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Climate change and road freight safety: a multidisciplinary exploration

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Abstract The freight and logistics sector is of significant importance as an enabler and driver of the global economy, but it is also inherently vulnerable to hazardous weather. Despite this, there is currently no quantitative assessment of how climate change may affect the sector. This paper applies multidisciplinary climate change impact assessment tools and conceptual frameworks to the road freight sector of Great Britain in order to identify potential future weather-related safety issues. Relationships between weather and freight accidents are determined using road accident data and meteorological observations, which are then used with climate change scenarios to arrive at projections of possible impacts across the regions of Great Britain. Included in the study are industry perceptions of future trends within the sector and wider economy which many affect freight's exposure and sensitivity to weather. These are elicited through interviews and an iterative expert Delphi study. Hence, unlike many other climate change impact assessments, this innovative study takes into account the potentially significant impact of socio-economic change (including institutional and operational). The results show that summer precipitation and winter ice-related accidents are likely to decrease across most of the country, whereas winter rain-related accidents are projected to increase. However, it is postulated that some of the impacts of climate change will be modified by reflexive behavioural change on the part of the driver and either institutional adaptation or complacency on the part of the road authorities. The paper concludes by framing the study in a range of future scenarios outlining how the socio-economic environment could influence the road transport network and how it is used, modifying the impact of climate change.

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1 Introduction

1.1 Background

Due to its importance as a key enabler of economic growth both nationally and globally (Eddington 2006), transportation has become an increasingly important area of interest when assessing the potential impacts of climate change. Much work has been conducted on the future vulnerability of hard infrastructure such as railway embankments (Liu et al 2012) and engineered slopes (Clarke and Smethurst 2010), aimed at informing a climate-resilient transport network. However, little work has been undertaken on the potential operational impacts road users could experience. Key among these are delays and accidents, the latter being the focus of this study.

When reviewing the current understanding of potential impacts of climate change on any sector or system it is important to understand that climate change impact assessment (CIA) should be a multidisciplinary endeavour, as change occurs not only in the climatic dimension, but also in socio-economic dimensions influencing development and behaviour of a sector. Tol (1998) gives a useful summary of the basic conceptual framework of the CIA process, emphasising that although exact methodological details vary, to create robust and holistic visions of future impacts a CIA will: (i) determine the current relationships between weather and climate and a given sector, (ii) project impacts using these relationships and climate change projections, and (iii) modify these impacts with scenarios of how the sector or system might develop in the future. It is this final step that is often missing, as the United Kingdom Climate Impacts Programme (UKCIP 2001) observes "studies to assess climate change impacts suffer from serious weakness if by default they merely assume that the projected future climates will take place in a world with a society and economy similar to today". The non-deterministic nature of the future (Berkhout et al 2002), often leads to the use of plausible qualitative and quantitative scenarios of the socio-economic environment of a country or region that can be used as the basis for expert-led sector-specific elaboration. An example of CIA utilising this conceptual framework is given by Dawson et al (2009), who integrate climatic change and future development along vulnerable UK coastal areas. Jaroszweski et al (2010) suggest how these concepts can be applied to the transport sector, the key being the application of the concepts of *exposure* and *sensitivity*, the former a measure of the amount of transport activity, the latter the physical and behavioural relationships between weather, vehicles, and drivers. Change in either exposure or sensitivity may ameliorate or exacerbate any impact of climate change.

Many studies have attempted to determine the effect of weather on accident rates. In the UK, as with many other countries, the weather type most frequently associated with road accidents is rainfall (Edwards 1999), and there is a clear emphasis on this weather type in the literature. For example, Andrey et al (2003) determined relationships between rainfall and accidents in large Canadian cities, whilst Keay and Simmonds (2005) carried out a similar study in Melbourne Australia. Qiu and Nixon's (2008) meta-analysis of previous studies confirmed that rainfall increases accident rates by up to 73%, although this figure falls to 24% in Britain, which may be due to the frequency with which this hazard is encountered. Snow generally produces a much higher increase in accident rates, with an average increase of 100% in Britain. However, the majority of papers that can be used to infer relationships between weather and accident rates look at road transport in general rather than disaggregate for vehicle type. Those that do usually focus on acute problems associated with that particular vehicle type. For example, Young and Liesman (2007) correlated records of high-sided vehicle overturning events with wind speeds.

This understanding of the relationships between weather and accidents has rarely been applied to CIA. Andersson and Chapman (2011) studied the impact of warmer temperatures on road accidents in the West Midlands, UK, and Hambly et al (2012) projected precipitation-related accidents in Vancouver Canada. Both studies satisfy the second step in Tol's (1998) conceptual framework and can be described as first stage CIAs under Füssel and Klein's typology (2006), in that they project current relationships onto future climates. However, the climate change scenarios used in these papers are deterministic, in that they represent a single scenario for each emission level and time-period, meaning that the low-probability/high-impact outcomes available in recent probabilistic ensemble projections (e.g. Murphy et al 2009) are not assessed. Another major drawback is that taken as standalone studies these assessments do not produce realistic visions of the future, as they do not address the third step in Tol's conceptual framework - the consideration of how the network itself might change. Recent work by Andrey (2010) and Qiu and Nixon (2008) has shown that relative risk of accidents during rain events has decreased over several decades, which may be attributed largely to improved vehicle technology and road surface construction. Finally, these assessments fail to disaggregate for vehicle types other than private passenger vehicles.

