Climate Change and Road Freight Safety: Impacts and Opportunities

By

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Abstract

This thesis aims to apply recent conceptual frameworks for climate change impact assessment to the road freight sector of Great Britain in order to identify potential future safety issues. The freight sector is a key component of Great Britain's economy, and one which is particularly vulnerable to the effects of adverse weather. An assessment of the current patterns in weather related freight accidents is produced, and existing studies on accident causation are elaborated upon to arrive at relationships between key meteorological parameters and freight accident rates. These relationships are extrapolated onto various climate scenarios under low, medium and high emissions for the 2020s, 2050s and 2080s using UKICP09 climate tools to arrive at projections of possible impacts at a regional scale. This thesis also addresses a key criticism of the previous climate change impact assessment literature; that studies usually neglect the consideration of what the network will look like in the future, how it will be used, and how this will impact upon its vulnerability to meteorology. The way in which the network is designed, the resilience of the vehicles that operate on it and the split of usage between the various modes will all affect the impacts that are likely to be seen, and are all determined by the broader socio-economic pathway of the country. Delphi techniques are used for short term forecasts of growth and to identify emerging issues with the industry. UKCIP data is used to extend these projections to 2050. By combining social and physical techniques, a more holistic picture of future impacts is found. 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 for winter precipitation events.

Keywords: climate change, climate change impact assessment, socio-economic scenarios, road freight, transport

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List of Acronyms

CDF – Cumulative distribution function

CIA – Climate change impact assessment

DJF – December, January, February

GCM – General circulation model

GDP – Gross domestic product

GHG – Greenhouse gas

GVA – Gross value added

HGV – Heavy goods vehicle

IPCC – Intergovernmental Panel on Climate Change

JJA – June, July, August

PDF – Probability distribution function

RCM – Regional climate model

UKCIP – United Kingdom Climate Impacts Programme

WG – Weather generator

Chapter 1 - Introduction

1.1. Introduction

"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" (UK Climate Impacts Programme, 2001, p. 3)

The failure of humankind to recognise, accept and respond to the effects of anthropogenic emissions of greenhouse gases (GHGs), including its hesitance to properly value and price the utility provided by atmosphere, has led to a global environmental crisis without precedent. Climate change during the course of the 21st Century is now unequivocal (IPCC, 2007a) and has become arguably the dominant issue of our time. Potentially all natural and human systems are at risk of being affected by the changes brought about by a new climatic regime (IPCC, 2007b). The primary focus of climate change policies over the last two decades has been the mitigation of impacts through targeted actions on the amount of CO_2 emitted into the atmosphere. Through international agreements, most notably the Kyoto Protocol (Nordhaus, 2001), and the resulting carbon trading schemes such as the European Union's Emission Trading Scheme (EU ETS) (Bohringer et al, 2009), governments have sought to slow and eventually cap future global increases in GHG emissions. The influential Stern Review (Stern, 2007) argues that although anthropogenic climate change is a result of 'the greatest market failure the world has ever seen', early action to correct these failures will outweigh the costs of behavioural and technological change. However, despite these actions, some degree of climate change is now unavoidable regardless of future emissions (IPCC, 2007a). As a result, adaptation has become an essential pillar of climate change policy, as a means of both capitalising on any benefits brought about by climate change, and minimising the expected negative impacts.

This need for adaptation has led to a requirement for a formalised impact assessment method. As early as 1994, the IPCC (Carter, 1994) identified the assessment of the potential impacts of climate change as a fundamental step in both highlighting the likely costs of inaction on mitigation policies, and providing a guide of what to adapt for and how. Although initially focussing on highly climate-sensitive sectors such as agriculture and energy, the assessment process is now being applied to more complex sectors, whose sensitivity is a product of daily fluctuations in meteorology and extreme events as well as the more general overlying climate. New theoretical frameworks such as those postulated by Füssel & Klein (2006), which include considerations of socio-economic change, are now providing the potential to gain a greater understanding of the impacts to complex sectors such as transport. It is this sector that this thesis is concerned with.

1.2. Weather and transport

Despite the importance of the transport sector as a key driver and enabler of the economy (Eddington, 2006), little research has been conducted either in Britain or globally into how vulnerable it will be to climate change. This is surprising, as comparative studies from several countries have shown that the lack of efficient and reliable transportation can severely impact on economic growth (Crafts and Leunig, 2005). As a sector, transport is almost continuously subjected to meteorological hazards which impact upon the efficiency and safety of its operations (Thornes, 1992) and cause injuries and fatalities across all modes (Edwards, 1998). The impacts of rain (Changnon, 1996; Andrey et al, 2003), wind (Baker, 1993), high temperatures (Chapman et al, 2006; Dobney et al, 2009), ice (Chapman & Thornes, 2006), and snow (Eisenberg, 2004; Thornes, 2005) are well documented, affecting road, rail and water transportation. A notable recent example of how weather can impact on transport and how this feeds into the UK economy were the events of 'Windy Thursday' on the 18th of January 2007. This event resulted in almost 50 goods vehicles overturned and was estimated to have caused £50 million in delay costs across the UK (Highways Agency, 2007).

Importantly, the current century will see a shift in how severely each of these hazards will impact upon the transport network. The Department for Transport identified road transportation's vulnerability to future climate change as early as 1991 (Department for Transport, 1991). Although climate change is likely to result in a decrease in certain hazardous events such as snow and ice, others, most notably high temperatures and heavy rain events, will occur with increased frequency (Murphy et al 2009; Jones et al 2009). As a result major climate change organisations such as the United Kingdom Climate Change Impacts Programme (UKCIP) and the Intergovernmental Panel on Climate Change (IPCC) have identified the growing need to take into account the changing climate when designing new, or adapting existing, transport infrastructure (IPCC, 2007b; Walsh et al, 2007).

Preliminary studies have highlighted the range of impacts that predicted climate change will have on all modes of transportation (e.g. Peterson et al, 2008; Koetse and Rieveld, 2009). These include direct impacts on vehicles (e.g. heavy rain reducing tyre friction or increased winds overturning heavy goods vehicles), the likely impacts to hard infrastructure (e.g. rail cuttings which may subside) as well as indirect changes to the operations and spatial distribution of transport due to shifts in global trade brought about by the impact of climate change on other sectors such as agriculture. However, there are also potential benefits including the reduction of cold weather hazards such as ice and snow, all of which must be considered when ensuring a resilient future transport network, emphasising the need for a formal assessment.

1.3. Road freight transportation

Together with the parallel work of Dobney, Chapman, Baker and Quinn on Britain's rail network (Dobney et al, 2009 and 2010) and the recently established ARCC FUTURENET project (Future Resilient Transport Networks), this thesis contributes to a clearer picture of the potential impact of climate change on the UK transport sector. It is concerned particularly with the impact on the road network, and more specifically the potential climatic impacts on the safety of road freight transportation. In 2007 and 2008, UK road freight moved 161 and 152 billion tonne kilometres respectively, by far the greatest proportion of inland freight (Department for Transport, 2009). This emphasises the critical importance of road transport to the UK's economy.

The mixed ownership of vehicles using the roads, being both private and public, means that unlike rail, ports and airports, the road network is rarely closed, with the result being that vehicles often operate in hazardous conditions (Thornes, 1992). As will become clear, this is a particularly important issue for freight transport, and especially for small companies where the decision to travel in hazardous conditions is often informed and carried out by the driver, with associated monetary considerations not usually faced by other road users (McKinnon 2006). It has been estimated that the losses associated with road accidents on the economy are around 2.5% of the Gross National Product (GDP) (Elvik, 2000). Although these accidents are caused by a multitude of factors including driver error and dangerous driving, the influence of weather on accidents and disruption is a major contributing factor, with over 20% of accidents having been associated with the effects of meteorology (Edwards, 1999).

Despite this highly visible relationship between weather and transport, the potential impact of significant alterations in the frequency, intensity and seasonality of meteorological hazards has yet to be formally assessed in a holistic manner. This is a significant oversight, given the economic benefits provided by an efficient national transport network (Eddington, 2006) and the costs associated with disruption (McKinnon, 2006). However, in certain atmospheric conditions road freight transport can be considered the weak link in the multimodal supply chain. Other modes of transport may need to cope with extreme differences in climate. For example, the international nature of aircraft and shipping require them to depart and arrive in vastly different and often harsh climates, allowing them to cope with what would be considered extreme events in Britain (Thornes, 1992). Road freight's vulnerability to severe weather, and the financial disincentives for avoiding exposure, creates an environment where weather-related accidents are numerous and often fatal. From a safety and economic viewpoint, identification of the potential future impacts of climate change on the road freight sector, both negative and beneficial (a point which is often neglected - Ausubel, 1991), is an essential procedure for the future planning of transport companies and road authorities. This thesis uses the latest assessment frameworks and tools in order to achieve this.

1.4. Climate change impact assessment: the existing paradigm

A standard climate change impact assessment (CIA) of the road freight transport sector would first determine the relationships between the intensity of a given meteorological parameter and the observed disruption and accident rates. This can be achieved through empirical statistical models or process-based models (Tol, 1998). In many cases such as high winds or cold temperatures this would also involve the identification of key thresholds where problems manifest. These relationships are then extrapolated onto future climates, as has been the format with studies on other sectors such as agriculture, water resources and energy. Previous research in the transport sector generally utilises this ‘dose-response’ and extrapolation process. In their review of empirical findings on the impacts of climate change on transport, Koetse and Rieveld (2009) report several such studies which follow this approach.

A start has been made on forecasting the impact of climate change on transport in the UK with projects such as BIONICS (Biological and Engineering Impacts of Climate Change on Slopes, http://www.ncl.ac.uk/bionics/) carried out under the SKCC (Sustaining Knowledge for a Changing Climate, http://www.k4cc.org) project, which focussed on the impacts on trackside embankment stability. UKCIP has also been involved in a project to assess changes to summer road maintenance caused by increased temperatures (Hudson, 2004). These are examples of projects which provide base projections for climate change impacts, with both being focussed on existing hard infrastructure where the consideration of socio-economic change is not essential.

The wealth of existing studies on the effects of meteorology on transport suggests that this base understanding of climate change impacts could also achieved in a similar way for road freight safety. For example, studies could use existing relationships between rain, snow or wind and transport accidents, inputting new values of weather from climate tools such as the UKCIP climatic scenarios (Murphy et al, 2009). This would give an indication of how the freight network in its current state may react to this new operating environment.

However, what this approach cannot tell us is what the freight industry will look like in the future and how this will affect the impacts of climate change. For example, it cannot tell us whether vehicle braking technology will improve, whether better forecasts will inform drivers of hazardous conditions or whether roads will be designed and maintained in such a way as to reduce the influence of meteorology. Neither can it tell us whether the emission scenarios that promote the most extreme climate predictions will also be those which promote a much larger freight fleet, or whether a greener future would mean less vehicles operating in a climate where the worst impacts of climate change have been avoided. Theoretical studies can predict that empty or half loaded trailers are more sensitive to high winds, but cannot tell us whether in the future this problem will be overcome by advances in 'pallet systems' that intelligently route vehicles and promote efficient loading. These considerations lie at the cutting edge of climate-impacts research, and have advanced in their treatment during the course of this thesis, from a recommended yet often neglected component of CIA (UKCIP, 2007), to an essential step for both the identification of impacts and promotion of stakeholder involvement (e.g. Holman et al, 2008). The attempt of this thesis to address these issues moves it away from the earlier generation of CIAs towards a more robust consideration of impacts. However, it also presents a multitude of new problems which must be resolved.

1.5. Socio-economic change

To fully understand the impact of climate change a key question that needs to be answered is: *what will the transport network look like in 50-years time and how will it be used?* Climate change impacts are not simply a function of the magnitude and frequency of meteorological events, but also the vulnerability of the network they are impacting upon. This changing vulnerability has been seen during the past 50-years, with increases in population and commerce driving a large expansion of the transport network, increasing the number of vehicles exposed to meteorological hazards and shifting this exposure between the different modes of transportation. Concurrently there have also been increases in the economic costs involved with each disruptive event. For example, the move towards low-inventory 'just-in-time' delivery (Wu and Olson, 2008) in the logistics sector has increased the risk of loses to the economy during disruptive periods. The continuous replenishment necessitated by this logistical approach has lead to an increased frequency of deliveries. The short shelf-lives of the products carried on these trips may also increase the pressure on carriers to travel during hazardous weather. These factors have, however, been offset to some extent by a reduced sensitivity of the vehicles themselves to hazardous weather with innovations such as anti-lock braking systems (ABS) for road transport (Broughton and Baughan, 2002). These types of considerations must be taken into account in a meaningful climate change impact assessment on the transport sector. It is also clear that an understanding of the underlying reasons for changes in the sector must be attained along with an idea of how these may drive development in the future.

In so doing, we must move yet further away from the fields of climatology and meteorology towards that of futurology, and embrace a truly multidisciplinary approach. In some senses this crossing of disciplines is not new within the climate community. Future socio-economic scenarios postulating the way regions and nations may look and act in the future have often been used in climate change models in order to imagine a range of potential future society types and predict the extent to which each one will emit GHGs, thus providing 'emission scenarios' such as those formulated by the IPCC (IPCC, 1998). These 'futures' are often highly descriptive, detailing how a society may develop and how certain sectors may be favoured due to the underlying political and social values which drive the scenario. More recently, these tools have been co-opted by the climate impacts community to provide a realistic range of future scenarios of how vulnerable future societies may be to climate change (for example, the BESEECH scenarios; UKCIP, 2006). This thesis uses these tools to account for future changes in the nature of freight transport. As transport accounts for over a quarter of global CO_2 emissions (IEA, 2000), its inclusion in these scenarios is already relatively strong. However, to arrive at a more useful set of futures, it is important to elaborate on these basic scenarios to include a greater level of detail on the potential future nature(s) of Britain's freight sector. This cannot be done by one researcher in isolation, and requires the tacit knowledge of industry experts to interpret what type of freight sector will emerge from a given socio-economic scenario. How to elicit this knowledge is a major methodological challenge developed empirically in this thesis.

As may be apparent, the range of techniques used in this thesis is relatively broad, and the existing frameworks within which they can interact are purposely mutable. Great effort has been made to arrive at a tailored methodological framework that could satisfy the requirements of a holistic assessment. As a result, this thesis can also be read as an exploration of the concept of CIA, a critique of its current utilisation and the trials of applying its framework to a complex and dynamic sector. It is also the reason why this thesis commences with a detailed examination of CIA, its structure and requirements, and the way in which it shapes the nature and focus of this project.

1.6. Objectives

The objectives of this thesis were to:

- Review the existing paradigm of CIA, the criticism of its current implementation, and the requirement for an understanding of a sector's relationship with its climatic and socio-economic environment;
- Study in detail existing knowledge of the relationships between meteorology and road freight accidents;
- Examine the way in which the current nature of the road freight network determines the sensitivity and exposure of the freight fleet to meteorological hazards, and the socio-economic drivers which may change it in the future;
- Develop a methodological framework in which both climatic and socio-economic change can be integrated to determine a range of impact-scenarios for the road freight sector;
- Determine a set of empirical relationships between observed meteorology and road freight accidents;
- Extrapolate the current relationships between meteorology and accidents onto a number of future climates;
- Create a set of expert-defined scenarios for the future of the freight sector, and;
- Integrate the future climatic and socio-economic scenarios into a holistic impact assessment.

1.7. Thesis Structure

It was deemed essential to begin this thesis with a discussion of the CIA framework, as a means of explaining how the demands of its interdisciplinary framework shaped the approach taken in this project. Chapter 2 presents this discussion in the form of a history of the development of CIA, with the requirements for background knowledge of the sector determined.

Chapter 3 deals with the requirement to understand the current relationship between adverse meteorological events and road freight accidents. Literature from the field of transport meteorology is reviewed to determine how different weather types impact on the sector, and how these meteorological hazards may alter in both frequency and intensity due to climate change. Chapter 4 expands this background by discussing how the industry may change in the future, and how these changes may either reduce or make worse the sector's current vulnerability to meteorology discussed in Chapter 2.

Chapters 5 and 6 discuss the two components of the methodology used in this thesis. Chapter 5 first presents a broad overview of the methodological framework, and the interactions between the various components therein. It then discusses the formulation of the methodology used to determine relationships between meteorology and recorded road freight accidents. It is explained how these were mapped onto future climates using the UKCP09 climate projections and weather generator tools. Chapter 6 discusses how interviews, the expert Delphi technique and existing socio-economic scenarios were used to determine a set of possible futures for Britain's road freight sector.

Chapters 7 and 8 present the results of the physical assessment of climate change. Chapter 7 details the relationships determined between meteorology and road freight accidents, presenting them in the form of predictive equations. Chapter 8 displays the results of climate extrapolation as regional maps of the Great Britain, highlighting how different areas may be subject to varying degrees of impact. In the case of road icing, the institutional impact climate change may have on the road salting industry is discussed. It must be noted that although climate projections are given for the UK (e.g. Murphy et al, 2009), Great Britain is used for the analysis in this thesis due to the lack of accident records in Northern Ireland.

