. road's share can be expressed as road tonne-kms divided by the total tonne-kms.

- **Handling factor –** indicates the number of links in a supply chain. It can be estimated by dividing tonnes lifted by the total weight of goods moved. As tonnes lifted are recorded every time goods are loaded onto a vehicle, the same load gets recorded several times as it makes its way through the supply chain. Thus, dividing tonnes lifted by the actual weight of loads moved gives a crude estimate of how many times, on average, goods are being handled as they move along the supply chain, i.e. number of links in the chain.
- **Average length of haul** –the average distance each unit of freight is moved on a single journey. It is estimated by dividing tonne-kms by tonnes lifted.
- **Lading factor** – the ratio of what an HGV actually carried to the maximum that it could have carried if, whenever loaded, it was loaded to its maximum carrying capacity.
- **Empty running –** the proportion of total vehicle kms run without a load.
- **Fuel efficiency –** expressed as distance travelled per a unit of fuel used (e.g. mpg).
- **Carbon intensity of fuel –** the amount of CO_2 emitted per unit of fuel used.

Further, handling factor and the average length of haul determine the supply chain structure. Lading factor and empty running are the two parameters of vehicle utilisation and fuel efficiency and carbon intensity of fuel can be subsumed under the heading 'fuel management'. This framework can be used to estimate how changes in each of the variables can, *ceteris paribus*, contribute to an increase or a reduction in the CO_2 emissions from road freight transport. This makes it particularly useful for this research project as it approaches the problem of minimising CO_2 emissions from a logistics industry perspective.

FUTURE OF ROAD FREIGHT TRANSPORT IN GREAT BRITAIN

A Delphi technique is a systematic, iterative procedure for "structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff, 2002, p.3). The Delphi survey usually involves sending a first-round questionnaire to a number of respondents, collating and analysing the data and then re-circulating the questionnaire accompanied by a summary of results. The experts are asked to confirm or modify their previous responses. This procedure is repeated for a pre-determined number of rounds or until a desired degree of consensus has been reached or response rates dwindle (Rowe and Wright, 1999, Linstone and Turoff, 2002).

The Delphi method has been relatively widely employed in the field of logistics and supply chain management. It had been applied particularly to the forecasting of future medium- and long-term logistics trends, at different geographical, industrial and operational levels. To date it has been used to forecast changes in the physical distribution of food products in the UK (Walters, 1975, Walters, 1976), project future directions in distribution systems, logistics and supply chain management at a national and European level (Cranfield School of Management, 1984, Cooper, 1994, McKinnon and Forster, 2000, Runhaar, 2002, Ogden et al., 2005), as well as to investigate factors affecting location decisions in international operations (MacCarthy and Atthirawong, 2003). In the most recent studies the Delphi method was used to investigate factors crucial for supply chain flexibility (Lummus et al., 2005) and core issues in sustainable supply chain management (Seuring and Muller, 2008), as well as to project the future of supply chain management up to 2011 (Melnyk et al., 2009) customer needs in 2020 and beyond (Deutsche Post DHL, 2009) and transport and logistics in 2030 (PricewaterhouseCoopers, 2009).

An invitation to join the Delphi panel was emailed to 347 potential participants. In the first round 100 invitees filled in the questionnaire giving an overall response rate of 29%. In the second round, the participants were offered an option to modify their answers in the light of the first-round results. They were also informed that if they did not fill in the questionnaire again it would be assumed that they did not wish to alter their first round responses. 66 participants filled in the questionnaire again, 59 of whom changed at least one answer in almost all cases increasing the degree of consensus. The average standard deviation of the responses declined between the rounds by 9%. A similar degree of convergence was achieved in the EU-TRILOG Delphi survey (McKinnon and Forster, 2000).