A critical mode of transport that has had little research conducted on either current or future impacts of weather is road freight transportation. In their reviews of transport-related climate change impacts both the IPCC (2007) and Koetse and Rietveld (2009) identified freight transport as an area which requires quantitative research. Road freight's vulnerability to severe weather (Baker and Reynolds 1992), and the financial disincentives for avoiding exposure, creates an environment where weather-related accidents are numerous and often fatal. Furthermore, broader macro-economic trends such as decentralised supply chains (Hesse and Rodrigue 2004), just-in-time delivery and increased product demand and consumption make efficient and reliable freight transport increasingly important to the economy. In 2010, UK road freight moved 151 billion tonne-kilometres, by far the largest proportion of inland freight (Department for Transport (DfT) 2011). Apart from Young and Liesman (2007) most research has focused on the effects of extreme storms, such as Baker and Reynolds' (1992) case study of the 1990 'Burn's Night Storm' in Great Britain.

The study of freight and logistics has benefited from a recent climate change mitigation-driven interest in decoupling freight from economic growth. McKinnon (2007) and Tapio (2005) attempt to draw qualitative and quantitative links between the overlying socio-economic environment, the resulting demand for freight and logistics, and the way these activities are carried out. From this research it can be suggested that the important exogenous and endogenous determinants of freight activity include changes in the composition of GDP, dematerialisation of products, changes in modal split, changes in the number of links in the supply chain, centralisation of logistics and the efficiency of freight transport. In terms of sensitivity, important aspects include tyre and braking technology, vehicle design, empty running and under-loading and road surface construction. Depending on the socio-economic scenario these domains may change to the benefit or detriment of road freight exposure and sensitivity, with potential regional differences.

1.2 Approach

The research reported here seeks to address several significant gaps in the CIA literature for an economically important mode of transport which has not previously been the subject of

CIA. Fundamentally, it attempts to apply the principles of CIA laid out by Tol (1996) and Füssel and Klein (2006) to the transport sector by:

(i) Determining relationships between weather and road freight accidents in Great Britain using accident records and meteorological data.
(ii) Applying these relationships to future climates under various emission scenarios to project the potential impact of climate change.
(iii) Performing expert-led scenario elaboration to explore potential changes in the freight sector which may affect future exposure and sensitivity.

Discussion is made on how the resulting freight sector under each scenario may ameliorate or exacerbate the raw accident projections. A comparison of the exposure, sensitivity and emission level promoted by each scenario is made to identify the best and worst case futures. This paper is concerned with the effect of rainfall and surface ice. Wind could not be included in the analysis due to its absence in the current climate change projections (Murphy et al 2009).

2 Methodology

2.1 Determination of relationships between weather and freight accidents

UK road accidents that cause injury are recorded by the police in the STATS 19 database (DfT 2009) at the site of the incident and take into account the location, the type of vehicle(s) involved, the severity of injury and the meteorological and road surface conditions. Accident records for the ten year period of 1998–2007 were obtained, providing a suitable number of records whilst limiting the impact of changes in vehicle safety. These were disaggregated into those involving freight vehicles where rain or ice was observed and split into the EU-defined regions of Great Britain (Fig. 1). The study used 14496 precipitation and 687 ice-related accident records. It must be noted that as the police observations are often based on the weather at the time of the report, not the time of the accident, the influence of meteorology in cases of short-duration events may be misreported. Additionally, as the data are concerned with accidents that cause injuries, the records do not represent all accidents caused by meteorological events. It should also be noted that although the data include multi-vehicle events, these are treated as a single accident for the purposes of this study.

Two sets of linear regression were performed between monthly weather and accident records. The temporal unit of the relationships, similar to that used by Eisenberg (2004), was necessarily coarse due to the inability of current climate tools to recreate the daily and sub-daily extreme events (Jones et al 2009) that are the focus of other accident analysis techniques. Monthly area-averaged precipitation records from the UK Meteorological (Met) Office were correlated with precipitation-related accident counts for summer (JJA) and winter (DJF), the main axis along which the UK climate is expected to change (Murphy et al 2009). Precipitation records were converted from quantities into anomalies against the 1961–1990 baselines, the format given by UKCP09. The threshold of 0°C for ice formation dictated a separate approach as projections for this threshold are not available in an area-averaged format. A similar method to that proposed by Edwards (1996) for the study of the effect of wind on accidents was adopted, using a measure for the number of days a season where the temperature falls below 0°C. Due to the relative low occurrence of ice compared to precipitation in Great Britain, relationships were determined at a seasonal resolution and also prompted a move towards larger