Chapter 9 presents a set of future scenarios for the freight sector of Great Britain, and discusses how each one may differ from that of today in respect to its vulnerability to meteorological hazards. It also highlights how climate change, safety, and the hazard of meteorology are viewed within the industry. Finally, chapter 10 presents the integrated assessment, determining those futures in which a combination of high emissions and a vulnerable road freight sector may lead to either the requirement for adaptation or the promotion of a precautionary principle within today's road freight industry towards climate change. This chapter also discusses the limitations of the approach taken and concludes with a discussion on what this project says about the concept of CIA.

Chapter 2: The Climate Change Impact Assessment and Socio-Economic Scenarios

2.1. Introduction

This chapter presents an examination of the principles, conceptual frameworks, methodologies and tools available for the assessment of potential climate change impacts, and importantly, the approaches to resolving the issue of concurrent climatic and socio-economic changes. The concept of forecasting the likely effects of climatic change has developed alongside the science of climate prediction. Unfortunately, the incorporation of non-climatic factors has, until recently, been treated simplistically and is often entirely absent. Although originating as a somewhat simplistic 'dose-response' tool primarily for physical assessments, climate change impact assessment (referred to in the literature as CIA) has developed into an integrated methodology, incorporating such concepts as adaptive capacity, vulnerability and, most importantly for this study, sensitivity and exposure (Füssel and Klein, 2006).

CIA can be conducted on global, international, national, regional and sub-regional scales. As will become apparent, although the theory behind the process of CIA existed at the outset of this project, it is only recently that these principles have been widely adopted by the research community in the form in which they were intended (for example; Dawson et al, 2009). This chapter examines the principles of CIA and how these have been achieved in practice, with a special focus on the use of futurology within these frameworks to account for the impact of socio-economic development. In the absence of relevant practical examples of CIA for transportation, reference is made to analogous studies from other sectors whose techniques will be applicable to this study. The development of the ideas discussed in this chapter into a project framework is detailed in Chapters 5 and 6.

2.2. The flaws of a purely physical approach

The assessment of potential climate change impacts has been a major point of discussion and argument in the climate change community since its necessity first became apparent in the early 1990's. The IPCC (2001b, p. 989) defines CIA as *"the practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems"*. This has an obvious relationship with the adaptation process, defined by the IPCC (2001b, p. 982) as *"the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities"*, in that CIA provides a framework within which the magnitude of these effects can be formally assessed. However, despite the involvement of national and international organisations, such as the Intergovernmental Panel on Climate Change (IPCC; UNEP, 1998) and the United Kingdom Climate Impacts Programme (UKCIP, 2001) in attempts to provide guiding principles, it is still very much open to debate as to how this process should be conducted.

In the form that it appears in many studies, CIA may seem a fairly straightforward continuation of established methodologies in the study of applied climatology and meteorology. Although often complex, it is possible to determine both statistical and process-based relationships between climate and almost any sector or system, be it natural, physical or social. Studies have demonstrated the ability to link climate with human health (e.g. McGeehin and Mirabelli, 2001), water resources (Sharma, 2000), agriculture (Hammer, 1996), and energy (Taylor and Buizza, 2003) to arrive at predictive models. Many of these relationships are successfully used in commercial predictive models incorporating either short range meteorological forecasts or longer-term seasonal forecasts to predict outcomes as diverse as the likely demand of certain foods on a given week through to whether roads will need to be salted on a given night (for example; Chapman and Thornes, 2006).

Logically, predictive models are essential for assessments of the future impacts of climate change, and have appeared in a multitude of studies. Berkhout et al (2002) highlighted examples of such research across a range of sectors, including Arnell (1998) and Stakhiv (1998) on water resources, Harrison et al (1995) on European agriculture, and Bentham and Langford (1995) on the impact of climate change on food poisoning in the UK. The critique Berkhout et al (2002) level at these studies is fundamental and quite common within the climate impacts community; <u>they do not account for the changes that will occur in the sector or how these developments will impact upon the sector's vulnerability to climate change</u>. In essence these studies simply extrapolate an existing climate-sector relationship onto a future climate without considering the socio-economic drivers that would affect the two key factors determining vulnerability; sensitivity and exposure. The consequences of this are unrealistic and misleading impact projections which are of questionable use to stakeholders in critical decision-making (Dessai, 2005). The absence of non-climatic considerations in CIA has been a serious flaw throughout its history, and has been identified as such by all major climate organisations (for example; Hughes et al, 2009).

2.3. Vulnerability, sensitivity and exposure

Although many definitions of sensitivity and exposure exist, the most authoritative come from the IPCC (2001b, p. 987, 993); sensitivity being *"the degree to which a system is affected, either adversely or beneficially, by a climate-related stimuli",* exposure being "*the nature and degree to which a system is exposed to significant climatic variations"*. These two concepts will play an important role in determining the eventual impact of climate change on any given sector or system, and are largely driven by socio-economic development.

For instance, the examples from Berkhout et al (2002) can all be shown to be subject to changes in their vulnerability to climate change through plausible developments in each sector that will occur between now and when climate change takes effect. For example, the impacts of climate change on water resources (Arnell, 1998; Stakhiv, 1998) will be influenced by the management of infrastructure, potential creation of new reservoirs and greater demand on resources from an increased population. Impacts on agriculture depend on a multitude of factors including the number of farms which have planted a specific crop and whether those farms are dependent on that cultivar, which will be influenced by how the country partitions subsidies and the access the farms have to new technologies (UKCIP, 2001). Finally, food poisoning may be influenced by food production technologies to delay or prevent spoilage, which will affect the sensitivity to climate change, and amount of that food produced and consumed in the future, which will determine the number of people exposed.

As discussed in Chapter 1, exposure for the freight and logistics sector will be determined by the number of vehicles on the road, the nature of their operations and their operating area (for example, an increase in the volume of high-sided freight vehicles utilising routes with exposed sections of road vulnerable to cross winds). Sensitivity will be determined by how the vehicles themselves react to meteorological events. Again, this is influenced by a multitude of factors, including safety technology (Broughton and Baughan, 2002), whether the vehicle is towing an empty trailer, the physical dimensions of the vehicle (Baker, 1993) and the ability of the driver to cope with adverse conditions (Elvik, 2006). A full discussion on the current and future sensitivity of the UK's road freight sector is given in Chapter 4.

The key question in developing visions of the future for any given sector is what drives these changes, and what would be the outcome if, owing to the influence of the broader socio-economic environment, these drivers followed a given trajectory in the future? As UKCIP (2001) noted, CIA ideally integrates both the physical impacts climate change will impose on a sensitive sector and the impact of socio-economic development on this sensitivity. Naturally, the frameworks within which an assessment takes place become increasingly complex. It is therefore necessary to have a clear understanding of the fundamental conceptual framework of an idealised climate change impact assessment. The United Nations Environment Programme's (UNEP) Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (1998) provides an effective base model of the components that constitute an idealised assessment, incorporating both climatic and socio-economic considerations.

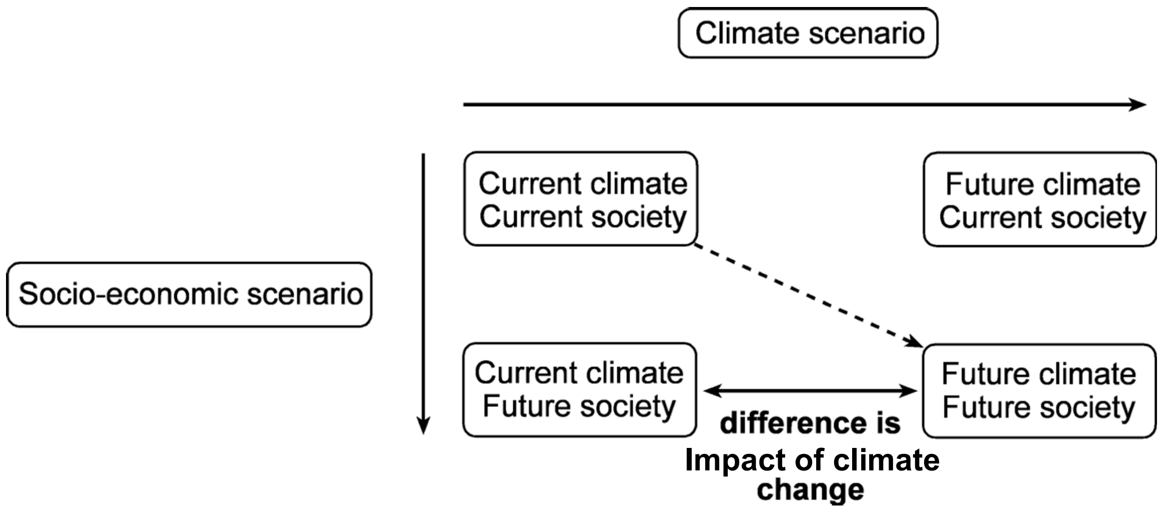


Figure 2.1. Climate change and socio-economic scenarios (Tol, 1998)

The concept of concurrent climatic and socio-economic change is displayed intuitively by Tol (1998) within the UNEP framework in Figure 2.1. The upper left section of the schematic represents the present-day situation, and as previously mentioned, many studies have been conducted to assess the relationship between the current climate and the transportation network in its present form. The upper right section represents studies where climate is perturbed, but society remains unchanged i.e. non-climatic factors are not taken into consideration and the fundamental relationship between meteorology and transport is unchanged. The lower left represents a theoretical state where climate remains as today but society changes, hence transportation develops, becoming either more or less vulnerable to the effects of meteorological events. Studies in this area would isolate the impact of socio-economic change. Finally, the bottom right section represents the 'complete' assessment, where both scenarios are incorporated. Thinking about socio-economic and climatic change in this way is helpful in designing an integrated assessment, but it must also be noted that the simplification hides important complexities and feedbacks. Climate and society are co-evolving systems and will not develop in isolation (Lorenzoni et al, 2000a; 2000b), providing considerable obstacles to the scope of impact assessments.

This basic framework provides a space within which a number of important questions can be asked. In a typical CIA these might include;

- How can relationships between the climate and a given sector be determined?
- How will these relationships alter as the sector or system develops in the future as society changes?
- How should non-climatic factors which affect a sector or system's vulnerability be handled by the assessment, if indeed they are included at all?
- How do we obtain baseline figures on the non-climatic factors which currently impact on a sector?
- What drives these changes to the sector, and which will become most important in the future?
- What year does the impact assessment extend to, and do the technical specifications of the climate or socio-economic scenarios put a limit on this range?
- How do we ensure that the impacts predicted by this study are in a format compatible with an integrated assessment of the wider economy?
- How are stakeholders and industry experts involved in the process?
- What requirements do the stakeholders put on the assessment?

It is therefore clear that a more sophisticated framework must be developed from the basic approach outlined by Tol (1998). The natural starting point with any CIA pertains to the first question listed above; how can relationships between climate and a given sector be determined, or as Tol has termed it, what would be the impact of climate change on society as it is today?

On closer inspection, most of the examples cited in Berkhout et al's (2002) study, and many of those cited by the major climate organisations as examples of simple climate assessments are in fact studies of highly climate dependent sectors (e.g. water resources and agriculture). Under these circumstances the observation that, initially at least, socio-economic and climate systems were viewed as separable for the purposes of CIA seems to some extent justified. A physical-based assessment of the impacts of climate change on water resources has value as a stand-alone tool to be used with existing forecasts for the exogenous strains which may be placed upon it by a future society, it being simply the first stage of a wider assessment (even if the other stages have not been completed). This stand-alone component is best explained via Figure 2.2 (Füssel and Klein, 2006), where the only non-climate influence comes from the mitigation policies which drive the emission scenarios (which in turn determines the extent of climate change). Sensitivity and exposure are treated as constants in this framework, and within an assessment would not be informed by potential socio-economic change.

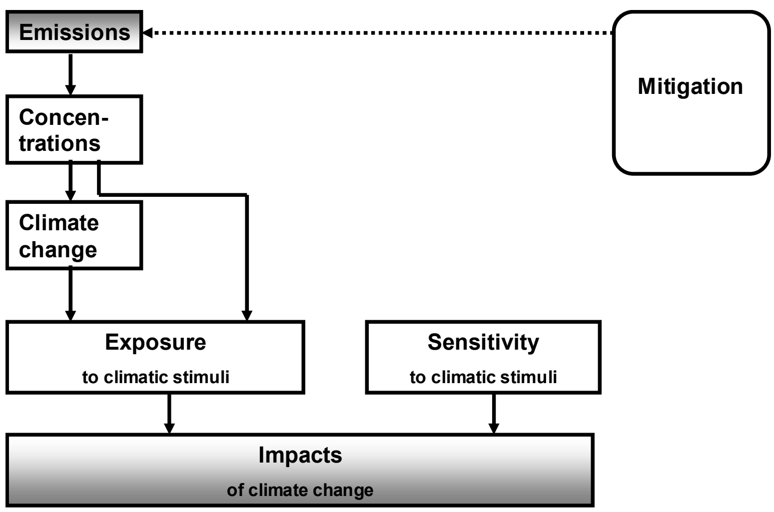


Figure 2.2. Climate change impact assessment framework (Füssel and Klein, 2006)

This initial component is essential and forms the base of all CIAs. Discussion on the specific application of these methods within transport meteorology is provided both in the following chapter and the physical assessment methodology chapter (Chapter 5), but it is important to briefly examine the underlying principles developed in the CIA literature. Among the methods put to use for these purposes are quantitative and predictive models, empirical studies, expert judgment and experimentation, with an emphasis put on those methods that provide quantification, allowing integration into other models and further methods such as sensitivity testing (in the statistical sense) to be carried out (Cohen and Tol, 1998).

These quantitative methods can be broadly split into three types; biophysical, socio-economic, and integrated system models (Cohen and Tol, 1998). The majority of the studies that are discussed in Chapter 3 and can be described as biophysical models, in that they seek to relate the behaviour of a system or sector to a natural stressor, in this case climate. In the simplest terms they are cause and effect models, where a given unit of climate produces an impact on a given exposure unit of a system. Another term for this, and the one used in this thesis, is 'dose-response' modelling.

Hence, there is a requirement to examine the existing relationships between road freight transportation and accidents. The relationships examined in Chapter 3 are largely empirical statistical models based on a quantitative relationship between the climate or meteorological stressor and the result this has on the sector or system (e.g. Eisenberg, 2005). Their effectiveness is contingent on the assumption that the relationship between the climate and the system remains the same. When dealing with the freight sector it is clear that this is a major weakness of this approach, due to the multitude of improvements in the safety technology of goods vehicles that have been introduced during the past two decades (e.g.

DfT, 2004). Another important point to make is that even though the models may produce results which seem very precise, this should not be confused with being correct or accurate, given the assumptions and simplifications involved in their production (UNEP, 1998). There is significant uncertainty involved in any predictive model, especially those dealing with the time frames involved with climate change.

Process-based models require a greater level of understanding of how the system works, the physical laws that govern these relationships, and first principles (Tol, 1998). This type of model is essential for studying the impact of climate change on sectors such as water resources, where models can be built which will accurately model the effect that climate change will have on the water levels in reservoirs. These types of problems are concerned with the impact of seasonal climate over large areas. The problem with applying this methodology to any type of transportation study, especially one concerned with accidents, is that it is impossible to say where an individual incident will occur or what the exact meteorological conditions will be at the time, making it impossible to feed such data into complicated models of, for example, vehicle stability in high winds or tyre friction on slippery road conditions.

Although Koetse and Rieveld (2009) present a range of research findings on the impact of climate change on transport, the most notable observation that can be made from a climate impacts perspective is that the nature of the future transport network and how it will be used is not taken into consideration. This is where assessments usually end, and this criticism is mentioned throughout the literature. The remainder of this chapter discusses how the future development of the system being studied has been taken into consideration, both theoretically through idealised methodological frameworks and how these frameworks have been adapted into actual studies.

2.4. Future studies in climate change impact assessment frameworks

"Systems that aim at evaluating impacts of climatic change on large spatial and temporal scales cannot be based on the assumption that infrastructure, economy, demography and other human factors remain constant while physical boundary conditions change" Barthel et al (2008, p.1095)

The evolution in the scope of climate assessment techniques has been determined largely by the shifting requirements of stakeholders and governments for more advanced and integrated forecasts. During the 1990s, the main focus of government policy in most Western countries broadened from purely mitigating actions, to include the idea of 'living with environmental change', based around adaptation (Stehr and Storch, 2005). Several researchers have attempted to trace the history of climate assessments and their conceptual frameworks, such as McCarthy et al (2001) and Rothman and Robinson (1997), both of whom comment on the lack of integration of climatic and socio-economic change in most previous assessments. Rothman and Robinson placed great emphasis on the idea of multiple baselines to deal with the activities that exert pressure on the human and environmental systems being considered. Rothman and Robinson's approach can be seen in Figure 4.3, which demonstrates an iterative technique with feedback between physical and human systems.