The survey consisted of 21 questions, many of them multi-faceted, resulting in a total of 119 variables. The experts were asked to express their views on a number of factors that may influence supply chain structures, modal split, vehicle management and fuel management up to 2020 and evaluate their likely impact. Only the projections constituting direct inputs into the forecasting model are presented in this section. The full results of the Delphi study are reported in Piecyk and McKinnon (2010).

As discussed above, underpinning the future trend in these CO_2 emissions will be the relationship between the volume of road freight movement and economic growth. The Delphi panellists were asked to rate how road tonne-kms will grow relative to GDP up to 2020, where -2 = much slower, 0 = same rate, 2 = much faster. The mean response was -0.5 with a standard deviation of 0.9. This indicated that freight transport activity will continue to grow at a slightly slower pace than economic activity. The evidence that the decoupling trend observed in the UK between 1997 and 2004 is now becoming less pronounced was recently examined by McKinnon et al. (2008). If the decoupling trend progresses at a pace predicted by the Delphi experts, it may not be strong enough to achieve major reductions in the environmental impact of freight transport. Thus, new measures may be needed to decouple externalities from tonne-kms growth. This also suggests that micro-level efficiency improvements at a company or supply-chain level are necessary to achieve the overall increase in sustainability in the road freight sector.

Next, experts were asked to indicate if total freight tonne-kms are going to increase or decrease by 2020 against a base index value of 100, representing the current situation. The average response was 127 with a standard deviation of 21. This suggests that total tonne-kms will rise from 255 billion in 2007 to 325 billion tonne-kms in 2020.

The environmental performance of the road freight transport sector depends on the proportion of freight moved by road, supply chain structure, vehicle utilisation and fuel management. Only a modest positive change in modal split was projected. The share of road freight is going to decline by 3% from the 2007 level (Table 1). The Delphi panellists did not expect any significant changes in supply chain structure. The number of links and their average length are going to remain stable. This suggests that that supply chain links are now almost fully extended and that, within a BAU scenario, the domestic pattern of road freight movement is going to experience only modest change by 2020. There will, however, be considerable improvements in the utilisation of HGVs by this date. Lading factor is expected to increase to 64.4 percent from 57 percent and only 21.9 percent of vehicle kilometres will be run empty, down from 27 percent in 2007. If these improvements can be achieved, they will yield substantial environmental benefit. Additional environmental benefit will accrue from increases in fuel efficiency (expressed as vehicle-kms per litre of fuel consumed) and a reduction in the carbon intensity of fuel (i.e. CO_2 emitted per litre of fuel) (mean responses of 1.1 and -0.7 respectively, where -2 = large decrease and 2 = large increase).

Table 1. Projected changes in supply chain structure and vehicle utilisation

How are the following road freight parameters likely to change between now and 2020?	**2007**	**2020 (Mean)**	**Standard deviation**
Percentage of tonne-kms moved by road (%)	63	60	5.6
Average length of haul (km)	86	85.7	15.0
Handling factor (road freight transport)	3.5	3.4	0.7
Lading factor (%)	57	64.4	5.8
Empty running (%)	27	21.9	4.3

MODEL DEVELOPMENT

A spreadsheet model has been constructed which simulates the relationship between freight traffic growth, a series of logistics variables and CO_2 emissions. The freight data from the Continuing Survey of Road Goods Transport (CSRGT) conducted annually by the UK Department for Transport was used to model HGV traffic. The CO_2 conversion factors necessary to translate the freight-related variables into the environmental performance measures were taken from 'Guidelines for Company Reporting on Greenhouse Gas Emissions' published by DEFRA in 2005. These guidelines have been revised since the modelling work presented in this paper was completed (DEFRA, 2009). However, the conversion factor for diesel fuel increased by only 0.3% (from 2.63 to 2.6391 kg CO_2 per litre of fuel). Thus, the recent revision of the CO_2 conversion factor used in this work should not affect the accuracy of the results.