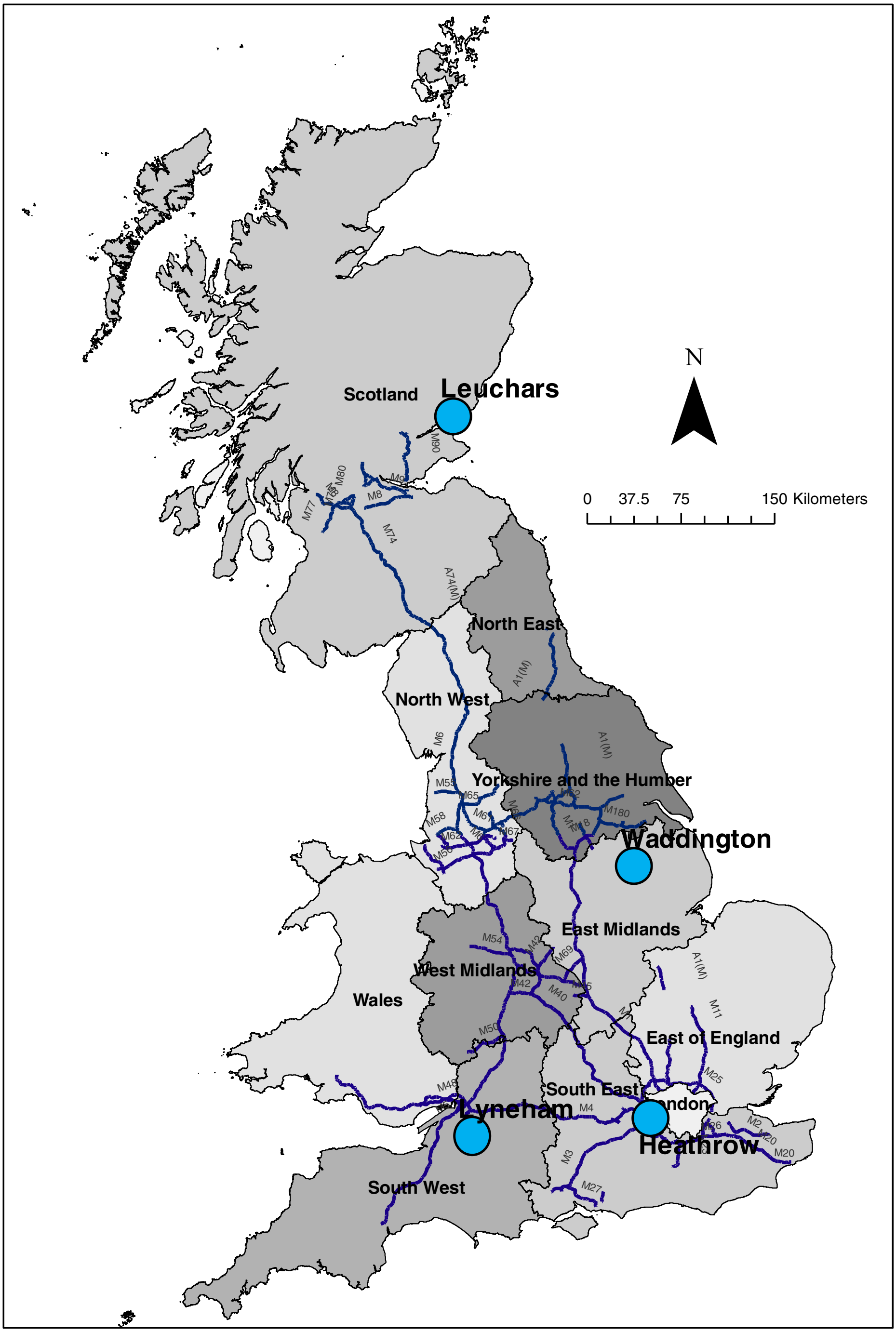

Fig. 1 Great Britain regions, trunk road network and weather station locations

collection areas (Table 1) with representative Met Office MIDAS surface meteorological stations (Fig. 1) similar to those used by Dobney et al (2010).

Table 1 Projections of percentage change in summer and winter precipitation-related accidents in the 2050s against 1998-2007 averages (brackets show percentage change in climate parameters against 1961-1990 baseline) and current relationships between seasonal climate anomaly and accident numbers. Ice-related projections given in the following combined regions: North (Scotland, North East, North West, Yorkshire), Central (West Midlands, East Midlands, East of England), West (Wales, South West), South East (South East, London)