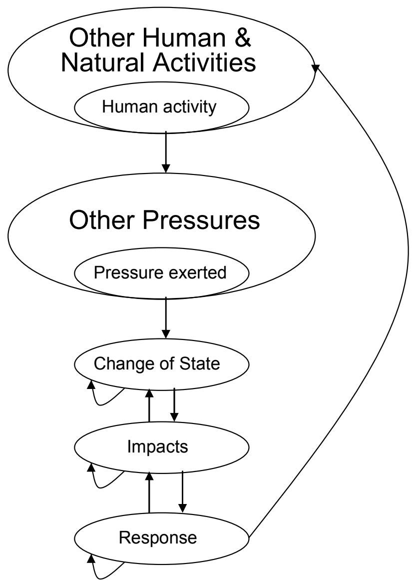


Figure 2.3. An early conceptual framework of climate change impact assessment (Rothman and Robinson, 1997)

One of the most authoritative assessments of the trends in climate assessment methodologies (Füssel and Klein, 2006) is used in this thesis as a guide to developing an appropriate methodology, giving more detail than the basic conceptual framework already outlined by Tol (1998) in Figure 2.1. The recent requirements for in-depth socio-economic considerations, as well as other factors including sensitivity, vulnerability and adaptive capacity are shown to be the most important of new additions to the CIA framework. The current trends identified by Füssel and Klein (2006) include:

- The growing importance of changes in climate extremes as the major determinant of future impacts and vulnerability.
- Increased incorporation of non-climatic influences on sensitivity and vulnerability.
- Increased consideration of adaptation strategies and capacities.
- A strong trend towards interdisciplinary analysis of the potential consequences of climate change.

The first point is directly relevant to this study, as Chapter 3 identifies changes in climate extremes as a key determinant of future impacts for the road freight sector. Many of the other trends can be verified in the UK with EPSRC projects such as BESEECH (Building Economic and Social Information for Examining the Effects of Climate Change), BKCC (Building Knowledge for a Changing Climate), SKCC (Sustaining Knowledge for a Changing Climate) and more recently ARCC (Adaptation and Resilience for a Changing Climate). Each of these projects is operating at the cutting edge of the discipline according to the trends given above, supplying the requisite socio-economic tools for future sensitivity analysis.

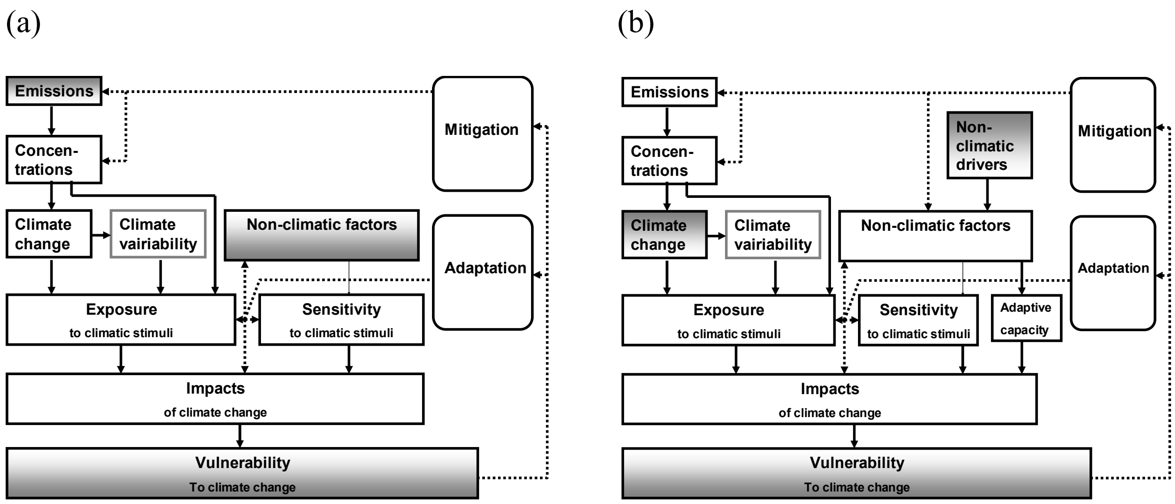


Figure 2.4. Conceptual framework for 1st (a) and 2nd (b) generation vulnerability assessments (Füssel and Klein, 2006)

According to Füssel and Klein's (2006) hierarchy, assessments considering socio-economic drivers are better described as "vulnerability assessments" (Figure 2.4). Vulnerability refers to the potential impacts caused by changes in exposure and sensitivity, but also introduces the concept of adaptive capacity. The most important point to note from these conceptual frameworks compared to Füssel and Klein's most simplistic models is the addition of two new inputs. The 1st generation vulnerability assessment (Figure 2.4a) adds 'non-climatic factors' as an input to both exposure and sensitivity whereas the 2nd generation vulnerability assessment (Figure 2.4b) adds 'non-climatic drivers' i.e. a consideration of how the non-climatic factors may develop.

The consideration of exposure and sensitivity has become a fundamental component within the idealised CIA framework. The climate change research community has appropriated several techniques from the future studies literature to arrive at a general framework for forecasting these key variables, including modelling, expert opinion, normative scenarios, and non-climate generic socio-economic scenarios. Modelling is still used in futurology for CIA, as a select group of factors can be modelled with some degree of certainty, such as population (e.g. United Nations, 2008). Many of the population and demographic trends are already set in place for the first half of this century. This means that it is already possible to theorise what impact this change in population and its structure will have on the economy and society. It is even possible to estimate what the impact of altered demographics might be on the demand for freight transport in the future, which is examined in Chapter 4.

In their review of future studies techniques for CIA, Hertin et al (1999) state that major transformations in technology and the arrangements of markets (globalisation, liberalisation) have made companies more vulnerable to sudden, exogenous shocks in their operating environments. It is suggested that possible impacts of climate change has been one of the major factors precipitating the interest in *scenarios* as a tool for examining possible socio-economic futures during the past two decades, and has led them to become considered an essential component of CIA.

2.5. Scenarios

"Socio-economic scenarios describe future evolutions of fundamental societal characteristics, based upon trends of past social and economic changes and visions of future developments" (Lorenzoni, 2009, p. 386)

The IPCC (2001b, p. 881) describes a scenario as *"a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships. Scenarios are neither predictions nor forecasts and sometimes may be based on a 'narrative storyline.' Scenarios may be derived from projections, but are often based on additional information from other sources".*

As will become apparent, it is impossible to predict exactly what will happen in the future, or in the case of this study, what the future nature of the UK's road freight sector will be. Modelling can only be extended for a limited set of variables (e.g. population, demographics) with any degree of certainty; the exact nature of future society can neither be predicted nor projected. However, it is possible to present a range of reasonably plausible scenarios that *may* happen. It is this concept of scenarios which is key to developing a useful climate change impact assessment. Depending on the dominant socio-economic drivers present over the coming century, the transport network of the future may be more or less vulnerable to the impacts of meteorological events. It will both drive the type of infrastructural projects which are commenced during this period (e.g. new motorways or high-speed rail) and influence the way in which they are used. By providing a range of scenarios it is possible for governments, organisations and companies to have a greater insight of the 'futures' into which their investments will be placed (Dessai and Hulme, 2007).

For instance, a scenario which promotes a large-scale increase in the number of freight vehicles on the roads will potentially increase the number of accidents during hazardous weather events. The number of vehicles on the road could be impacted by a multitude of factors including the future price of oil, whether alternative modes are affordable and reliable (such as rail in the case of freight transport: Berkeley, 2005), whether road transport is made less attractive or affordable by measures such as road pricing, green taxes or other soft measures (see Chapman, 2007 for a full review), and fundamentally by societal demand for freight transport. There will also be changes in the sensitivity of the vehicles to meteorological events as technology improves. All of these factors will be affected by the future governance of the country, driven by the overlying socio-economic scenario.

Another reason for the popularity of scenarios is that they account for the uncertainty in socio-economic pathways over several decades. The adoption of scenario-based approaches carries with it the following assumptions made by Berkout et al (2001);

1. *That the future cannot be described as a persistence of past trends and can be shaped by human choice and action.*
2. *The future cannot be foreseen, but exploring the future can inform the decisions of the present.*
3. *There is not only one possible future. Uncertainty and ignorance calls for a diverse set of futures (scenarios) mapping a 'possibility space'.*
4. *Developing scenarios involves both rational analysis and subjective judgement. It therefore requires interactive and participatory methods. Users of scenarios must participate in their generation and evaluation.*

Stemming from the IPCC emission scenarios (Nakicenovic and Swart, 2000), generic socio-economic scenario toolkits have been produced by the major climate organisations and these form a fundamental base for sensitivity and exposure assessments. Although all sets of scenarios differ, their construction follows a fairly standardised framework. Unlike normal trend extrapolation which would produce one outcome over a relatively short period (5-10 years), for scenarios to be useful over the time periods involved with climate change (50-80 years), a wide range of underlying drivers need to be considered.

The construction of scenarios for CIA generally commences with a consideration of the most important dimensions of change, in the cases of the UKCIP Socio-Economic Scenarios (2001), IPCC Special Report on Emission Scenarios (SRES) and the Foresight scenarios

(Nakicenovic and Swart, 2000), these are 'social and political values' and the 'nature of governance'. The future trajectories of these dimensions will influence all other important dimensions including economic growth, demographic change and technological change, although it must be noted that in reality the relationships between these dimensions are far more complex. Other scenarios (e.g. Environment Agency, 2003) use different dimensions, for instance, UK consumption patterns from 'dematerialised' consumption through to 'material'. A common way of exploring the interaction of two dimensions is through the use of axes (Figure 2.5), which present a range of contrasting scenarios within a 'reality space' along with an approximation of the 'business as usual' scenario - a proportional amalgam of scenarios termed as conventional development in this instance. This creates a wide range of possible futures for decision makers to explore.

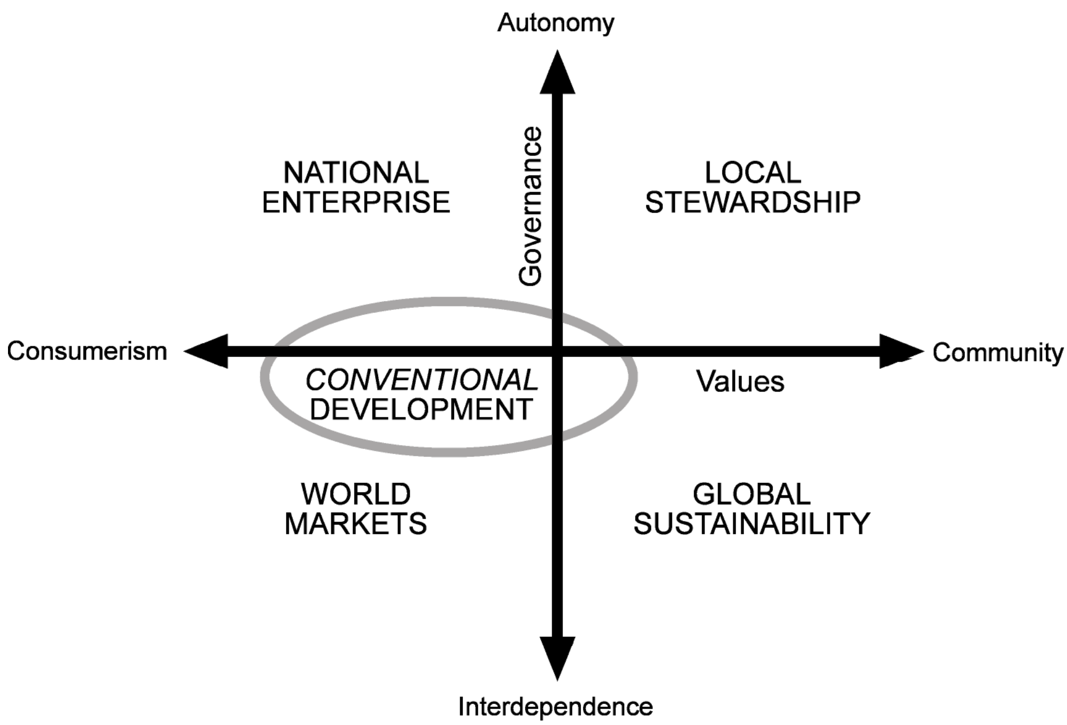


Figure 2.5. The UKCIP socio-economic scenarios (UKCIP, 2001)

As many impact scenario sets have evolved out of GHG emission scenarios (as mentioned in Chapter 1), each scenario has an associated range of future climate change. An interesting point is the interaction of resources, economic growth and climate change. Recent work by Nel and Cooper (2009), suggests that fossil fuel depletion may constrain the maximum extent of global warming. This may mean that some of the most dangerous combinations of socio-economic and climate scenarios are unlikely, although they cannot be discounted within the assessment framework. It has been argued that a closer integration of socio-economic and climate scenarios will more clearly describe the relationship between climatic and societal changes (Trumbo and Shanahan, 2000).

Both the 2001 UKCIP socio-economic and the subsequent BESEECH (Dahlström and Salmons 2005) scenarios provide a useful starting point for discussion of the possible outcomes as they retain sector-based storylines, allowing a useful discussion of the impact a future socio-economic environment may have on the road freight sector. For example the storylines arrived at from the UKCIP scenarios argues that under a 'World Markets' regime social and political values are centred around personal consumption and material well being, with the market seen as the best way to deliver these goals rather than the state. Under this scenario the development team of the UKCIP and the consulted sector experts argued that transport demand is likely to increase significantly. However, it is suggested that this increased traffic would be more efficiently managed, using new control systems and would run on better quality infrastructure.

Conversely, under a 'Global Sustainability' scenario social values are centred around community, with a strong emphasis on enhancing social equity and protecting the environment. Although the UKCIP research team argued that new roads, rail and airport infrastructure would be built, the nature of these will be determined by demands for sustainability. This scenario also sees the greatest increase in the cost of transport due to environmental considerations and mitigative pressure.

Further outcomes can be envisaged by considering those scenarios that tend towards a more autonomous economy. As shown in Figure 2.5, a move towards consumerism on the values axis and autonomy and on the governance axis produces a 'National Enterprise' scenario. This scenario sees a retreat from globalisation and the promotion of a more nationalised economy. Traditional industries are favoured, with low levels of investment in research and development. Environmental issues are generally given a low priority, resulting in a continued dependence on road transportation which would act to increase exposure. Low economic growth rate limits expenditure on infrastructure would likely act to increase sensitivity. These two negative influences along with high emissions resulting from an industrialised economy create the potential for significant increases in weather-related road freight accidents.

Many of the same influences are also present in the Local Stewardship scenario. A similar move away from globalisation and towards local production is predicted, yet the drivers of change differ. This is chiefly a product of the greater importance of environmental issues coupled with a trend towards community values. The twin aims of reduced emissions and decentralisation of economic activity are achieved through regional production, allowing products to be sourced and processed locally. More freight would also be expected to be carried by rail, again reducing exposure. This along with lower emissions should act to reduce weather-related accidents. However, this scenario suffers from a low level investment in research, development and infrastructure, which would result in a relatively high level of sensitivity.

The UNEP (1998) handbook recommends that sector-specific scenarios should utilise and modify existing scenarios so that a continuum of development can be maintained (Feenstra et al, 1998). The original UKCIP scenarios attempted to provide a comprehensive list of indicators for many sectors including transportation. These were reached by expert consensus and include indicators for modal shift at time intervals of 2025 and 2050. Dahlström and Salmons (2005) highlighted a critique of these indicators, based on comments by the BKCC (Building Knowledge for a Changing Climate) consortium regarding both the lack of rigour in their construction and the lack of clarity on the assumptions behind them.

This critique was part of the motivation for the BESEECH (Building Economic and Social information for Examining the Effects of Climate Change) socio-economic scenarios. These scenarios, along with other recent additions, dedicate more resources to the prediction of fewer key indicators at a greater temporal resolution using modelling approaches. These indicators include population, life expectancy, number of households, average household size, gross expenditure on technology research and development as a percentage of GDP and figures on the relative importance of individual sectors as a share of overall GVA (Gross Value Added). This more rigorous modelling approach provides greater power and reliability in decentralised scenario elaboration to the sectoral research teams tasked with constructing more detailed qualitative storylines and indicators. In this way the researchers with the best expertise to interpret the broad socio-economic environment will be able to assess its likely impact on the sector. However, it is important that these sector-specific indicators are constructed in a way that will allow them to serve as inputs into the wider integrated assessment across a wide range of sectors.

Dawson et al (2009) offer a useful example of these techniques in practice with their use of scenarios for coastal sensitivity to flooding and cliff erosion derived from the UKCIP toolkit. Here, climate change scenarios are linked with corresponding patterns of settlement along the cliff. For example, the socio-economic scenario predicted to cause the greatest level of climate change is also the one which has the largest growth in population and least controls over development along the cliffs. The result is a scenario with high levels of coastal erosion and increased economic and human exposure.

Despite the emphasis on qualitative storylines, much modelled data goes into driving the development of scenarios for climate change, and helps to anchor the scenarios in the realms of plausibility. Part of the reasoning for studying road freight as opposed to general road transportation is the stronger and more direct links between growth in the sector and aspects of the overlying economy. The literature in Chapter 4 (e.g. McKinnon, 2007; Tapio 2005) offers a wealth of available expertise to be utilised in this type of process, providing a suitable forecasting technique is used.