Spreadsheets have been used successfully in the past to model future vehicle exhaust emissions (e.g. Bailey, 1995, He et al., 2002). The flow chart of the model constructed for the purpose of this research is presented in Figure 2. The model is based on the theoretical framework introduced above. The 'current' situation is represented by the 2007 data. The modelling starts with the total tonne-km figure for all modes. Using the modal split variable, this is then converted to the amount of goods moved by road. Dividing road tonne-kms by the average length of haul yields a figure for road tonnes lifted. Laden vehicle kms are calculated using the total vehicle kms statistics and the empty running ratio. The average load for the GB HGV fleet can be then estimated by dividing road tonne-kms by laden vehicle kms. The average load is then used for two purposes. Firstly, to calculate the maximum load. The maximum load is assumed to remain unchanged in the future (i.e. current restrictions on gvw are not expected to be relaxed by 2020) and is then input into the 2020 forecast. Indirectly, this also implies that the relative proportions of rigid HGVs and articulated HGVs remain at current levels. Secondly, the average load and road tonnes lifted values are used to estimate the total number of loads per year. This is then transformed to laden vehicle kms and total vehicle kms (through average length of haul and empty running figure, respectively).

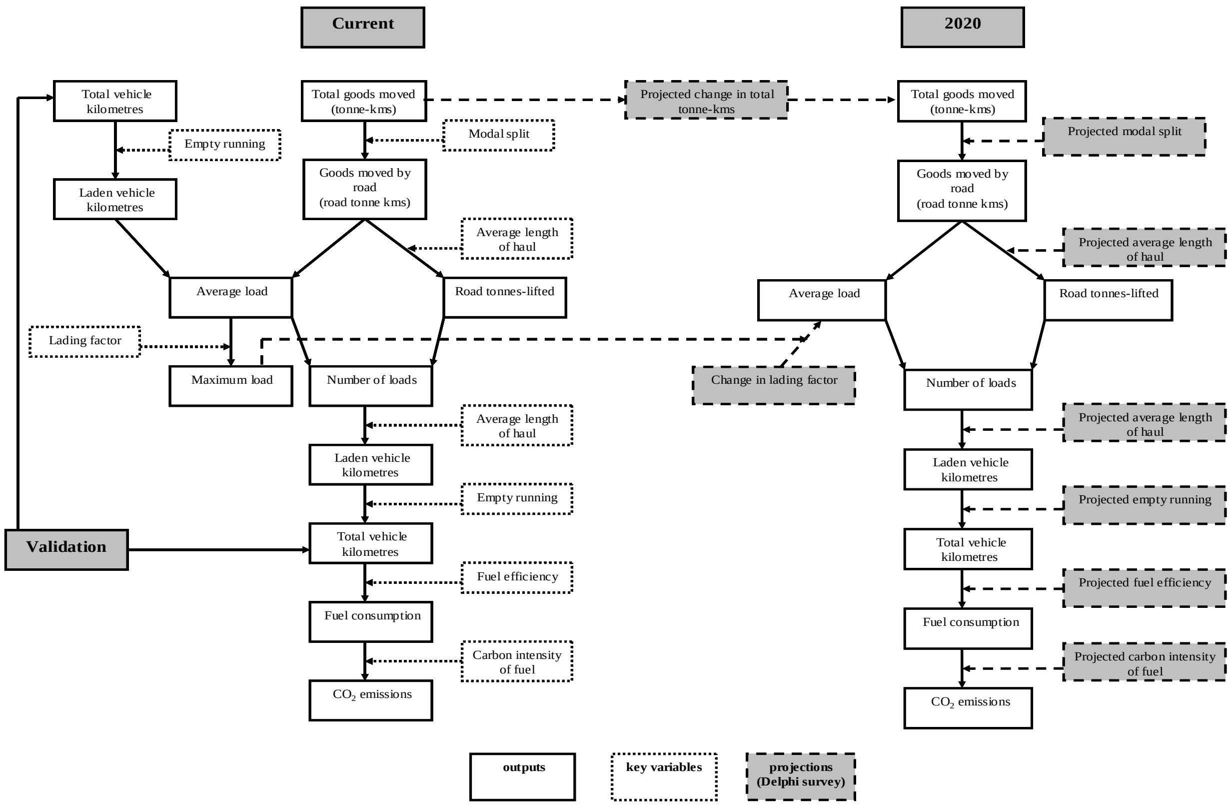

Figure 1 - Forecasting model

The accuracy of the calculations can be then validated by comparing the calculated vehicle kms with the CSRGT estimate. Average fuel efficiency multiplied by the total vehicle kms gives the amount of fuel consumed across the British truck fleet. By applying the carbon intensity conversion ratio the total CO_2 emissions from road freight transport in the GB in 2007 are calculated.

The following model variables can be altered to produce the 2020 forecast:

- Total tonne-kms
- Modal split
- Average length of haul
- Empty running

- Lading factor
- Fuel intensity
- Carbon intensity of fuel.

CARBON FOOTPRINT OF ROAD FREIGHT TRANSPORT IN 2020

In this section the modelling results are presented. First, the BAU case is discussed and then the likely impacts associated with alternative scenarios are outlined.

Business-as-usual (BAU) case

The BAU scenario was constructed on the basis of the mean responses of the Delphi panellists. The BAU case assumes the absence of any new policy interventions (e.g. road charging schemes, carbon taxes, relaxation of current restrictions on the size and weight of HGVs, etc), i.e. there will be no real change in external forces shaping the current course of logistics and road freight transport trends. In the cover letter, the Delphi panellists were asked to assume the BAU scenario when responding to the survey questions.