Region	Low 10th percentile	Low central estimate	Medium central estimate	High central estimate	High 90th percentile	Equation	R^2	Low 10th percentile	Low central estimate	Medium central estimate	High central estimate	High 90th percentile	Equation	R^2
Summer precipitation								Winter precipitation						
South East	+9% (+14%)	-10% (-12%)	-13% (-16%)	-13% (-16%)	-28% (-38%)	y = 0.59x + 34	0.55	-3% (+10%)	-4% (-2.7%)	+1% (+6%)	+2% (+10%)	+12% (+20%)	y = 0.88x + 125	0.44
Greater London	+10% (+14%)	-25% (-12%)	-27% (-17%)	-27% (-17%)	-39% (-39%)	y = 0.17x + 18	0.32	-3% (+17%)	-5% (-1%)	+1% (+12%)	+2% (+17%)	+11% (+41%)	y = 0.35x + 42	0.39
West Midlands	+2% (+16%)	-12% (-14%)	-15% (-19%)	-15% (-19%)	-27% (-43%)	y = 0.29x + 19	0.48	-1% (+12%)	-1% (-1%)	+1% (+9%)	+3% (+11%)	+9% (+26%)	y = 0.21x + 79	0.33
South West	+11% (+17%)	-16% (-15%)	-20% (-20%)	-20% (-20%)	-41% (-44%)	y = 0.34x + 4	0.70	-2% (+17%)	-3% (-1%)	0% (+12%)	+1% (+15%)	+7% (+36%)	y = 0.16x + 53	0.22
North West	+5% (+7%)	-9% (-12%)	-11% (-15%)	-12% (-15%)	-23% (-31%)	y = 0.48x + 29	0.35	-3% (+13%)	-4% (-1%)	-1% (+9%)	0% (+11%)	+4% (+27%)	y = 0.40x + 93	0.16
East of England	+1% (+16%)	-16% (-14%)	-19% (-19%)	-19% (-19%)	-32% (-43%)	y = 0.31x + 16	0.46	-1% (+14%)	-1% (0%)	+1% (+10%)	+2% (+13%)	+6% (+30%)	y = 0.25x + 95	0.11
Wales	-15% (+7%)	-14% (-11%)	-17% (-14%)	-18% (-14%)	-33% (-29%)	y = 0.16x + 5	0.48	+1% (+18%)	0% (0%)	+3% (+13%)	+4% (+16%)	+7% (+40%)	y = 0.08x + 29	0.10
Yorkshire and the Humber	-11% (+14%)	-25% (-13%)	-20% (-17%)	-28% (-17%)	-38% (-39%)	y = 0.25x + 12	0.47	-3% (+16%)	-4% (0%)	-2% (+11%)	-1% (+13%)	+3% (+33%)	y = 0.25x + 71	0.09
East Midlands	+2% (+15%)	-14% (-13%)	-19% (-18%)	-16% (-18%)	-30% (-40%)	y = 0.28x + 14	0.63	-1% (+13%)	-1% (-2%)	+1% (+8%)	+1% (+13%)	+5% (+27%)	y = 0.21x + 79	0.08
North East	-10% (+9%)	-18% (-15%)	-20% (-18%)	-20% (-18%)	-27% (-37%)	y = 0.08x + 7	0.41	-2% (+14%)	-2% (-2%)	-1% (+9%)	0% (+14%)	+2% (+31%)	y = 0.06x +36	0.05
Scotland	-3% (+9%)	-16% (-15%)	-18% (-18%)	-18% (-16%)	-29% (-37%)	y = 0.30x + 7	0.43	-3% (+17%)	-3% (0%)	-2% (+11%)	-2% (+14%)	-1% (+35%)	y = 0.35x + 42	0.04
Great Britain	+1%	-15%	-17%	-17%	-31%			-0.03	-0.02	+1%	+2%	+8%		
Ice														
North	0% (-67%)	-38% (-31%)	-46% (-37%)	-54% (-44%)	-89% (-72%)	y = 3.0x + 18	0.59							
Central	+11% (+15%)	-23% (-24%)	-25% (-29%)	-31% (-32%)	-60% (-65%)	y = 3.1x + 7	0.38							
West	-3% (-3%)	-28% (-34%)	-34% (-42%)	-34% (-41%)	-54% (-68%)	y = 0.7x + 5	0.22							
South East	+17% (+18%)	-25% (-27%)	-33% (-35%)	-36% (-38%)	-66% (-71%)	y = 2.3x + 3	0.31	Overall projection						
Great Britain	+7%	-29%	-36%	-40%	-71%			-1%	-5%	-5%	-5%	-7%		

2.2 Projection of climate change impacts

The UKCP09 climate projections were used for projecting precipitation-related accidents. These are the most recent UK climate projections available to CIA practitioners and are notable in their treatment of uncertainty, with a move from previous deterministic approaches such as using single regional climate model runs to probabilistic projections utilising large ensembles of runs. The projections are presented over seven overlapping 30-year periods. For example, the 2080s period represents the average climate of 2070 and 2099. Precipitation projections, as a percentage change from the 1961–1990 baselines were obtained for each region for summer and winter at the 2020s, 2050s and 2080s under low, medium and high emissions and used with the accident relationships to arrive at regional accident projections.

The UKCP09 Weather Generator (Jones et al 2009) was used to create probabilistic projections of future frost events. The weather generator statistically downscales the UKCP09 climate projections to create synthetic weather time series that are consistent with the overlying climate projection. 100 model runs were generated for each time period and emission level combination at the four station locations in Fig. 1. Each of these model runs contain a 30-year time series of daily weather. Counts were made of the number of days with minimum temperatures of 0^{0}C or lower over the winter period for each of the 100 runs. These were used with the accident relationships to create regional accident projections. The impact projections are reported probabilistically. Cumulative distribution functions of the 100 impact projections were made. The lower bounds were given by the 10^{th} percentile, the median value was termed the central estimate and the upper bounds were given by the 90^{th} percentile.

2.3 Exploration of freight futures

Unlike medium-term freight forecasts arriving at a single outcome (e.g. Piecyk and McKinnon 2008), the potential divergence in freight futures over the timeframes associated with climate change required a methodology allowing the consideration and elaboration of multiple scenarios for the future society and economy. It has been suggested that stakeholder involvement can ground CIAs in the interests and knowledge of users rather than those of researchers (UKCIP 2001), and may be a method of reducing scepticism of the science within that community (Norgaard and Baer 2005). Hence, a small set of interviews and iterative questionnaires were conducted with managers in the freight industry to elicit tacit knowledge on how socio-economic scenarios may affect the freight industry in terms of exposure and sensitivity to weather.