2.6. Stakeholder involvement

Achieving the goal of sensitivity and exposure scenarios for the freight sector requires an elaboration of the futures presented in the economy-wide generic scenarios produced by the major climate change organisations. It has been suggested that stakeholders can be important in defining the appropriate level of complexity required of the sensitivity analysis, and also helps the study to be grounded in the interests and knowledge of the users rather than that of the analysts (UKCIP, 2001). Stakeholder engagement in CIA is also a method of reducing scepticism of the science within that community (Norgaard and Baer, 2005). The involvement of stakeholders in climate change impact assessment has emerged as an important component in filling the gaps where modelling fails. This is particularly relevant for sector-specific scenario elaboration, where the tacit knowledge and experience of sector stakeholders can be utilised in predicting the outcome that a particular socio-economic scenario would have on a given sector, through expert opinion, focus groups or other collaborative methods such as the expert Delphi (UNEP, 1998). A detailed exploration of these methods is presented in Chapter 6.

One of the greatest difficulties with incorporating a participatory approach to CIA is the inherent difference between how far into the future an individual can visualise and the timescales where climate change becomes acutely noticeable. Lorenzoni et al (2000) argue that individuals more easily relate to timescales up to 20-years ahead, whilst modelling divergences in climate scenarios dependent on socio-economic futures become more distinguishable in 50-years time, due to the inertia of GHG emissions. There is also much discussion over the target anchor year used and how stakeholders react to this. Green et al (2002) report that unless experienced in such techniques, participants often initially regard the timescales involved as considerably long. It is also not fair to say that past experiences can always be used as a good yardstick for predicting future change, due to the quickening pace of societal change during the past 50-years (Green et al, 2002).

An interesting question associated with CIA is who or what constitutes a stakeholder? Unlike the use of the term in other disciplines, it involves timescales where potentially no obvious impact will be seen by the individuals currently involved in vulnerable industries. The IPCC (2007, p. 881) defines stakeholders as *'a person or an organization that has a legitimate* *interest in a project or entity, or would be affected by a particular action or policy'*, drawing the distinction between those who would be interested in the findings and those that would be impacted. However, as the impacts to individuals are so distant in the future, it may be questionable as to what *stake* they have in its outcome and what role (indeed right) they have in identifying the 'futures' of future generations. People are naturally biased, tending to consider the risks and potential impacts of climate change as greater than the potential benefits, while concurrently believing that the impacts to society as a whole will be greater than those to them as an individual (Poortinga and Pidgeon, 2003). As Lorenzoni and Hulme (2009, p. 385) observe *"climate change is perceived by most people as distant in both space and time, affecting more vulnerable people and places elsewhere, or future generations"*. Climate change is typically ranked below other personal and social issues such as health, family, safety and finance (Poortinga and Pidgeon, 2003), precisely because it has less personal immediacy, and therefore presents considerable barriers to the successful engagement of stakeholders within a participatory framework.

2.7. Conclusion

This chapter has emphasised the need to utilise an interdisciplinary approach to CIA taking into account both climate and socio-economic scenarios. To-date, the majority of climate change studies relating to transport have looked at the effect of a changing climate in terms of hard infrastructure (i.e. 'dose-response'). In reality, this represents only the first stage of a CIA as it solely uses probabilistic climate scenarios (e.g. UKCIP, 2001) and assumes the status-quo in terms of socio-economic development. The transport network 50-years ahead could be virtually unrecognisable to that of today, given the rate of change during the past 50 years.

While assuming the status quo is the only way to identify the key thresholds for disruption which exist on the transport network as it is today (as seen in Chapter 3), there is a need to repeat the analysis for a number of socio-economic scenarios in order to fully cost and understand the impact of future climate change. It has been shown that by considering how a number of key dimensions may change in the future, most notably those of social and political values and governance it is possible to account for uncertainty in the future socio-economic environment of a country or region. Although ideally sector specific scenarios should be reached by elaborating on generic toolkits such as those provided by UKCIP, this is rarely undertaken. The potential to use existing scenarios from alternative sources should not be discounted. Overall, a pure physical study on transportation and other complex, reactive and highly changeable sectors would be of questionable value without a greater understanding of the potential future sensitivity of the sector weather and climate. The examination of the current and future sensitivity of the UK's road freight sector in Chapter 4 provides a base of understanding for such a study.

Chapter 3: Meteorological Challenges to the Safety of Britain's Freight Operations and the Likely Impact of Climate Change

3.1 Introduction

This chapter addresses the requirements of the first stage of the CIA process. The aim is to evaluate this existing knowledge base in order to retrieve a suitable quantitative relationship from the literature or, alternatively, to inform the determination of a new set of relationships more appropriate to this study. To understand fully the potential impact of climate change, the current relationship between meteorology and accident rates must be understood. This exploration includes empirical studies of physical relationships; computational and laboratory-based studies such as those on the effect of wind-loading on high sided vehicles (e.g. Baker 1993), and statistical examinations of the observed effects in practice, based on accident records and meteorological observations, such as the observed increase in accident rates during precipitation events (e.g. Andrey et al, 2003). In cases where sufficient meteorological or accident data are not available (such as accidents during high winds), this review provides resources for a later qualitative discussion of impacts. This chapter also investigates the current understanding of potential future climate change and how these changes may impact on freight transportation, based on the relationships arrived at in the first section.

3.2. The atmosphere as a hazard

Weather is a major factor in vehicle accident causation (Edwards, 1999), with its effects having unique characteristics depending on the mode of transport. The impact of weather is dependent on numerous factors, including the type (e.g. car, bus, heavy goods vehicle) and the characteristics (e.g. braking technology, height, weight) of the vehicle, the type and intensity of weather, the construction of the road surface (Yehia and Tuan, 2000), roadside warning systems (Carson and Mannering, 2001), lighting conditions (Fridstrom et al, 1995; Wanvik, 2009), and the skill and experience of the driver (Elvik, 2006). The reduction of weather-related accidents through better infrastructure and management, weather forecasts and warnings, vehicle design, vehicle laws and public information has been a feature of road authorities since the introduction of the automobile. For example, roads are salted to prevent ice (Thornes, 1992) and warnings systems have been set up to warn hauliers of high winds (Highways Agency, 2007). To these ends, a sizeable literature regarding the effects of meteorology on vehicle accidents and the interaction of the aforementioned physical and behavioural factors has arisen.

Although the literature relevant to this project features studies on the effects of precipitation, snow, ice, heat and fog, it is important to mention that the degree to which the relationship between meteorology and accidents has been studied specifically for freight transport depends largely on the meteorological parameter in question. As will become apparent, little distinction is made between different forms of road transportation in the majority of studies, the exception being where the physical characteristics of freight make it particularly vulnerable e.g. high winds on exposed sections of road. This is important, as the manner in which freight vehicles react physically to meteorological hazards, the way they are used on the road network and the capability of the drivers themselves to cope in adverse conditions may all be different to other constituent parts of the road fleet such as cars (Koetse and Reitveld, 2009). For example, the behavioural impacts of meteorology on the timing of travel, and hence exposure, will be significantly different for freight companies which have very little capacity to delay their operations until conditions are less hazardous.

The focus of this thesis on freight means that methodologically, there exists a problem of statistical validity, as many of the existing findings may not represent the actual relationship between weather and freight accidents. For example, the generalised observation by Qiu and Nixon (2008) that crash counts are influenced by exposure, and that hazardous meteorology usually acts to reduce volume and hence reduce exposure, may be only partly true for freight where the option not to operate has monetary consequences. This caveat may also be considered for the theory that where weather is viewed as more of an inconvenience than a hazard, such as with precipitation, traffic volumes generally increase, along with accident numbers, as people decide to drive rather than walk (Bertness, 1980). However the influence of non-freight traffic on weather-related freight accidents should not be ignored. For example, reduced passenger traffic brought about by heavy precipitation may reduce likelihood of multi-vehicle collisions. Furthermore, freight typically operates over the full 24-hour time period whereas car travel is limited at night, again creating fundamentally different exposure patterns. The observation of Palutikof (1991) that there are 'safe days' (Monday to Thursday) and 'dangerous days' (Friday to Sunday) for general traffic may be reversed when looking at freight transport, which has its highest volumes during weekdays.

As mentioned in the introduction, a myriad of physical and statistical relationships between meteorology and accidents have been published in the scientific literature. Although many theoretical physical relationships have been determined, (e.g. computer or tunnel studies on the effect of wind e.g. Summerfield and Kosior, 2001), statistical relationships based on observed accident rates are the most common methodology (e.g. Changnon, 1996). This is especially true for relationships with gradual increases in risk with meteorological intensity, but less for those that demonstrate a clear meteorological threshold, such as road ice which forms at temperatures below 0°C. The aim of the majority of road accident studies examined in this thesis is to elicit causal relationships by determining a statistical link between meteorology and accidents. However, it must be noted that the term "causal" in studies on meteorological accidents does not imply a strictly deterministic relationship (Hall and O'Day 1971; Elvik, 2003).

3.2.1. Behavioural theories

The ways in which the weather acts as a hazard are multitude. Although the focus of the literature is on the direct impact of weather on physical aspects of the vehicle such as the reduction of friction between the tyre and road surface in snowy weather (Sokolovskij, 2007), or decreased stability and handling caused by high winds (Chen and Cai, 2004), there are also associated behavioural and psychological impacts which, although less prevalent in the literature, have arguably equal importance in accident causation. While these less direct impacts are inherently less suited to empirical investigation, Elvik (2006) presents a typology of mechanisms or 'laws' of vehicle accidents through which they can be discussed. The laws can be summarised as follows:

1. ***The universal law of learning.*** *This states that the ability to detect and control traffic hazards increases uniformly as the amount of travel increases. This law implies that accident rate per unit of exposure will decline as the amount of exposure increases.*
2. ***The law of rare events.*** *This states that the more rarely a certain risk factor is encountered the larger is its effect on the accident rate.*

3. ***The law of complexity.*** *This law states that the more units of information per unit of time a road user must attend to, the higher the probability an error will be made.*
4. ***The law of cognitive capacity.*** *The more the cognitive capacity of the driver approaches its limits, the higher the accident rate.*

Caution is required when using the term 'law', as they cannot be considered as true scientific laws, as epistemologically there is a distinction between scientific laws and accidental generalisation, where phenomena are observed a great number of times but do not represent an invariant relationship (Elvik, 2006). However, the majority of observed behaviour under meteorological conditions can be explained through these principles. For example, the first two laws can be used to explain why ice is such a dangerous hazard, why its effect is felt with such severity in marginal climates as the UK, and why freight drivers should theoretically be more able to deal with this hazard compared to other drivers. The law of rare events would explain why a road icing event has a higher relative impact than other driving conditions, as this condition is encountered infrequently and offers drivers fewer opportunities to learn how to respond. It also explains why a road icing event would have a higher relative accident rate in a marginal climate, as a ground frost temperature is reached less frequently than in colder climates, again reducing exposure. The law of learning suggests that as freight drivers spend more time on the road, their exposure to icing events is increased, hence increasing their ability to overcome this hazard compared with other road users who travel less.

This theory has been demonstrated by an observed sharp drop-off in the relative accident rates on snow or ice covered roads as the exposure to these conditions increases (Figure 3.1, Brüde and Larsson, 1980). However, one potential problem not addressed in the literature is that of complacency, both individual and institutional, towards more common forms of meteorological risk, such as precipitation. The fact that precipitation is often referred to as a 'chronic' hazard (e.g. Andrey et al, 2003), is perhaps a telling indication of the effect its prevalence has on risk perception, in that it becomes something which is lived-with and accepted, despite its overwhelming cumulative impact.

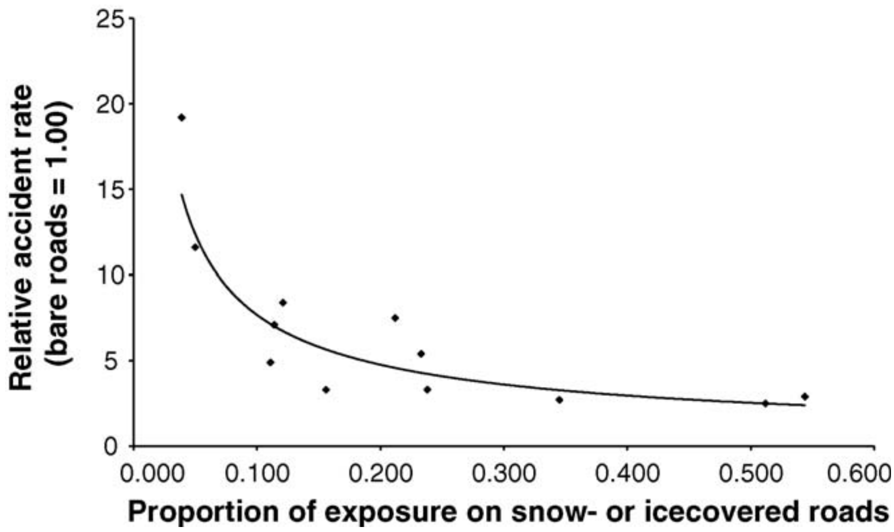


Figure 3.1. Relative accident rate (bare road surface = 1.0) on roads in Sweden as a function of the proportion of driving on roads covered by snow or ice. (Brüde and Larsson, 1980)

The insights by Elvik (2006) help explain the paradox that the severity of a climate does not necessarily determine the level of risk to transportation. In less marginal northern regions, such as the majority of Scandinavia, certain weather conditions are taken as a given at particular times of the year. For instance snow can be considered as a near constant in Northern Sweden during the winter (Eriksson, 2001), which impacts both how drivers behave in these conditions including adaptation of their vehicles and how authorities design the infrastructure. This is mitigated by drivers being permitted to use studded tyres or tyre chains to counter the effect of reduced friction (Elvik, 1999). Conversely, in the UK it is not always cost effective to climate-proof infrastructure to perform safely in events with very low probabilities, or for private companies or the public to purchase vehicles which are suited to these conditions. It is certainly the case that the majority of freight vehicles used in the UK do not perform as well under severe conditions as those designed for the harsher environments of North America or Scandinavia.

Thornes (1992) mentions that where the weather hazards can be mitigated, research is usually channelled towards this end. This is the case for road icing in a marginal climate, which is dealt with through road salting, urea de-icing and road design. Other meteorological hazards such as precipitation cannot be nullified, so the emphasis of the expenditure on research shifts away from the infrastructure and management, and towards the design of the vehicle to cope with such road conditions. However, the findings of Elvik (2006) also point towards the importance of driver training. Initiatives such as the British government's SAFED (Safe and Fuel Efficient Driving) scheme can help reduce the relative risk of dangerous driving conditions by increasing the driver's ability to predict and cope with challenging situations.

3.2.2. General patterns of road weather accidents in Great Britain

Edwards (1999) presents a highly useful breakdown of accidents recorded by the police Stats19 road accident database in England and Wales between 1980 and 1990 (a more current overview of the broad patterns of the effect of meteorology as a hazard is described in Chapter 7). Table 3.1 shows the relative prevalence of meteorological conditions recorded at the site of accidents. Note that road surface conditions, including the presence of ice, are not considered in this analysis.

Table 3.1. The weather codes recorded in section 1.22 of the Stats 19 and the percentage occurrence of these conditions recorded by the police for 1980-1990 (Edwards, 1999)

Condition	Percentage
Fine, without high winds	78.2%
Raining, without high winds	13.7%
Snowing, without high winds	0.7%
Fine with high winds Raining, with high winds Snowing, with high winds	3.7%
Fog (or mist if hazard)	1.1%
Other	2.1%
Unknown	0.5%

This analysis shows that almost 20% of all accidents recorded are associated with adverse weather conditions. However, caution is required when implying a causal link between weather and accidents. This caveat applies to all weather types, but probably most to precipitation, due to the frequency and duration of rain events in the UK. It must be concluded that a certain number of these accidents would have happened regardless of the meteorology at the time. Despite this inherent overestimation of accidents in the breakdown in Table 3.1, these results indicate that precipitation is the leading meteorological factor in road accidents.