The mean values for projected changes in tonne-kms, modal split, average length of haul, empty running and lading factor, were inserted into the model to show the combined effects of the changes in the key logistics parameters expected by the participants. Assumptions were made about changes in fuel efficiency (+5%) and the carbon intensity of fuel (-5%) as the survey did not attempt to quantify these directly, i.e. the survey questions were formulated to indicate the magnitude and directions of future changes rather than to ask about exact quantification of the extent of these changes. The BAU forecast assumes that the relative proportions of work carried out by rigid HGVs and articulated HGVs remain at current levels, as this has been stable over the last 10 years (Department for Transport, 2009b) and there are no projections available to indicate how this is likely to change in the future. The results of the analysis are shown in Table 2.

When the BAU scenario is considered, positive developments in modal split, vehicle utilisation, fuel efficiency and carbon intensity are likely to result in a 10% percent reduction in CO_2 emissions from the current level, decreasing the carbon footprint of road freight transport to 17.4 million tonnes of CO_2 in 2020. This occurs despite the fact that there would be an underlying growth in road tonne-kms of 21%. As the average length of haul is likely to remain relatively stable at around 86 kms, the increase in tonne-kms is driven mainly by a growth in the weight of goods transported (to 2.3 billion tonnes in 2020). Panellists predicted that the average number of links in the supply chain will also remain stable, suggesting that future increases in the transported weight will be due mainly to an increase in the physical mass of goods in the economy. The 21% increase in tonne-kms will be largely offset by better loading (resulting in the weight of an average load rising to 11.1 tonnes from 9.8 tonnes) and less empty running of HGVs (5% reduction between 2007 and 2020). As a result, total truck-kms will not change. This is a very positive development when compared to the results from the Great Britain Freight Model (GBFM) which feeds into the Department for Transport's National Transport Model (NTM) and is then used to produce national road traffic forecasts (Department for Transport, 2008a). The GBFM projects a 0.7% growth in HGV kms per annum between 2004 and 2025 (MDS Transmodal, 2008). This would imply a 9.1% growth in truck kms between 2007 and 2020. When improvements in fuel efficiency and reductions in carbon intensity are factored into the calculation, total CO_2 emissions from road freight transport will actually fall by 2020. It is worth noting that the 5% improvement in fuel efficiency (on a litre/km basis) is assumed despite improvements in vehicle loading (i.e. heavier loads being carried). A study by Coyle (2007) suggests that fuel consumption deteriorates at an average rate of 0.112 mpg (0.316 litre/km) per tonne of increased payload, thus small changes in payload weight will have only a little effect on the overall fuel efficiency.