The managers while having different job titles were nevertheless responsible for strategic decisions in the organisations such as procurement of vehicles and related technology, with all apart from the respondent from the largest firm being involved in the day-to-day management of operations. The majority of respondents were selected from two company types: small to medium sized (up to 250 employees) third party logistics (with respondents codified as TPLs A-K) and 'green logistics' (ECO A and B) which use biofuel-powered vehicles. One national TPL company was also included (Large TPL A).

An initial round of six interviews was carried out during the summer of 2008 followed by a ten-member correspondence Delphi study, an iterative questionnaire methodology where consensus or groups of opinions are sought by collating the views of one round and allowing respondents to modify their initial responses based on the collective views of the group (Linstone and Turoff 1975). The iterations of the Delphi were undertaken in November 2008 and March 2009. The Delphi was intended to ascertain, both qualitatively and quantitatively, how different socio-economic scenarios may affect the growth and safety of the freight sector and took the following approach.

2.3.1 Past change

The long timeframes associated with the anchor year of 2050, potentially unfamiliar in an institutional context, required the introduction of concepts of change grounded in those experienced by the participants. Identification of the important components of observed trends in the freight sector was important, as the potential effect of future socio-economic change on these could later be discussed. Initial interviews identified nine important factors in the observed reduction of weather-related accidents (DfT, 2009) over the previous two decades such as improved vehicle maintenance and safety regulations which were then scored for their importance on a Lickert scale in the Delphi.

2.3.2 Medium-term change (2020)

Future change was introduced with an initial anchor year of 2020, with respondents being asked to identify the important components of change in exposure and sensitivity under a 'business-as-usual' scenario. Delphi respondents were asked how strongly they agreed with statements elicited from the initial interviews on changes to the freight sector by 2020 such as "more long-distance freight will be taken by train". A percentage figure for growth in freight activity by 2020 was ascertained, with each respondent stating the three most important components contributing to this figure. During the first round of the Delphi, respondents were asked to score how important the nine previously identified factors would be in determining future safety by 2020 and how likely significant improvements in each factor would be. An estimate of percentage change in safety by 2020 was also obtained. The results of these forecasts were disseminated during the second round, with respondents allowed to change their estimates based on the opinions of the group.

2.3.3 Long-term change (2050)

The final stage of the Delphi required respondents to discuss the potential effect of four divergent UKCIP socio-economic scenarios (UKCIP 2001) on the freight industry in 2050. The UKCIP SES are currently the primary toolkit of their type for UK CIA and use two axes of socio-economic change; firstly, values, which range from consumerism to community, and second, governance, which ranges from autonomy to interdependence. The four resulting scenarios are; World Markets, National Enterprise, Local Stewardship and Global Sustainability (Fig. 2). Each has a qualitative storyline element and quantitative indicators for socio-economic dimensions such as population, GDP, health and transport, as well as an associated emission level (low, medium, high) which were used to integrate the accident projections. A detailed summary of the scenarios is given in the Supplementary online materials.

Due to its grounding in conventional and largely experienced development the World Markets scenario, under which economic growth is a priority and is achieved through neoliberal policies, was introduced to the experts in the first round of the Delphi. A description of the scenario and summary of important indicators was provided, with respondents being asked what the effect in percentage terms would be on freight activity and safety. Respondents were asked to select which three indicators from the summary would be most important in promoting the changes they forecast. The remaining scenarios (taken to be

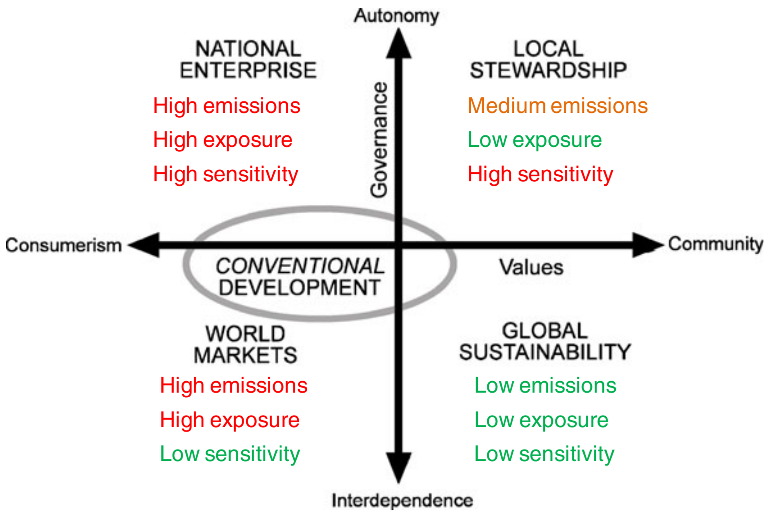

Fig. 2 Modified UKCIP scenarios (2001) showing relative emission levels, road freight exposure and sensitivity

newer to the respondents) were introduced in the second round, along with a summary of results for the World Market scenario. Opportunity was given for respondents to give illustrative descriptions of future freight development to avoid the hazard of suppressing radical views in the pursuit of consensus that Linstone and Turoff (1975) describe.