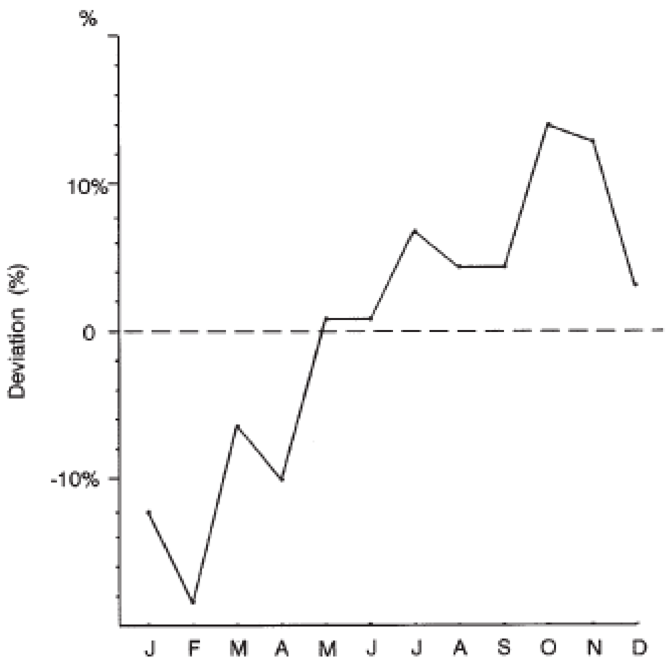


Figure 3.2. Deviation from the 1980-1990 monthly mean of road accidents in England and Wales (Edwards, 1999)

The statistics presented by Edwards also highlight another important phenomenon mentioned throughout the literature; the observed pattern of accident rates during the year (Figure 3.2), with a characteristic upwards trend peaking in the final three months of the year in most of the countries studied (these being countries in the Northern Hemisphere). It would be expected that accident numbers would broadly follow the most hazardous periods of the year in terms of meteorology, but clearly there are confounding factors as the number of accidents drops in January and February even though this is arguably at least equally as hazardous a period as the preceding two months. This relationship also holds for the similar analysis carried out by Palutikof (1991) over earlier time-periods. The simplest explanation comes from the observation (Qiu and Nixon, 2008) that drivers can make a conscious decision not to drive, to drive less or to delay their journeys until conditions are safer. These actions, combined with the lower traffic numbers during the first months of the year, may account for at least part of the observed drop in accidents. However, most studies make no distinction between passenger car traffic and freight. As the majority of freight transport companies are bound into making journeys regardless of the weather, they cannot be rearranged and therefore freight could show a significantly different monthly accident rate pattern with less of a drop off in accidents during the start of the year. These under-researched differences between the reaction of the general road transport fleet and freight transport to meteorology are a reoccurring caveat as this chapter takes a more in-depth investigation into specific weather types. This is especially true of precipitation, and will need to be overcome in order to understand how climate change will impact upon freight transport.

3.3. The impact of precipitation

Although the impacts of all common forms of weather on road traffic accident rates have been investigated to at least some extent, the effect of precipitation has been the focus of the greatest number of statistical studies. Its relative importance in the UK is clear; precipitation is reported in more accidents than all other meteorological parameters combined (Edwards, 1999). The potential for large-scale changes in the precipitation regime of the UK (Murphy et al, 2009) makes a detailed understanding of its current impact on freight transport essential.

Precipitation causes accidents through two main mechanisms; the reduction of friction between the tyre and the road, and the reduction of visibility both through precipitation in the atmosphere and by directly obscuring the windscreen. The effect of reduced visibility should not be underestimated, as Andrey and Yagar (1994) showed that the increase in accident rates from precipitation is almost completely concentrated into the period when the rain is falling, with a sharp decrease when the rain recedes, even though road surface remains wet. This suggests that at the very least, the visibility effect of rain adds an extra level of complexity, relating to Elvik's (2006) 3rd law, as well as the law of cognitive capacity, creating a driving environment with multiple hazardous stimuli. This is probably the most likely explanation, but Andrey and Yagar's (1994) findings may even suggest that the effect of reduced visibility is the leading mechanism by which precipitation causes accidents. The hazard presented by precipitation has even influenced the law in several countries, with France, for example, having a lower speed limit on highways during rain events. It has also prompted electronic signs which warn of dangerous driving conditions during rain events.

Compared with temperature, precipitation can be more spatially variable, which has previously been a major impediment to forming useful statistical relationships. The magnitude of this spatial variability also varies seasonally, with patchy convective rainfall in the summer requiring even finer spatial resolutions when building statistical relationships. Edwards (1999) observes that there is no pronounced seasonal tendency to rain-related accidents (Figure 3.3), although the slight trend towards more accidents during the last three months of the year fits in with the general observation that this is the most accident intensive time of the year.

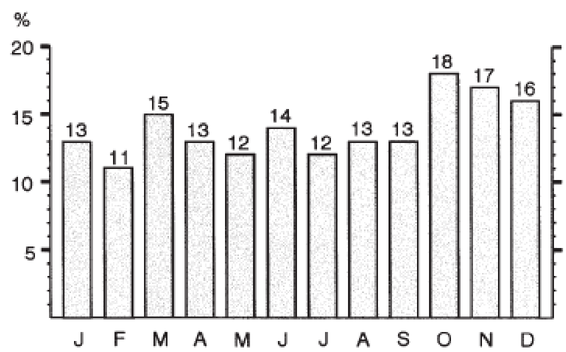


Figure 3.3. Rain-related road accidents by month expressed as a percentage of all accidents (Edwards, 1999)

Many of the studies examined in this section were used by Qiu and Nixon (2008) as part of a systematic review and meta-analysis of the adverse effects of weather on traffic accidents. By collating a large number of studies, the authors sought to determine generalised equations to predict the contribution that rain (and later snow) has on accident rates. One possible criticism is that in gathering a suitable number of studies the collection period includes findings between 1967 and 2005. This period of time has seen a range of safety improvements made to vehicles, road surfaces, road management and weather forecasting, with a broad reduction in accident rates despite an increase in traffic volume (Highways Agency, 2006; DfT, 2009) meaning that several confounding factors will have been missed. This caveat is partially addressed by the authors in terms of a decadal analysis of relationships, which is discussed in relation to the methodology (Chapter 5), showing a broadly decreasing sensitivity.

Also, this analysis includes studies from many different countries, and as has already been discussed, the reaction to meteorology is in part determined by how often drivers are exposed to that hazard and how the infrastructure has been designed to mitigate this impact. Although not included in the headline figure, some attempt has been made to separate the relationships in different countries (Table 3.2), although there is the obvious problem of reduced study size when splitting the data.

Table 3.2. Percentage crash and injury rate increase for rain by country (Qiu and Nixon 2008)

Country	Crashes (%)	Injuries (%)
USA	58	21
Canada	73	50
Britain	24	42

Regardless of these caveats, this study offers a very useful holistic view of the study of precipitation on accident rates and is referred to several times in this chapter. One of the major considerations of road accident studies is the number of factors apart from meteorology that may influence the accident rate. Eliciting the contribution of meteorology is difficult when traffic volumes influence exposure (Andreescu and Frost, 1998) and low lighting conditions increase vulnerability (Fridstrom et al 1995; Andrey et al, 2003). The way in which these confounding factors are accounted for provides a major dividing line in the literature, with two separate methodologies emerging. Firstly, there are those which use a comparative method, comparing accident rates on days with no precipitation to those at various levels of precipitation. To adjust for confounding factors days are chosen that have a number of fixed factors such as traffic volume or daylight hours, and only differ in respect to either a binary measure of rain (raining or not raining) or a graded measure of rain at banded ranges. The other type of studies are those based on regression, which link the accident rate to a unit of weather recorded by a nearby meteorological station (e.g. Eisenberg, 2004). In these studies the extraneous factors are controlled statistically. Both of these methods are also applied to snow within the literature (e.g. Eisenberg and Warner, 2005; Qiu and Nixon, 2008).

Taking these studies as a whole, the meta-analysis by Qiu and Nixon (2008) showed that accidents usually increase during precipitation compared with fine-weather conditions, with crash rates increasing by 84% and injury rates increasing by 75%. However, several important caveats must be highlighted. Firstly, almost all of the studies are based in urban areas, and are not usually concerned with an arterial road system. For instance, Keay and Simmonds (2005, 2006) studied the effect of convective and frontal rain in Melbourne, whilst Andrey et al's (1993, 2003) studies are based in Canadian urban environments. Apart from the usual caveat of no distinction between types of road transport, the focus on urban environments is not representative of the types of route that freight vehicles operate on, which are mostly inter-urban. Edwards (1998) analysis of the degree of injury severity across the regions of the UK highlights this point. This research shows a clear distinction between the severity of injuries in predominantly rural and urban counties, with rural areas having more severe injuries for all weather types. Edwards (1998) attributes this to the higher speeds, the absence of the moderating effect of heavy traffic and less road lighting.

Furthermore, the findings by Qiu and Nixon (2008) should not be taken as an indication of consensus on the effects of rainfall. One of the more curious aspects of the relationship between precipitation and accident rates is that the magnitude (and in some studies, even sign) has been found to change depending on the temporal scale it is being analysed at. This initially puzzling aspect has been highlighted by Eisenberg (2004), who noticed that analysing the number of fatal accidents in a given day against that day's precipitation total gave a strong positive relationship, whereas analysing a month's fatal accident total against that month's precipitation total had a strong negative relationship. Hence, Eisenberg's study suggests that when looking at a monthly scale, increased precipitation in a month actually decreases the number of fatal accidents. Simultaneously, the daily analysis clearly indicates that increased precipitation increases the number of fatal accidents.

The explanation proposed by Eisenberg revisits the important concept of behaviour. It suggests that after an initial heavy rain day, driver behaviour and awareness to the difficult conditions will increase. This creates a lagged negative impact of precipitation, where the initial rain event following a period of benign weather has a strong impact, affecting a behavioural change that reduces further accidents. This is another strong piece of evidence supporting Elvik's (2006) laws of accident causation.

It is interesting to relate Eisenberg's finding to freight transport, most notably whether the negative association will hold on a monthly basis for that sector. It can be assumed that the overall exposure to rain will be far higher than for the majority of other road users, as freight drivers spend the majority of their work hours on the road. A similar phenomenon is examined in the snow section of this chapter, which is probably more expected, due to the seasonality of this weather type, its relative rarity and the long periods between exposures. It might be assumed that the increased exposure to precipitation would pass a critical level for freight drivers, placing them much further along the learning curve presented in Figure 3.1, thus creating a situation where the accident rate is far more a product of the intensity of precipitation, and not a product of the period of time between events.

Another key issue not addressed in the literature is whether the observation that the presence of a hazard causes a reduction in both speed and exposure can be replicated for freight vehicles, which have less room for travel alteration. It is important to note that for the general road fleet, the increase in accidents previously mentioned occur even though the speed of traffic is reduced. Martin et al (2000) showed a reduction of 10% during wet conditions from rainfall. In terms of exposure, most studies show a more modest reduction in traffic volume. Codling (1974) shows a reduction of 2%, Keay (2005) shows a decrease of 1.35% to 2.11%, with a 3.43% reduction during very heavy precipitation. Qiu and Nixon (2008), who collated the results from various studies, calculated the following traffic volume reduction values, although these are fairly similar and the quantitative distinctions between the categories are not clear; Light precipitation = 1.35%, Precipitation = 1.65%, Rain = 2%. It must also be remembered that some studies show an increase in traffic volume and exposure during precipitation events (e.g. Bertness, 1980).

Finally, it is unclear whether rain increases the rate and severity of injuries resulting from accidents. Edward's (1998) study seems to suggest that rainfall reduces the proportion of fatal accidents compared to those of a lower severity. One interpretation may be that drivers take more care in these conditions and limit their speed. However, as the study is concerned with ratios, the results may be misleading, and gives a more likely explanation, that rainfall increases the number of vehicles involved in minor collisions, hence reducing the ratio of fatal accidents, whilst not necessarily reducing the absolute number. This interpretation in supported by a number of studies (e.g. Andrey et al 2003).

3.3.1. Climate projections for precipitation

Annual mean precipitation in England and Wales has not changed significantly since records began in 1766 (Jenkins et al, 2009). However, the spatial and temporal distribution of this rainfall *has* changed significantly (Osborn and Hulme, 2002; Jenkins et al, 2009), and its future pattern will be a key determinant of the distribution of precipitation-related accidents. Studies into recent changes in intensity were conducted by Osborn et al (2000) and Osborn and Hulme (2002). These examined the daily intensity of precipitation between 1961 and 1995 and found that precipitation has generally become more intense during the winter and less intense during the summer. Precipitation patterns are also spatially variable, with Maraun et al (2009) demonstrating that extreme 1-day rainfall events tend to be caused by frontal precipitation in the West, whilst convection is the main process generating extreme rainfall in the South East.

The central estimates from the most recent UKCP09 projections (See Figure 3.4) again predict the mean amount of precipitation over the UK to remain the same over an annual resolution, with even estimates at the 10% probability level only showing maximum annual regional increases of 14% and decreases of 16% (Murphy et al, 2009). However, the projected seasonal changes, especially for summer and winter, pose several challenges to future road safety. For example, winter precipitation across the western side of the UK is projected to increase by 33% under the central estimate, with a 10% probability of increases exceeding 70%, although winter precipitation amounts in the Scottish Highlands may see a small decrease. Conversely, summer precipitation sees a strong decreasing trend, with a central estimate of up to -40% in parts of the far south of England, with a 10% probability of this exceeding -65%. Again, Scotland shows the least potential change to its precipitation regime. The daily intensity of precipitation is also set to change, with the wettest day of winter increasing in rainfall amount by up to 56%, and the wettest day of summer decreasing by 38%, yet still showing a potential increase in intensity (a 10% probability of a 51% increase) in parts of Scotland.

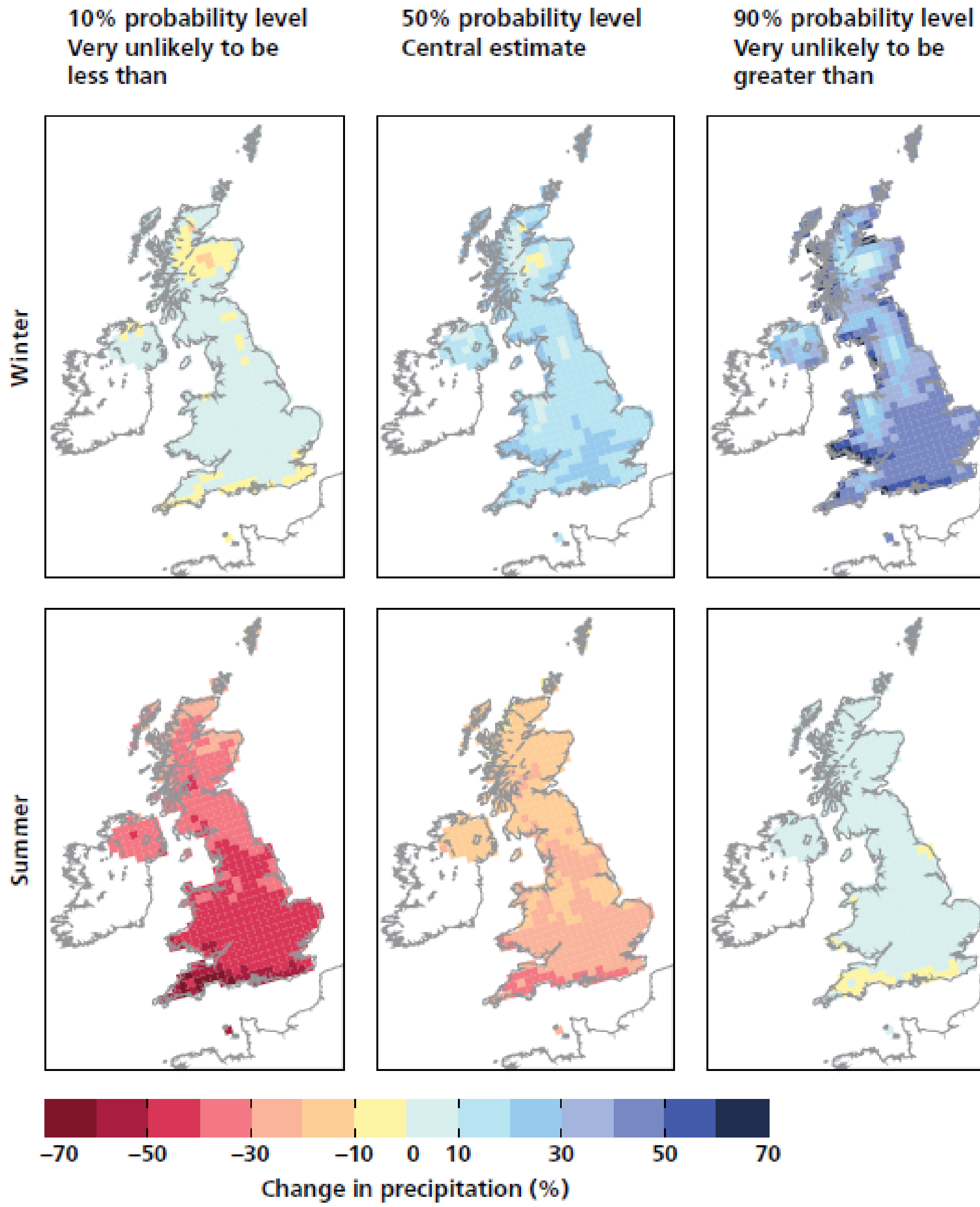


Figure 3.4. Percentage change in mean winter and summer precipitation (Murphy et al 2009)

However, it must be noted that not all precipitation falls as rain. The proportion of precipitation in the form of snow, fog and mist is likely to alter due to climate change. Snow in particular is likely to reduce under most future climate scenarios, yet is not handled in any useful detail by existing models (Murphy et al, 2009). During the winter most precipitation begins as snow and then melts as it falls. Any increase in temperature will lead to more of this snow turning to rain before it reaches the ground. This treatment of precipitation should be remembered when discussing climate impact projections based on the current generation of climate tools.