Table 2. Carbon footprint of road freight transport in Great Britain now and in 2020 (BAU scenario)

	Current (2007)	**2020 BAU**
Total tonne-kms (billion)	255	325
Share of road (HGVs)	63%	60%
Road tonne-kms (billion)	161	195
Lading factor	57%	64%
Empty running	27%	22%
Average length of haul (kms)	86	86
Tonnes lifted (billion tonnes)	1.9	2.3
Average load (tonnes)	9.8	11.1
Laden vehicle kilometres (billion)	16.4	17.5
Total vehicle kms (billion)	22.4	22.4
Projected change in fuel efficiency		+5%
Fuel efficiency (mpg)	8.7	9.1
Fuel efficiency (litre/km)	0.33	0.31
Projected change in carbon intensity of fuel		-5%
Conversion ratio (kg CO2 / litre of fuel)	2.63	2.50
Total fuel consumption (billion litres)	7.3	7.0
Total CO_2 emissions (million tonnes)	**19.3**	**17.4**
% change from current level		-10%

Optimistic and pessimistic scenarios

After the BAU case was modelled, the optimistic and pessimistic scenarios were constructed. This was done to reflect the fact that, although a substantial degree of consensus was reached, the experts were not unanimous. Thus, constructing extra scenarios helps to reflect the differences in opinion. The optimistic and pessimistic scenarios were defined, respectively, as being one standard deviation above and below the mean value of each key parameter. The standard deviation is a statistic that shows how tightly all the various responses are clustered around the mean in a set of data. One standard deviation away from the mean in either direction accounts for around 68% of the responses in the group. Two standard deviations away from the mean account for roughly 95% of the responses, and three standard deviations account for about 99%. It was decided to use one standard deviation as this covers more than two-thirds of responses. This also means that extreme opinions are excluded from the modelling reducing the risk of the results being over-optimistic or over-pessimistic. It should be noted at this stage of the analysis that the extreme opinions are still valid data points. Completely unrealistic values which appeared to be erroneous were eliminated from the data set before the analysis. The optimistic and pessimistic projections of CO_2 emissions in 2020 are presented in Table 3.

Table 3. Carbon footprint of road freight transport in Great Britain now and in 2020 (optimistic and pessimistic scenarios)

	Current (2007)	**2020 Optimistic**	**2020 Pessimistic**
Total tonne-kms (billion)	255	271	378
Share of road (HGVs)	63%	54%	66%
Road tonne-kms (billion)	161	147	248
Lading factor	57%	70%	59%
Empty running	27%	18%	26%
Average length of haul (kms)	86	71	101
Tonnes lifted (billion)	1.9	2.1	2.5
Average load (tonnes)	9.8	12.1	10.1
Laden vehicle kilometres (billion)	16.4	12.1	24.5
Total vehicle kms (billion)	22.4	14.7	33.2
Projected change in fuel efficiency		+10%	-5%
Fuel efficiency (mpg)	8.7	9.6	8.3
Fuel efficiency (litre/km)	0.33	0.29	0.34
Projected change in carbon intensity of fuel		-10%	no change
Conversion ratio (kg CO2 / litre of fuel)	2.63	2.37	2.63
Total fuel consumption (billion litres)	7.3	4.3	11.4
Total CO_2 emissions (million tonnes)	**19.3**	**10.3**	**30.0**
% change from current level		-47%	+56%