3 Results

3.1 Accident analysis and climate projections

The strongest summer precipitation relationships (Table 1) were found in the South West (R^2=0.70), the East Midlands (0.63) and the South East (0.55). Only two relationships had an R^2 value below 0.4; the North West (0.35) and Greater London (0.32). The low score for the North West (0.35) is unfortunate due to the large number of baseline accidents in this area. The South East, North West, East of England, East Midlands and the South West are among the regions with the largest gradients. Interestingly the gradient of the South East is steeper than that of London, suggesting that any change in climate will have a far lower impact in London than in the surrounding regions. An explanation of this may be that the predominance of urban travel in the London area limits speed and hence reduces risk, which would agree with Edwards' (1996) findings on urban accident rates.

Although the relationships between winter precipitation and accidents are weaker, the fact that the South East (0.44), Greater London (0.39) and the West Midlands (0.33) have the strongest relationships is beneficial, as these regions contribute disproportionately to baseline accident numbers. Although the ice-related accident relationships show R^2 values comparable to those for summer precipitation (0.59–0.31), it must be noted that these were determined with seasonal rather than monthly data, reducing the number of observations. It must also be noted that in reality the relationships would tend towards zero weather-related accidents as monthly precipitation and frost-days reach low values, for which observations are not available. Although linear regression was appropriate within the range of monthly values studied in this paper, it is likely that non-linear regression could be used to cater for the lower values. It was decided to take all regions through to the climate projection stage due to the contribution of each region to the final national total.

The climate projections (Table 1) show divergent trends for the three weather types, with summer precipitation and winter frosts reducing and winter precipitation increasing across most regions. As a result summer precipitation-related accidents show a decreasing trend under all but the most outlying emission and probability scenarios across the majority of regions by the 2050s. There is a projected increase in winter precipitation-related accidents, but of a lower magnitude compared to summer-precipitation. There is a trend towards increased accidents in the South East, decreasing in magnitude to the West and North, with very little change in Scotland. Winter ice-related accident projections show the greatest percentage change and greatest range of potential outcomes. For instance, the North shows a potential decrease of 46% for the central estimate under medium emissions, greater than any regional change in precipitation-related accidents under even the highest emission scenarios or the most outlying probability level. However, these projections are highly sensitive to the emission scenario and show a great amount of variance within the weather generator output.

When viewed in real-terms for net change across Great Britain (Fig. 3), the impact on accident numbers is far higher for winter and summer precipitation-related accidents compared to winter ice-related accidents. The importance of this detailed examination of the spatial and temporal changes in weather-related accidents of different causation is exemplified by the integrated assessment in Table 1 which shows that the reduction in summer precipitation and ice-related accidents is largely cancelled out by the increase in winter precipitation-related accidents, resulting in a very marginal net reduction in weather-related accidents.

Although the net impact of climate change on weather-related road freight accidents appears to be negligible under both high and low emissions, the shift in seasonality and causation varies greatly under most scenarios. Although smaller than those for precipitation in real-terms, the potential reduction in frost days down to single figures in some regions represents a step change in the operating environment for freight companies in Great Britain. However, there are several logical reasons to suggest that not all of the projected changes in weather-related accident numbers will be seen in reality. Firstly, a reduction in frost days may prompt a reduction in the provision for winter road maintenance (Andersson and Chapman 2011). Both the projected increased and reduced frequencies of precipitation and ice events may have strong psychological and behavioural impacts similar to those outlined in Elvik's (2006) laws of accident causation. For instance, as the frequency of ice days decreases, so does the opportunity for drivers to learn to cope in these conditions, increasing the relative accident rate during these events. However, potentially the largest modifying factor on the raw accident projections will be developments within the sector. The raw projections in Fig. 3 contain an indication of the influence of each scenario's associated emission level and each weather type, with Global Sustainability for instance having the lowest projected winter precipitation-related freight accidents, followed by Local Stewardship, with the National Enterprise and World Markets scenarios having the highest accident projections. However, each will also have a modifying effect in terms of exposure and sensitivity, the implications of which are now explored.

3.2 Industry perceptions of change

3.2.1 Past and medium-term (2020) change

It is suggested that a combination of factors contributed to the observed reduction in weather-related freight accidents, with improvements in driver training, new vehicle maintenance and