As yet no studies have empirically addressed the impact these potentially sizeable changes will have on the safety of road transportation. The greatest area of interest in existing transport CIAs is on the impact to infrastructure. This is understandable, as many of the infrastructural projects undertaken now will have operational lifetimes throughout the current century. Interestingly the Scottish Executive (2005) present two scenarios for the effect of changed precipitation, both of which could plausibly happen due to the expected seasonal pattern of climate change. A reduction in groundwater level would lead to an increase in pore water pressure, increasing the level of the groundwater table, potentially causing instability and landslips around cuttings. A reduction in groundwater levels also has implications for the stability of slopes. This has been addressed in detail by the BIONICS project (Davies et al, 2008), but these findings apply more to rail transport. The Scottish Executive (2005) also mention that the durability of pavements in wet conditions will be reduced. Increased soil moisture will increase the likelihood of flooding due to antecedent rainfall. Interestingly the report does not mention the direct effect of increased accidents due to heavier precipitation.

In terms of freight accident rates, there is a clear seasonal split. The increase in precipitation in the winter may have a disproportionate impact, as winter driving conditions are generally more dangerous, mainly owing to the reduced number of daylight hours (Fridstrom et al, 1995). This combination of hazards may stretch drivers' cognitive limits (Elvik, 2006) and cause more accidents than a similar increase in summer, when there are generally fewer potential hazards to cope with (Fridstrom et al, 1995). A key question is whether the increase in accidents during the winter is likely to be more than the increase in summer accidents. However, as yet the current seasonal patterns of specific rain-related freight accidents have not been elicited in the literature. The need to uncover these patterns and to build separate seasonal relationships is thus a clear requirement of this CIA.

3.4. The impact of temperature

Temperature is an atmospheric parameter which causes a large number of accidents, and one that features heavily in the literature. Hot weather can cause accidents by creating uncomfortable driving conditions, mainly through heat stress (Stern and Zehavi, 1990; Nofal and Saeed, 1997). However, this is not a significant problem in Britain, the only serious effect of hot weather being that it is more probably that people will travel for pleasure (Edwards, 1999). As previously mentioned, this is not an issue with regards to this study, as there is little choice involved in when freight drivers travel. High temperatures can also cause tarmac to melt or 'bleed', which is treated by spreading stone and dust (Thornes, 1992). However, this is less of a safety issue as much as it is a disruption or maintenance issue.

In Britain, the main problem is caused by low temperatures, which results in road ice forming. Ice generally forms at 0ºC, although the freezing point may be lower depending on the composition of the water solution. Ice is most slippery at 0ºC (Moore, 1975), which is significant for Britain because of the marginal climate which results in a high frequency of icing events at this temperature. Low temperatures as a cause of accidents are unique, as attempts are made to reduce the effects of the hazard on an event basis. The problem is infrequent enough to rule out the use of studded tyres on automobiles as has been used in other countries (e.g. Germany, Austria) to confer a slight increase in safety (<5% reduction in accidents; e.g. Elvik, 1999). However, as studded tyres have increasingly been banned in most countries due to the negative impacts on the road surface (e.g. Takagai, 1997), winter tyres are now more commonly used. These tyres use softer rubber for better traction at lower temperatures, as well as a tread pattern that allows water to escape, reducing hydroplaning. Hjort et al (2010) show that winter tyres offer better traction compared with summer tyres, although this is further improved with studded winter tyres.

The provision for permanent road signs marking areas of ice risk has been made, although these are used rarely in the UK. The effectiveness of these signs in reducing accidents has been brought into question, with scope for research into the effect of placement and design (Carson and Mannering, 2001). In the UK the main preventative measure comes through treating roads with rock salt. There are thresholds related to the types of maintenance that can be used, with below -10ºC rock salt becoming less effective and below -5 ºC urea being ineffective (Thornes, 1992). Since the humidity of the UK is usually above 80%, the hygroscopic properties of rock salt mean that salt remains in solution and makes the roads even more slippery than when they are dry (Thornes, 1992).

In theory, winter road maintenance should make ice a fully preventable road hazard. However, in reality this is not achievable, mainly due to the difficulties in forecasting where and when certain sections of the road network will reach freezing temperatures. The microclimate for road surface temperatures is determined by geographical features of the area. These include altitude, topography, road surface construction, land-use, and most importantly sky-view factor, a measure of overhead exposure (Chapman et al, 2001). The more sheltered a section of road is, the longer it takes to freeze. This factor, combined with land use, links in with the socio-economic scenarios investigated in this thesis, with scenarios for urbanisation having a potentially significant impact on the factors determining the road-surface microclimate.

Vehicles themselves also play an important role in determining risk. By thermal-mapping different lanes of motorways, Chapman and Thornes (2005) found temperature differentials of 1.5 ºC. This correlates with the traffic volumes of the lanes, with vehicles warming the road (or preventing it to cool) through the numerous mechanisms mentioned by Prusa et al (2002), including heat from the engine, friction from the tyres and the blocking of long-wave radiation from the road surface. Future traffic volumes and the way they are managed on the roads could have a significant impact on this phenomenon. It is clear that in terms of infrastructure, traffic flows and maintenance, the impact of temperature can be considered to have a more complex relationship with socio-economic development than precipitation. The potential evolution of these dimensions is discussed in Chapter 4.

3.4.1. Climate projections for temperature

The most recent UKCIP projections (Murphy et al, 2009) suggest that all areas of the UK will become warmer, with a greater warming trend in the summer compared to winter. For example, the central estimate suggests that parts of Southern England will see average summer temperatures rise by 4.2°C by 2080, with a 10% chance of average summer temperatures rising by more than 6.8°C. This warming signal is least strong in Scotland. Although this raises maintenance concerns through road surface problems, the potential impact on accident rates is low. The main area of interest to this study comes from warmer winter temperatures and the reduction in frequency of frost days. Mean daily minimum temperatures are projected to increase across the UK, with an average rise of 2.1°C by 2080, with a 10% chance of rises over 3.7°C and a 10% probability of rises less than 0.6°C (See Figure 3.5).

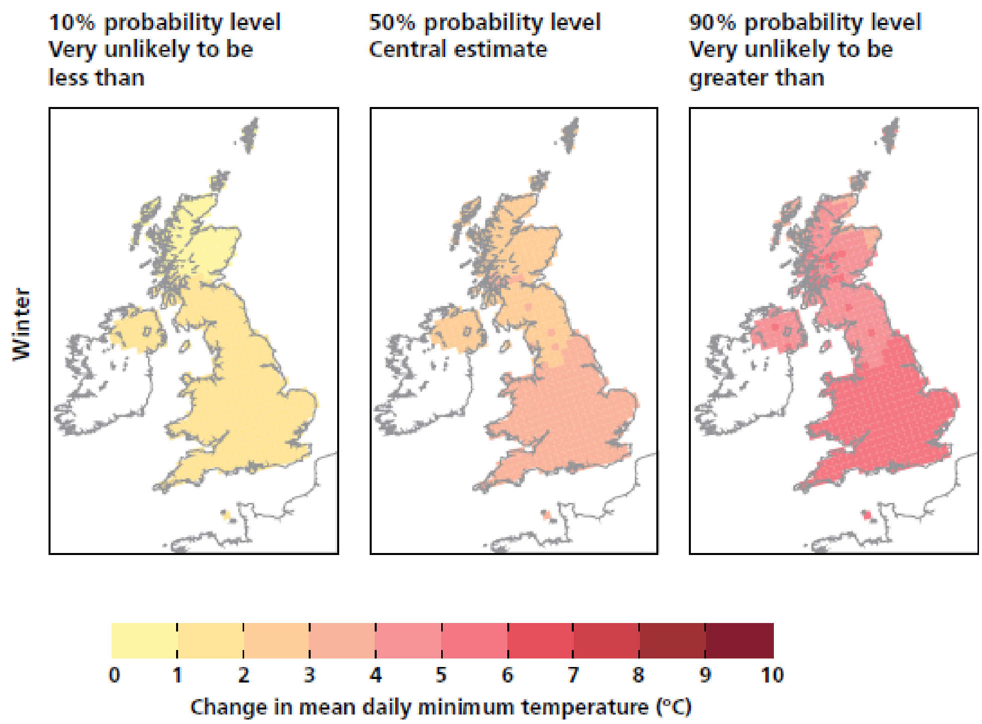


Figure 3.5. Percentage change in mean daily winter temperature (Murphy et al 2009)

Furthermore, when these climate scenarios are examined with the UKCIP Weather Generator (Jones et al, 2009), a significant reduction in frost days is forecast (Table 3.3). For example, Heathrow, which currently has an average of 39 frost-days a year, has a 90% probability of at the least a reduction to 26 frost-days, a central estimate to 11 day and a 10% probability of a reduction to just 3 frost days a year by 2080 under medium emissions.

Table 3.3. Observed and projected (2080, medium emissions) annual number of frost-days (Minimum temperature <= 0°C) at 10%, 50% and 90% probabilities (Jones et al, 2009)

Location	Observed	10%	50%	90%
Heathrow	39	3	11	26
Yeovilton	54	3	12	27
Coltishall	49	3	13	29
Dale Fort	11	0	2	9
Ringway	43	4	13	28
Aldergrove	44	4	13	28
Eskdalemuir	94	16	38	64
Wick	52	6	18	35

Several caveats should be made regarding these projections. Firstly, the UKCIP models do not take changes of urban heat island into consideration. Secondly, although it is regarded as unlikely (Murphy et al 2009), an abrupt change in the Atlantic Ocean circulation causing rapid climate change is not presented as a scenario. However, the UKCIP projections fit in with recent trends. Global temperatures have been warming during the last century, with the ten warmest years on record having occurred since 1997 (Met Office, 2010). This trend is also shown in the UK, with the Central England Temperature, the world's longest reliable temperature observation record showing a warming trend since the 1850's (IPCC, 2007). However, the projected warming will not necessarily be linear or constant. The complexity of the climate system may lead to periods of rapid or slower warming. For example, the relatively subdued warming during the past decade (2000-2009) could be due to a combination of low solar activity, providing less incoming energy, and a La Nina period, storing energy in the oceans which is released in an El Nino period, for example during 1998, the hottest global year on record. It is estimated that oceans have significantly increased their store of energy during the past decade (through sea level evidence) which should be released in the next El Nino event.

The obvious impact of the above projections, at least at first glance, is a safer operating environment for road freight transportation. Several regions will see annual frost days approaching single figures by 2080 under medium emissions (Jones et al, 2009). As there is currently no formal assessment of the relationship between the number of ice days and accident rates it is hard to quantify the reduction in accident rates. Although it is highly likely that while the absolute number of annual frost days will reduce, the relative accident rate per frost day may increase, as drivers become less used to these conditions, again as would be predicted by Elvik (2006). It is recommended by the Scottish Executive (2005) that additional road user education programmes be introduced to counter the effects of road users becoming less used to dealing with these conditions.

It is also likely that this change in relative accident rate will vary spatially. For instance, freight drivers based or frequently exposed to conditions in Scotland may be able to retain coping skills for ice, as the number of frost days is projected to reduce less than the rest of the country. In regions seeing a significant reduction in frost days there are several potential problems. The maintenance infrastructure that exists today is designed to cope with a significant number of icing days per year. A significant decrease in road ice events could lead to cuts in the service provided, with the potential for complacency. The difficulties of forecasting road icing events have long been established (Thornes and Stephenson, 2001). Due to the topographic influences on ice formation mentioned by Chapman (2001), it is foreseeable that under a new climatic environment, roads which would have completely frozen before may now only freeze in certain locations. The difficulty of forecasting the thermal fingerprint of stretches of road and pinpointing which specific locations require road-salting is significant.

3.5. The impact of wind

Due to its position in the mid-latitude westerlies, Britain is one of the windiest countries in the world (Perry, 1990; Edwards 1994). The literature regarding wind-related road accidents consists of the highest proportion of studies focussing solely on the impact on freight vehicles. This relates to the physical nature of the vehicles themselves, having high and sheer sides and the potential for a far higher centre of gravity than other road vehicles. As well as having significantly strong winds, Great Britain is also vulnerable due to the way its road network is orientated. As traffic generally moves along a northwest to southeast direction, traffic is frequently and disproportionately at right angles to the prevailing westerly wind direction (Perry, 1990: Edwards 1996). Often high winds lead to major roads and bridge crossings being closed as a precaution, with traffic being diverted to less suitable minor roads, which reduces speed. Barker and Reynolds (1992) suggest that vehicle speed should be limited when gust speeds exceed 38-45 mph.

Summerfield and Kosior (2001) used a dynamic simulation to show that vulnerability is increased further when trailers are lightly loaded or empty, as the reduced downwards force allows lower wind speeds to exert a great shear force and increases the likelihood of overturning. The risk of overturning is not purely a function of the weight and shape of the truck and wind speed, as it has been found that a fluctuating wind is more dangerous to truck instability than a steady wind, due to the resonance effect on the trailer (Summerfield and Kosior, 2001). Another significant problem is that of sliding-related accidents, where the force of the wind interacts with a truck driving on wet or icy roads (Saiidi and Margalas, 1995). An additional indirect hazard is caused through the fallen trees, wall or panelling which are blown onto roads during wind events (Edwards 1998).

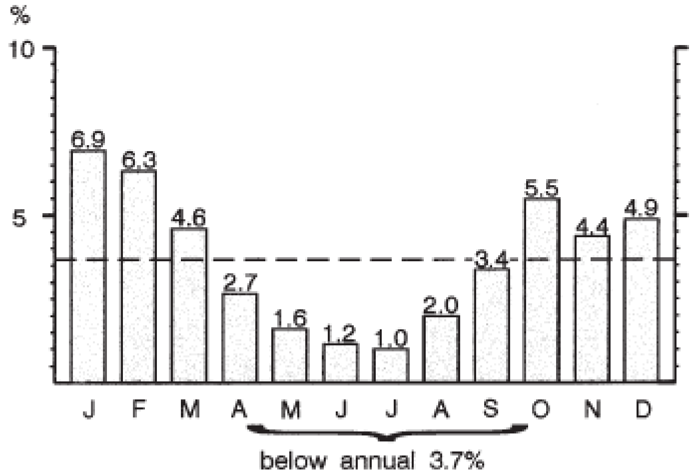


Figure 3.6. High wind related road accidents by month expressed as a percentage of all road accidents (Edwards, 1999).

Edwards (1999) (Figure 3.6) shows an increased number of wind related accidents between October and March associated with winter storms, with injury analysis (Edwards, 1998) showing an interesting spatial pattern that highlights the geographical application of Elvik's (2006) laws of accident causation. The study showed that some UK counties reported an increase in accident severity during high winds, whilst others showed a decrease. It was hypothesised that counties such as Nottinghamshire which saw an increase in severity, are those which are known for infrequent high wind events, reducing the exposure of drivers, limiting their acquisition of the skills to cope under these conditions and hence increasing vulnerability. Wind is also a good example of the disproportionate level of exposure of freight vehicles compared to other modes of road transportation. For example, the United State's road freight fleet makes up 3% of all vehicles, yet accounts for 7% of all vehicle miles travelled and 12% of the total fatality count (Cerrelli, 1998).

3.5.1. Climate Projections for Wind

The North Atlantic Oscillation (NAO) is a major determining factor of the severity of the winter storm season. The phase of the NAO (either positive or negative) has a large influence on the climate of Europe, in particular the spatial distribution of storm winds and precipitation. When the NAO is in a positive phase, the subtropical high is stronger than usual and the Icelandic low is deeper (Bojariu and Gimeno, 2003). As the pressure differences are greater than usual, westerlies across the mid latitudes are stronger than usual, with strong storms coming into Europe from a more northerly direction. The impact on the general climate of Europe is to make it warmer and wetter in Scandinavia with dryer conditions being present over Southern Europe. Both weaker subtropical highs and sub polar lows are present in the negative phase of the NAO. These weaker conditions lead to weak storms which approach Europe on a more west-east track (Bojariu and Gimeno, 2003). This fundamental system has yet to be properly modelled within climate change projections, hence the results for future wind speeds and direction are inconclusive.

The team leading UKCIP 09 climate projections deemed that wind was too complex to predict, and as a result is largely absent in the final report. Although individual model runs do show a slight variance, when averaged they predict changes in mean wind speed of a few percent over the UK (Murphy et al, 2009). However, there is probably the potential for extreme outlying scenarios which may not be properly captured with the techniques currently available. Rockel and Woth (2007) argue that one problem with many models is the lack of parametisation (the representation of sub grid scale processes) of gust speed. Those that included this showed a 20% increase in the frequency of storm peak events greater than 8 on the Beaufort scale over Central Europe. Significantly, storms (also classed as gales) of this intensity and above are known to cause vehicles to veer, as well as presenting the additional hazards of damaged trees and windblown debris (Royal Meteorological Society, 2010).