In the optimistic scenario CO_2 emissions from road freight would be 47% below the current level (10.3 million tonnes of CO_2 in 2020). The modest increase in the total tonne-kms (6%) and a 9% shift of freight away from road, resulting in almost a half of all freight being transported by alternative modes and shortening of the average length of haul by 15 kms to 71 kms, would lead to a decrease in road tonne-kms of 8% (to 147 billion kms in 2020). Significant improvements in vehicle utilisation parameters (lading factor of 70% and empty running of only 18% resulting in the average load weighing 12.1 tonnes), would further convert this decrease in tonne-kms into a 34% reduction in the total vehicle kms (14.7 billion in 2020). In this scenario, the fuel efficiency of HGVs is assumed to improve by 10% and the carbon intensity of fuel to fall by 10%, reinforcing the beneficial CO_2 trend.

In the pessimistic scenario, the carbon footprint of the road freight sector increases to 30 million tonnes of CO_2 in 2020 (56% above the present level). An underlying growth in total tonne-kms of 48% is supplemented by a slight increase in road's share of the freight market (from 63 to 66%). Very modest improvements in vehicle utilisation (1% reduction in empty running and 2% increase in lading factor) will fail to offset this growth in road tonne-kms, resulting in a 48% increase in the total vehicle kms travelled (33.2 billion kms in 2020). This scenario also assumes slight worsening of fuel efficiency (-5%) which could be a consequence, for instance, of increasing traffic congestion or a further tightening of regulatory controls on emissions of other pollutants (for example, the imposition of the Euro 6 emission standard in 2013 can carry up to 10% fuel penalty (European Commission, 2007, Keenan, 2008). No change in the carbon intensity of fuel is assumed in this scenario, i.e. diesel fuel is assumed to remain the sole fuel option in the road freight transport sector.

The optimistic and pessimistic scenarios represent extreme cases and should be used for illustrative purposes only. It is highly unlikely that all changes in the key logistics variables would go only in one, i.e. positive or negative, direction. It is possible that 'worsening' of one of the variables would induce a counteracting positive trend either directly or indirectly (i.e. by optimising other variables). For example, lengthening of the average length of haul is likely to intensify efforts to ensure optimum loading. Conversely, improvements in one aspect of logistics operation (e.g. improvements in fuel efficiency), may lead to a so-called rebound effect, where efficiency improvements result in the generation of more traffic as companies paradoxically increase transport use. Other examples of similar interdependencies are shown in Figure 3. However, it is possible that in the longer term, when climate change concerns become more important in corporate decision making (in line with what the Delphi survey results indicate), there will be a major shift towards the optimistic scenario in all the variables .