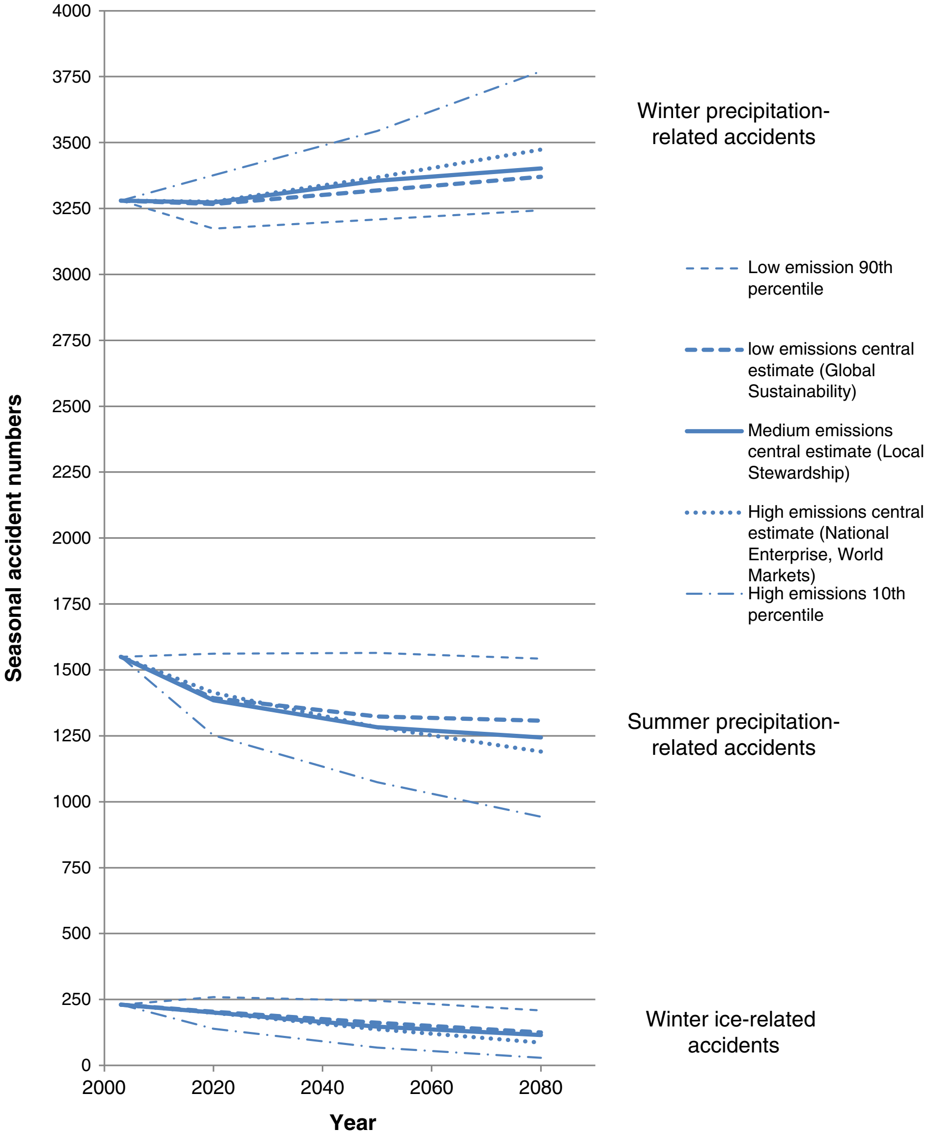

Fig. 3 Projected road freight accident numbers for summer precipitation-related, winter precipitation-related and winter ice-related under different emission levels and associated socio-economic scenarios

safety regulations, and improvements in vehicle technology being the three highest scoring factors. The lowest scoring factor was 'reduced frequency of hazardous weather', indicating that the decrease in accidents is as a result of a reduction of freight sensitivity through an improvement in a multitude of technological and institutional factors.

Looking towards 2020, respondents indicated a shift in importance towards technological innovations for reducing sensitivity, with improved vehicle braking technology and distance sensors for low visibility being highly ranked. While the majority of the potential developments, including improvements to winter road maintenance and weather warnings were considered ‘likely’, very few ‘highly likely’ and no ‘highly unlikely’ responses were offered, suggesting that the developments presented were plausible but not inevitable by 2020. All but one of the respondents indicated an improvement in safety between 10-20% during the following decade.

The future trends affecting exposure by 2020 that promoted the strongest agreement were that the growth of just-in-time deliveries will continue, that new technology and computer systems will allow freight operations to become more efficient and that tighter margins and customer demands will increase the costs associated with delays. Of the trends that divided opinion, one of the most significant was whether the average leg length (the distance of each part of the supply chain journey) will increase or decrease. While a majority thought there would be further centralisation of logistical structures, which has the potential to increase leg length (McKinnon 2007), others held the opposite to be true, which could contribute to freight accidents through exposure and tiredness. The potential movement of freight to the rail network also produced a clear split in opinion. Rail’s resilience to meteorological impacts is significantly different to road transportation’s (e.g. Dobney et al 2010), so any change in modal split would be important for exposure and sensitivity of freight transport. All but two of the respondents predicted that the changes in the freight sector and wider economy that they forecast would promote a rise in exposure by 10-20% by 2020.

3.2.2 Long-term change (2050s)

When presented with the World Market scenario eight respondents indicated that this environment would promote an increase in freight activity and exposure by 2050, and two suggested that exposures would decrease, although no respondents indicated a significant shift. One respondent predicted a decrease due to the smaller manufacturing base and therefore less freight being moved, with increased imports carried either by larger vehicles or by rail. Another argued there would be an increase because of high economic growth rates, increased population and the overall increase in transport demand. This fits with previous theories that couple freight activity with economic growth. It was also suggested that population growth could lead to an increase in transport demand for fast moving consumer goods (FMCG) and other consumer items, and that the high economic growth, freer trade and innovative infrastructure associated with this sector would promote growth. The majority of respondents indicated that sensitivity would increase by 2050 under the World Markets scenario. These views suggest a modifying effect on the raw accident projections in Fig. 3 and Table 1 in a negative direction in terms of exposure but a positive direction in terms of sensitivity.