3.6. The impact of snow

It has been shown that accident rates can increase by up to 1000% when snow is present (Qiu and Nixon, 2008), but a more complicated question is whether the injury rate increases or decreases during snowfall. It has been suggested that although the overall accident rate increases, the slower speeds that most drivers travel at during these events means that the severity of the accident may be less than during clear conditions, resulting in less injury. Eisenberg and Warner (2005) and Fridstrom (1999) demonstrate the reduced severity of injuries during snow events, but the low number of crashes makes statistical analysis difficult. Martin et al (2000) show a reduction of 25% for wet and slushy conditions, with Knapp et al (2000) showing an even higher figure of 29% for heavy snow. As with rain, Qiu and Nixon (2008) collated studies on traffic volumes under snowy conditions and came up with the following (Table 3.3) generalisations, with the same caveats as the previous figures.

Table 3.4. Percentage crash and injury rate for snow by country (Qiu and Nixon 2008)

Country	Crashes (%)	Injuries (%)
USA	73	45
Canada	85	79
Britain	100	50

Another key characteristic of snow as a hazard is the disproportional impact of the first snow event of the season (e.g. Eisenberg and Warner, 2005). Almost all studies record the high crash and fatality rate of these events, especially when they come very early in the season. This links directly with Elvik's (2006) first two laws of accident causation. However, the lack of studies on the effect of snow makes it difficult to confirm whether this phenomenon also occurs in the UK. It is arguable that it would not, as apart from some areas of Scotland, snow never presents a constant winter hazard, with the few events that do occur offering little chance for drivers to become sufficiently accustomed to that driving condition. The temporal distribution of accidents (Figure 3.7) shows the trends that would be expected, with almost all accidents being concentrated between the months of December and March. However, an interesting point to note is that August is the only month not to have a recorded snow-related accident.

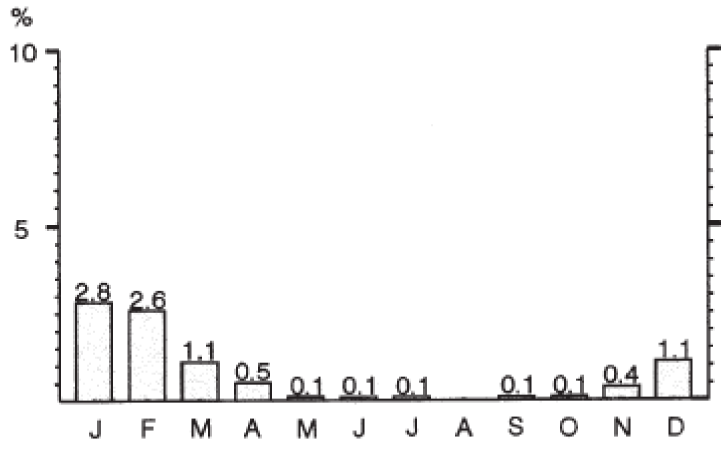


Figure 3.7. Snow-related road accidents by month expressed as a percentage of all road accidents (Edwards, 1999)

3.6.1. Climate projections for snow

Like wind, snow is not handled very well by climate models, owing to the complex nature of snow formation and the importance of small scale topographic features which are not captured in the model parameters (IPCC, 2007; Murphy et al 2009). The 2009 edition of the UKCIP climate scenarios present a less detailed picture of future snowfall than previous iterations, in part due to the acknowledgment of the weaknesses of the methodology. In much the same way as wind, only a small note on the change in snowfall is given, estimating that snowfall will be reduced by between 65% and 80% over mountainous areas of the UK and by 80% to 95% everywhere else. Similar to temperature, the impact of climate change on snow-related accidents is likely to be positive, apart from potential institutional and driver complacency brought about by a more benign climate

3.7. The impact of fog

The reduction of visibility during fog events is a significant cause of road traffic accidents, and acts in a similar way to the aforementioned visual effects of precipitation. Fog forms either through radiative cooling or humidification, with topography playing a major role in its temporal persistence (Pagowski et al, 2004). Part of the construction criteria of motorways is a design which limits the build up of fog (Musk, 1988). Thornes (1992) points out that although it is always recommended that drivers reduce speeds when visibility is less than 200m, evidence suggests that this is not done until visibility is less than 100m.

Hermans et al (2006) found a statistically increasing impact of fog on accidents. Although now dated, the figures from Moore and Cooper (1972) are striking, showing that despite traffic volumes being reduced by 20% during fog events, accident numbers increase by 16%. The temporal analysis by Edwards (1998) (Figure 3.8) shows a clear concentration of fog-related accidents between the months of November and February. Again, Edwards (1996) provides evidence of the role of exposure and experience to adverse driving conditions. It was shown that the areas known to be the most fog prone, such as the Midlands, report a decrease in accident severity during fog events, compared to those with a low occurrence of fog. Although not considered in this thesis, similar effects to those discussed for fog are also seen with smoke, which is more prevalent in arid climates (Lavdas and Achtemeier, 1995). Although no statistical studies exist for the UK, it could be argued that Elvik's laws of accident causation (2006) may suggest an increasing sensitivity in the UK to individual fog events, as improvements in air quality have reduced the number of smog events, a condition which was common before the clean air acts of 1956 and 1968.

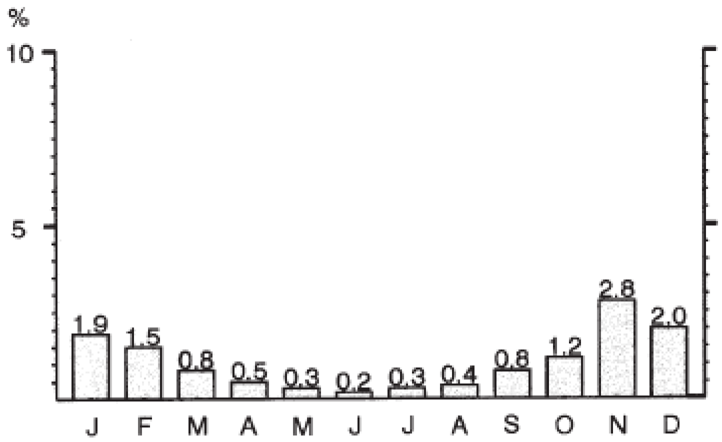


Figure 3.8. Fog-related road accidents by month expressed as a percentage of all road accidents (Edwards, 1999)

3.7.1. Climate Projections for Fog

Fog is not a parameter generally produced by climate models, partly due to the required topographic resolution and partly due to the prioritisation of temperature and precipitation projections. It can be inferred that there will be a reduction in the number of fog days (UKCIP, 2009). An increase in the occurrence of fog creates hazardous driving conditions and may cause more accidents. In addition there may be a need for better road design to reduce the formation of fog.

3.8. Conclusion

This chapter demonstrates several aspects of weather-related road accidents. Alongside the physical impacts of hazardous weather, the behavioural and psychological mechanisms involved with risk have been highlighted, in an attempt to explain the temporal and spatial distributions of current accidents rates, and to examine how changes in these hazards due to climate change may impact on relative risk throughout the UK. In so doing it is apparent that potential reductions in the frequency of a hazard may not necessarily lead to dramatic reductions in the number of accidents caused by that hazard.

By examining current accident rates in the UK it is clear that precipitation is the most frequently recorded weather-type at the scene of accidents, even though this may not always infer a causal link. The impact of climate change shows potential for significant shifts in the temporal distribution of weather-related accidents, and in some cases large scale decreases across the year. For example, ice-related accidents should become far less widespread by 2080 under most emission scenarios. This is also true for snow-related accidents. However, the most interesting and potentially significant change will be in precipitation-related accidents, which should see a reduction in the summer and an increase in the winter. The characteristics of the meteorological hazards discussed in this chapter are summarised in Table 3.5. The next chapter then goes on to discuss the contribution exposure and sensitivity make to the vulnerability of freight vehicles, and examines the extent to which this is determined by the overlying socio-economic environment.

Table 3.5. Summary of atmospheric hazards, their effect on transportation and likely impact of climate change

Hazard	Mechanism of Hazard	Current Temporal Distribution of accidents	Current Spatial Distribution of accidents	Climate Projection	Likely Impacts
Precipitation	• Reduction of friction between tyre and road surface • Reduction of atmospheric visibility	• Prevalent throughout the year • Increased accident rates during final three months of the year	• Affects entire UK, with similar county figures for percentage of total accidents (For England and Wales - Edwards, 1996)	• Large decreases in summer precipitation amounts (central estimate of 40% by 2080 in South-East England) • Large increases in winter precipitation amounts (central estimate of 33% by 2080 across western UK).	• Potential disproportionate increase in accidents during winter due to combination with other risk factors e.g. low daylight hours • Strong decrease in summer rain-related road accidents
Ice	• Reduction of friction between road surface and tyre	• Little research on temporal distribution of accidents. • Road ice season between October and April	• Ice season determined by geography and latitude	• Large increase in average mean temperature • Increase in minimum daily temperatures • Large reduction in frost-days through to 2080	• Large reduction of ice-related accidents • Possible increase in the relative impact of each ice event as drivers become less used to this driving condition
Wind	• Vehicle overturning due to cross-winds • Skidding • Wind-blown debris	• Greatest number of accidents between October and March, although accidents occur throughout the year	• Roads with a northwest to southeast orientation greatest affected	• No consensus of sign of change, although magnitude is limited to around 10% • Very little scientific certainty on wind projections	• UKCIP projections suggest little impact • However, individual model runs suggest both slight increases and decreases in accident rates

Table 3.4 (continued). Summary of atmospheric hazards, their effect on transportation and likely impact of climate change

Hazard	Mechanism of Hazard	Current Temporal Distribution of accidents	Current Spatial Distribution of accidents	Climate Projection	Likely Impacts
Snow	• Reduction of friction between tyre and road surface • Reduction in atmospheric visibility	• Greatest number between December and February • Shows accidents through all months apart from August	• Relative accidents rates highest for areas with infrequent return periods for snow	• Little spatial detail on projections, although large scale reductions (up to 90% by 2080) are likely)	• Large reduction in vehicle accidents • Possible increase in the relative impact of each ice event as drivers become less used to this driving condition
Fog	• Reduction of atmospheric visibility	• Greatest number of accidents between November and February • Accidents reported throughout year	• Areas such as the West Midlands show the greatest prevalence of fog • However, areas with infrequent fog events show the greatest increase in accident rates	• Inferred reduction in fog days • However, not routinely handle by climate models	• Potential reduction in fog-related accidents

Chapter 4 - The Vulnerability of the Road Freight Sector of Great Britain: Determinants of Current and Future Resilience

4.1. Introduction

The volume of freight vehicles on the road, their design and performance, the ways in which they are used and the type of training given to drivers are continuously changing, and together determine the severity of the impact of a given meteorological hazard. The way in which the freight sector develops during the coming decades is therefore a key issue for this CIA. The evolution of these aspects of freight transport will be neither a simple continuation nor a complete break from the past, and will be in large part influenced by the future socio-economic environment. The wealth of recent research on the links between the economy and road freight growth (e.g. Tapio, 2005; McKinnon 2007), along with the creation of several detailed sets of scenarios for the future socio-economic environment of the UK (e.g. UKCIP, 2001; Foresight, 2006), suggests sufficient understanding and resources exist to systematically hypothesise what the future state of the freight sector may look like and hence how it might react to meteorological hazards.

Therefore, this chapter first revisits the concepts of sensitivity and exposure, highlighting the factors which determine the relationship between adverse weather and road freight accidents, including universal factors such as traffic volume as well as those specific to certain weather types. These include vehicle trailer loading and body design in the case of high winds, and winter road maintenance infrastructure in the case of ice. The chapter then examines in detail the current understanding of the relationship between various aspects of the overlying economy and the freight sector. This is split into influences on exposure in terms of traffic volumes and types of operations undertaken, and influences on sensitivity in terms of vehicle design and technology. As will become clear, there is a far greater understanding of the links between the economy and exposure than for sensitivity. Examples are given of the potential impact of various future socio-economic scenarios on the freight sector, paving the way for the more systematic assessment arrived at in Chapters 5 and 9.

4.2. Sensitivity and exposure of road freight transport

It is common within the climate research community to discuss extreme weather as *rare*, *intense* or *severe* (IPCC, 2001; Beniston et al, 2007). Both 'rare' and 'intense' weather events are statistical terms referring respectively to the frequency and deviation from the norm, a rare event being one that occurs infrequently, and an intense one being of a relatively high magnitude (IPCC, 2001). In contrast, 'severity' is a much more nuanced concept, referring to the socio-economic impacts of an event (IPCC, 2001). Although subtle, the distinction between the concepts of rarity and intensity and that of severity is a useful way of highlighting the importance of the issues discussed in this chapter and explaining the adoption of interdisciplinary techniques for CIA.

The severity of an event is to a large extent relative and mutable, mostly determined by the sensitivity and exposure of the system or sector to the hazard (Tol, 1998; Holman et al, 2008). Much like the effects of other natural hazards such as earthquakes and floods, the magnitude of the impact on people, sectors and infrastructure is influenced by the ability of that society or sector to cope with the hazard, the number of people exposed and the extent to which the hazard can be predicted and prepared for. This is a temporal and spatial concept, as what is considered severe weather in Great Britain is different to concepts of severity in the past, and is also different to what other countries would consider severe. In terms of transportation this concept is demonstrated by Qiu and Nixon's meta-analysis (2009) where the impact of weather is shown to be greater in the past and in countries which are less used to coping with a given hazard.

Of course, within transport meteorology it is not necessarily severe events which cause the greatest number of accidents. Chapter 3 demonstrated that relatively common meteorological events such as rain cause cumulatively more accidents than extreme event such as ice and snow (Andrey et al, 2003; Eisenberg, 2004). However, the severity of these events (even if low) is likely to change as technology makes vehicles safer and economic demand influences the volume of traffic exposed to these hazards.

The factors determining the exposure and sensitivity of the freight sector to meteorological hazards are numerous. Table 4.1 attempts an overview of these based on the literature reviewed in Chapter 3. All of these factors have changed to a greater or lesser extent during the previous two decades. For example, exposure in terms of traffic volumes has increased (DfT, 2008), trucks have become larger and heavier (DfT, 2008), truck loading has improved with a reduction in empty running (McKinnon and Ge, 2006), braking technology has improved (Edwards, 1996; Broughton and Baughan, 2002) and weather warning systems have been introduced (Highways Agency, 2007).

Table 4.1. Example of factors affecting sensitivity and exposure to atmospheric hazards

Hazard	Factor
All hazards	• Traffic volume (e.g. Qiu and Nixon, 2008) • Road lighting (e.g. Fridstrom et al, 1995; Wanvik, 2009) • Forecasting ability (e.g. Thornes and Stephenson, 2001) • Weather warning systems (Carson and Mannering, 2001) • Rural/urban split (e.g. Edwards, 1998)
Precipitation	• Road surface construction (e.g. Leden et al, 1998; Sokolovskij, 2007) • Vehicle technology – visibility (Andrey and Yagar, 2004) • Vehicle technology - braking (e.g. Edwards, 1996)
Ice	• Winter road maintenance infrastructure (e.g. Norrman et al, 2000; Thornes and Stephenson, 2001; Andersson and Chapman, 2010) • Road surface construction (e.g. Leden et al, 1998; Sokolovskij, 2007) • Urban heat island (Graham, 1993) • Winter tyre use (Vaiskunaite et al, 2009, Hjort and Jansson, 2010)
Wind	• Vehicle design (e.g. Baker, 1993) • Empty running / under-loading (e.g. Summerfield and Kosior, 2001)
Snow	• Winter road maintenance infrastructure (e.g. Thornes and Stephenson, 2001; Andersson and Chapman, 2010) • Road surface construction (e.g. Leden et al, 1998; Sokolovskij, 2007) • Winter tyres use (Vaiskunaite et al, 2009, Hjort and Jansson, 2010)
Fog	• Vehicle lights / Distance detectors (e.g. Cavallo et al, 2001)

The relative importance of these factors is unknown at present. Statistics on weather-related road freight accidents are not routinely produced by the Department for Transport. However, figures are available for general accidents (Figure 4.1: DfT, 2009), which show a general decrease in heavy goods vehicle accidents between 1998 and 2008, mirroring that of the rest of the road fleet (DfT, 2009). Although not focussed on the hazard of meteorology, it is useful to discuss the possible reasons for this reduction.