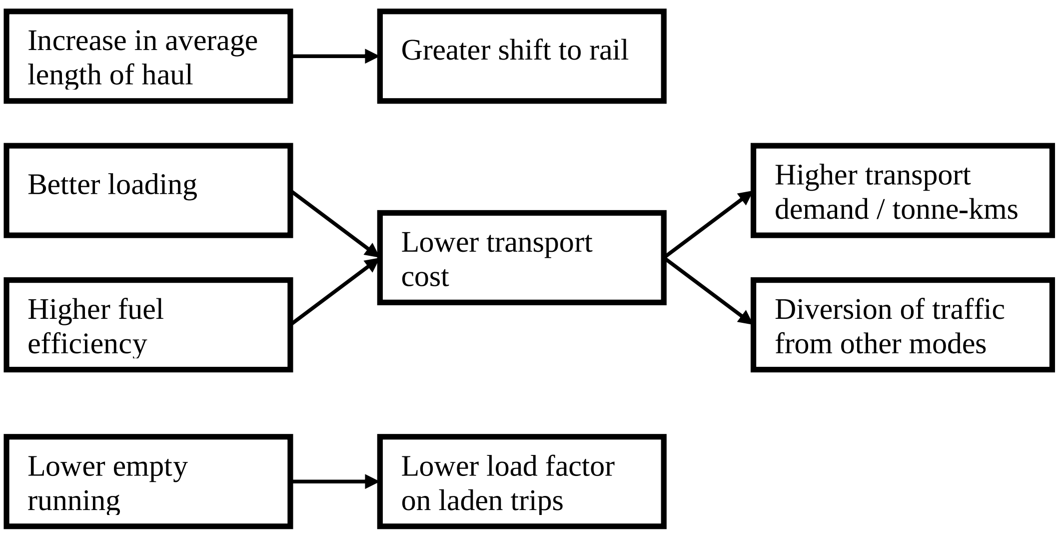

Figure 3. Possible interactions between key logistics variables

CONCLUSIONS

The future impact of changes in key logistics parameters on freight-related energy consumption and emissions is difficult to quantify. In this paper, an attempt has been made to produce a forecast of CO_2 emissions from HGVs in Great Britain using a spreadsheet-based forecasting model and calibrating it with the Delphi experts' opinions on future developments in logistics and freight transport trends.

The mid-range BAU scenario indicates that the most likely outcome in 2020 is a marginal reduction in CO_2 emissions from road freight transport of around 10%. This would occur despite an increase of 21% in the amount of road freight movement above the 2007 level. Substantial improvements in vehicle utilisation and fuel efficiency and shifts to alternative transport modes and lower carbon energy sources would more than offset the effect of this growth in road tonne-kms on CO_2 emissions. The optimistic and pessimistic scenarios, defined by a one standard deviation range on either side of the mean Delphi scores, envisage road-freight-related CO_2 emissions falling by 47% or rising by 56%.

The UK is currently the only country in the world that has a legally binding framework to respond to the climate change challenge. The Climate Change Act, introduced in 2008, requires UK greenhouse gas (GHG) emissions to be reduced to at least 80% below 1990 levels by 2050. The interim target for 2020 requires an emission reduction of at least 34% relative to 1990 levels (21% relative to 2005) (Committee on Climate Change, 2009). It needs to be emphasised that the targets have been set for the UK economy as a whole and may not be applied uniformly across all sectors, i.e. some sectors may be required to cut their emissions above the legal target, while in others reaching the 80% target will not be possible. The Low Carbon Transport – A Greener Future strategy document published by (Department for Transport, 2009c) recognises that due to the nature of the road freight transport, achieving the reductions in this sector in line with the overall UK GHG emission reduction target will be very challenging. It also states that switching to low carbon technologies and focusing on measures to improve fuel efficiency will be vitally important in improving the environmental performance of the road freight sector. The contribution of logistics to ensuring the long-term sustainability of the UK transport system is discussed in Department for Transport (2008b). If an assumption is made that a 21% cut in CO_2 emissions in line with the GHG national targets (relative to the 2005) levels would be required by 2020, this sets a target of cutting HGV-related emissions to 14.5 million tonnes in 2020. It is worth noting that, when the optimistic scenario is considered, this target is easily exceeded by 4.2 million tonnes of CO_2. If, however, the mid-range BAU forecast is adopted, as it reflects the majority opinion of the Delphi panellists, the road freight sector will fall well short of the necessary 'carbon pathway' to an 80% CO_2 reduction by 2050 (or 21% by 2020). Government and business will then have to intensify their efforts to decarbonise the movement of freight by road by implementing appropriate policy measures.

The challenge facing public policy makers trying to design an optimal portfolio of carbon reducing measures for freight transport is that different options are likely to influence the various freight and logistical variables in a complex and often unpredictable way. More research is needed to quantify the impacts of different policy options on freight transport variables and the sector's CO_2 emissions. The model presented in this paper offers two main benefits. First, the BAU scenario is presented. This provides a reliable baseline against which the effectiveness of future initiatives can be benchmarked. The model is also a useful tool constructing and comparing various scenarios, and offers the decision maker a means of assessing the environmental consequences of policy interventions in this sector.

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