Several relatively radical visions of the future were also elicited during the interview stage. Stephen of TPL A and Brian of TPL B described a possible move towards city-based distribution centres. Although exposure would be reduced due to fewer vehicles on the often topographically exposed trunk road network in this scenario, the sensitivity of larger vehicles to crosswinds may counteract some of the benefit. This vision contrasts with Paul of TPL D, who suggests that freight will become more regionalised, with shorter average leg lengths and companies operating within a 50 mile radius. Frank of TPL E revisits the potential shift to rail freight mentioned earlier. This would have the obvious impact of moving freight off the roads, hence reducing exposure to meteorological hazards. However, some participants were more conservative with their predictions, often maintaining that freight would change very little, e.g.:

> I can’t see anything changing that much from the way it’s done today, it’s very much ‘as you were’, until they can find something that can teleport freight, there’s always going to be a need for trucks (Henry, TPL C)

4 Discussion and conclusions

The results of the first round of the Delphi which focused on the World Markets scenario gave a generally conservative prediction of growth by 2020, with further increases in freight growth and improvements in safety by 2050. The second round of the Delphi failed to elicit the requisite number of responses on the potential influence of the other UKCIP scenarios to enable the development of expert-led qualitative and quantitative visions for these. An important factor may be the anchoring year of 2050, which is essential for CIA due to the predicted timing of significant climate divergence, but arguably is very difficult for people to visualise in terms of potential characteristics and implications for them. This has been noted previously as a potential barrier to scenario elaboration by Lorenzoni et al (2000).

It is possible to draw logical conclusion as to the influence of the socio-economic scenarios on future exposure and sensitivity informed by the literature. The Local Stewardship scenario, which promotes medium emissions and has relatively low GDP (1.5%) and population growth, can be assumed to have a smaller freight sector than other scenarios, with the environmental awareness and willingness to act on this associated with this scenario also promoting a shift towards rail in the passenger sector. Regionalisation of production may reduce exposure by leading to the type of supply chain restructuring hypothesised by Böge (1995), with economic growth, and hence freight growth being spread more evenly across the country. Despite the environmental priorities of this scenario, the economic geography it promotes may curtail the use of rail freight which is most cost-effective over longer distances. It is likely that this scenario would see a continued reliance on road freight, albeit with cleaner fuel technology. The scenario may suffer from low investment in infrastructure, thus increasing sensitivity. The modifying effect on the impact projections (Figs. 3 and Table 1) is therefore mixed, with medium emissions and high sensitivity providing hazardous winter precipitation conditions and a higher sensitivity, yet fewer vehicles exposed and a reduction in winter ice and summer precipitation hazards (Fig. 2).

The National Enterprise scenario may see potentially greater impacts for winter precipitation accidents than the other scenarios due to the associated high emission coupled with increased exposure and sensitivity. Heavy industry and the production of bulkier goods will increase freight growth, and the low investment in infrastructure would act to increase sensitivity (Fig. 2). In contrast Global sustainability is associated with higher economic growth (2.8%) and a potentially greater demand for freight transport (albeit with a similar trend towards rail). The high levels of innovation, especially in the efficiency and miniaturisation of products would be expected to further reduce exposure, along with a reduction in sensitivity due to investment in infrastructure. Global Sustainability would also likely see similar trends to those predicted under World Markets, such as the centralisation of distribution centres. However, under this scenario these centres may more likely be supplied by rail. The low emissions, exposure and sensitivity of the Global Sustainability makes this scenario the most favourable for freight safety, with National Enterprise showing the opposite trends. Although the interviews and first stage Delphi focused on World Markets, James commented on the both the need for change from business as usual, coupled with the difficulty in doing so:

> This (Global Sustainability) is the direction we need to go in, absolutely. I'd say this is where we are now (World Markets), and will continue to go without a lot of help from the government (James, ECO A)

James' company was one of two included in the Delphi on the basis that as an environmentally-leading (Welford, 1997) company (in these cases having switched to the use of biofuels) the managers might have more proactively developed views on socio-economic development and climate change.

Although researcher-led elaboration of the scenarios was possible, partly informed by the links between past and medium-term change and the overlying socio-economic environment discussed by the experts was possible, the fact that the second round of the Delphi did not elicit further qualitative and qualitative elaboration of the scenarios for 2050 may indicate a barrier to scenario elaboration within sectors that are unfamiliar with the timeframes associated with climate change. This is important as it is precisely the aim of the most recent 'open-source' approach to scenario elaboration advocated by the IPCC (Kriegler et al 2012). However, the relatively small size of this survey may also be of issue, and it is also possible that other deliberative methods such as workshops may offer a better way of way of introducing the concepts behind socio-economic scenarios to those who are unfamiliar with them.

In summary, although the confluence of safer technology and a reduction of winter road icing and summer precipitation events could potentially lead to a safer operating environment, certain scenarios which promote high emissions, a larger freight fleet and low investment in infrastructure could cause problems, especially with winter precipitation events. There remains a need to assess the current and future impact of wind on road freight safety, although existing climate projection tools do not cater for this in the UK. This research has taken an innovative approach to including socio-economic and behavioural dimensions in a CIA, but given the size of the study in terms of number of companies involved, the results may only be considered indicative. Certainly, further survey work with the sector could confirm the representativeness of the results and also help to explore further the underlying drivers of the road freight sector's responses to climate change.

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