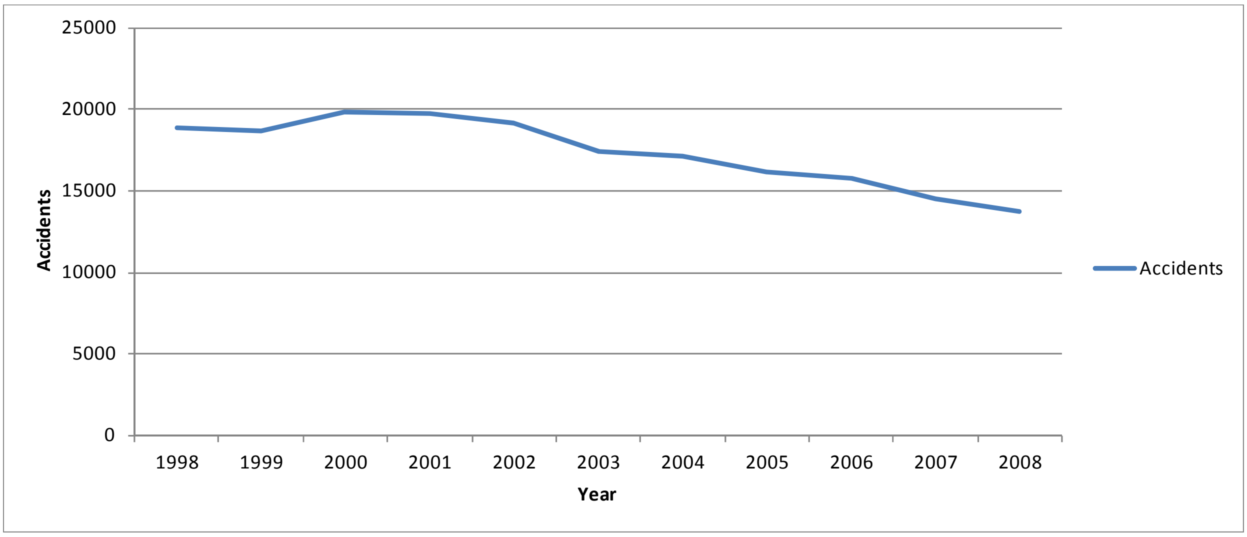


Figure 4.1. Heavy goods vehicle accidents between 1980 and 2008 (DfT, 2009)

As the method of reporting has not changed during this period (DfT, 2009), the most obvious potential explanations would come from a reduction in traffic volumes, an improvement of the design and handling of vehicles, or most likely a combination of the two. Figure 4.2 shows that vehicle kilometres in the freight sector, a partial surrogate for exposure, have reduced slightly during the 1998-2008 period (DfT, 2009). However, this may not fully explain the reduction in accident rates in Figure 4.1, as the accident rate per kilometre has also fallen (Figure 4.3).

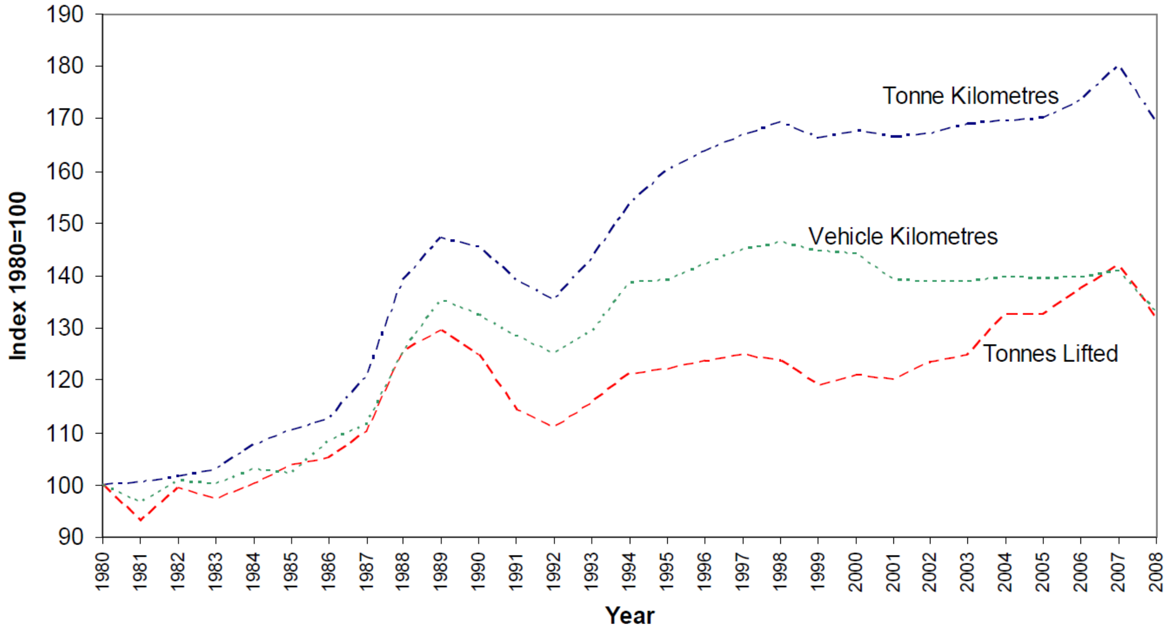


Figure 4.2. Tonne kilometres, tonnes lifted and vehicle kilometres for 1980-2008 (DfT, 2009)

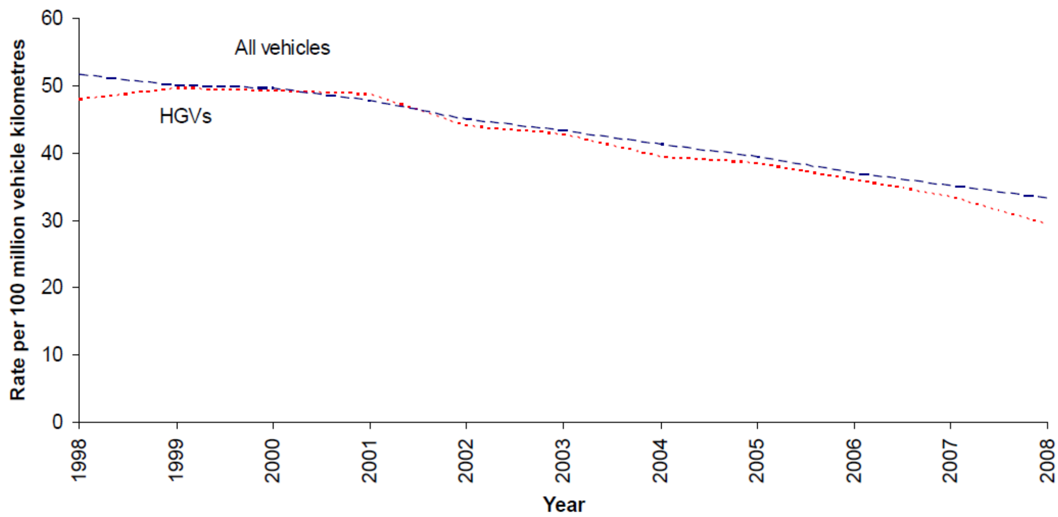


Figure 4.3. HGV accident rates per 100 million vehicle kilometres between 1998 and 2008 (DfT, 2009)

Figure 4.3 suggests that the safety of the vehicles themselves has improved. Improvements in handling and braking technology during this period may account for at least part of the reduction in accidents seen in Figure 4.1. Another potential reason may be improved driver training, as well as limits to driver hours brought in with the 1998 Working Time

Regulations and enforced through tachograph records. As mentioned earlier, these figures are not concerned with weather-related accidents. However, they illustrate the need to understand how exposure and sensitivity change, and more importantly why they change. As will become apparent exposure tends to be much more variable, with opposing trends occurring concurrently in superficially similar economies, such as the UK and mainland Europe (e.g. McKinnon, 2007). Sensitivity, on the other hand, tends to follow a much steadier trajectory, yet the specific developments that confer improvements in safety are much harder to predict (Sessa et al, 2009). For these reasons exposure and sensitivity are treated separately below. However, it must be remembered that in several instances such as vehicle-loading (Summerfield and Kosior, 2001; McKinnon and Ge, 2006), the two concepts are linked.

4.3. Exposure

Much research during the past two decades has been concerned with the reasons behind trends in freight growth. McKinnon (2007), Tapio (2005) and Sorrell et al (2009), among others, have explored the complex interactions between the economy and the amount of freight transport on the roads. Prior to this, general consensus suggested that these links were fairly simplistic and almost entirely coupled to economic growth, mostly based on the observed strength of correlation between GDP and freight. This led to the conclusion that the relationship between GDP and freight growth was invariant. McKinnon (2007) cites government road traffic forecasts in the 1970s that were based on this assumption (Tanner, 1974), with the logical conclusion being a perpetual increase in freight to unrealistic and unsustainable levels, as explored by Adams (1981).

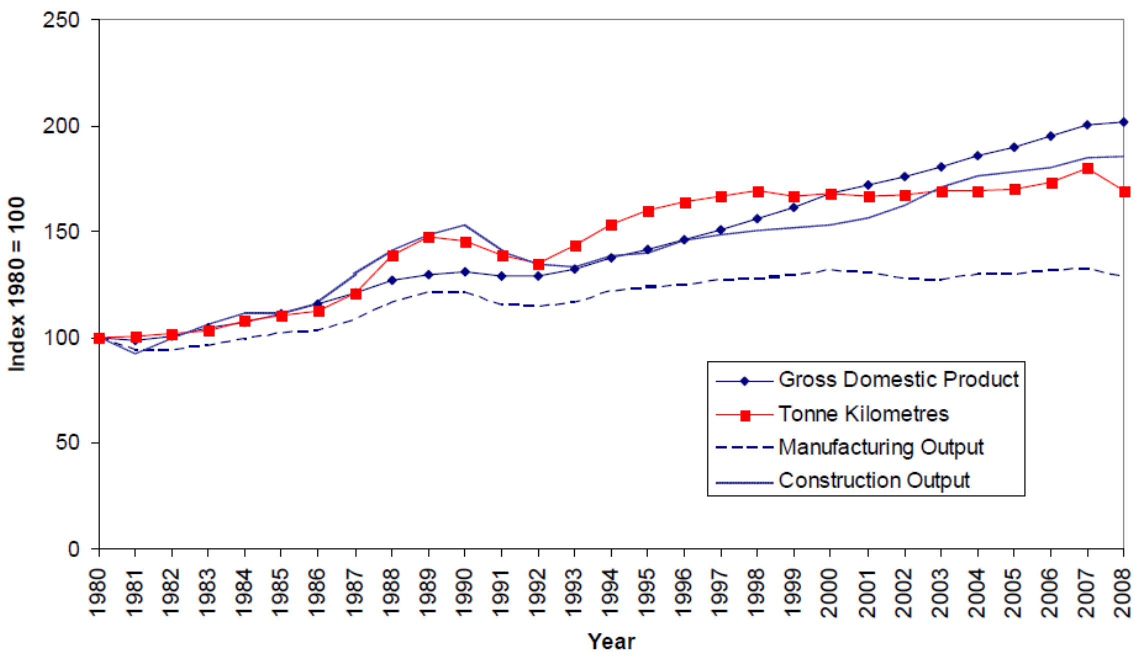


Figure 4.4. HGV freight and economic growth between 1980 and 2008 (DfT, 2009)

Indeed, from the late 1980s through to the late part of the current decade freight growth, measured in tonne kilometres, has 'decoupled' from GDP. As shown in Figure 4.4, freight began to outstrip GDP towards the end of the 1980s, and then proceeds to level off despite GDP continuing to grow. According to the definition of Tapio (2005), positive decoupling occurs when the volume of freight transport increases at a slower rate than GDP, whereas freight growth with a higher rate than GDP is termed as negative decoupling. As can be seen, both negative and positive decoupling occurred during this period. Another important point to note is the sharp reduction in freight in the final year of Figure 4.4, which may be an indication of the impact of the current economic crisis, an event discussed in Chapter 9 with reference to the Delphi study conducted during this time.

However, one caveat of much of this previous work is the concentration on the measure of freight intensity in terms of tonne-kilometres, which is not necessarily a measure of exposure. A more useful measure for this project would be kilometres or kilometre-hours. Figure 4.2 (DfT, 2009) shows that the trend lines for tonne-kilometres and vehicle-kilometres over the 1980-2008 period are not exact fits. There are several reasons why these two measures may diverge. For instance a reduction in the weight of goods transported without a corresponding change in volume may see a greater reduction in the tonne-kilometre statistics compared to those for vehicle kilometres.

Increased awareness of environmental issues in recent decades, especially climate change, has prompted governments to seek ways of promoting positive decoupling of GDP and freight growth (Schleicher-Tappeser, 1998; McKinnon, 2007). To this end, much research has attempted to disaggregate the reasons for recent instances of decoupling. Rather than being caused by one broad measure of the economy such as GDP, McKinnon (2007) investigated the decoupling as the net effect of a multitude of changes in the economy and the freight sector. The components in the following subsections are those used by McKinnon (2007) to explain the period of positive decoupling between 1997 and 2004. This provides a useful analytical framework for discussing the components that determine road freight exposure.

The decoupling framework first analyses the factors influencing the amount of goods produced by an economy and then goes on to those which influence the ways in which it is transported. For example, the value, weight and volume of goods produced and consumed is the highest order, and is determined by the composition of GDP, dematerialisation and the erosion of industrial activity to other countries. The amount of this freight taken by road is determined by the modal split, an aspect of transport which is well catered for in recent socio-economic scenarios. Finally, the number of road kilometres used is determined by the number of links in the supply chain, the rate of spatial concentration and the efficiency of freight transport.

It must be noted that the importance that each component has towards freight growth will almost certainly change in the future. For instance the cost of freight, which was judged to be of limited importance during the 1997-2004 period of decoupling may becomes more significant in the future, especially under the Global Sustainability and Local Stewardship scenarios produced for the UKCIP (2002: Figure 2.5), where environmental concerns are key drivers for public policy and private enterprise. Certain components such as the increased penetration of the UK haulage market by foreign operators are more of an issue for recorded freight intensity than exposure, therefore are not discussed here.

4.3.1. Changing composition of GDP

Changes in the composition of GDP determine the type of goods which are transported. Scenarios that promote a shift towards sectors which produce lighter goods may therefore reduce exposure, especially if the goods themselves experience further dematerialisation. However it must be noted that the volume of goods is perhaps a better indicator for exposure.

Sorrell (2009) makes the important point that future demand for freight will depend on the future demand for manufactured goods, as opposed to services. The rise of E-commerce is also an important influence on exposure. There is evidence that the impact of e-ecommerce in terms of increasing dematerialisation of certain products into electronic forms discussed by Crowley (1998) is becoming a reality. Although the impact of e-readers on the printed press is still uncertain, emerging technologies such as 3D printers may one day allow production and manufacture to be shifted to home, eliminating almost all links in the supply chain. Further discussion of the possible impact of socio-economic development on dematerialisation, the composition of GDP and the resulting influence on freight exposure levels is given in Chapter 9.

4.3.2. Dematerialisation

Changes in the relative contribution different economic sectors to overall GDP, as well as changes to the weight of the goods they produce are potentially key determinants of future freight exposure. Furthermore, they are factors that regularly feature in socio-economic toolkits, often diverging quite significantly under different political and economic environments. The reduction of the weight of goods in the economy is termed as dematerialisation. McKinnon (2007) mentions several processes which cause dematerialisation including the miniaturisation of products, replacement of heavier materials for lighter ones and the substitution of physical goods for electronic ones, with the shortening of product life cycles and the growth of packaging having the opposite effect.

4.3.3. Modal split

McKinnon (2007) calculates that the decline of road transport's share of the freight market accounted for 22% of the observed decoupling of road freight from GDP between 1997 and 2004. This is partly attributed to the increase in market share of water-based services, from 21% in 1997 to 24% in 2004. The privatisation of railfreight services in 1996 also spurred an increase in rail's market share from 7% to 8%. Although the amount of freight transported by road still rose during this period (Figure 4.2: DfT, 2009), the effect of the increase in rail and water-based transport's share of the freight market acted to limit this increase, and almost certainly also acted to reduce the exposure of vehicles to meteorological hazards in terms of kilometres travelled. McKinnon (2007) also calculates that a further 12% of the observed decoupling can be explained by the 16.7% increase in the real cost of road freight transport between 1997 and 2004. Although the main effect of this was to increase freight efficiency through better vehicle utilisation (examined in Section 4.3.4), it is plausible that it promoted at least some of the modal shift seen during this time.

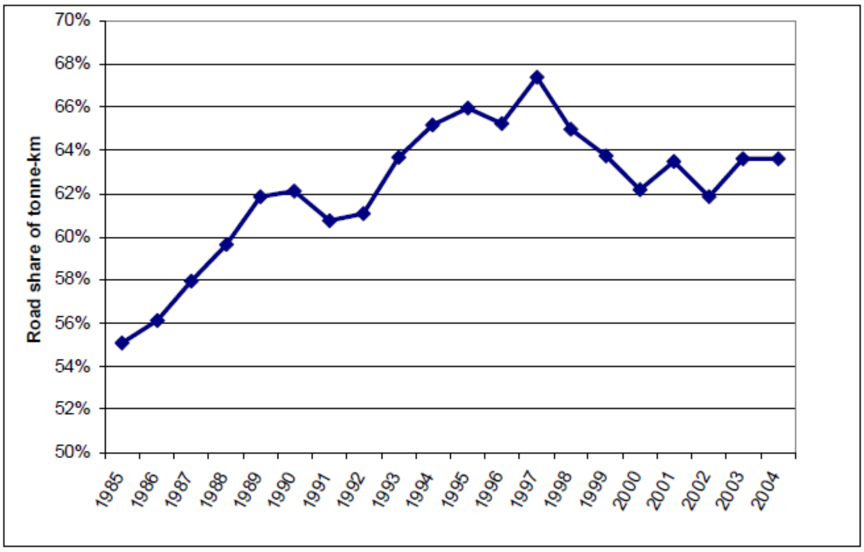


Figure 4.5. Percentage of total tonne-kms moved by road between 1985 and 2004, based on DfT (2005) data (McKinnon, 2007)

The movement towards rail taking a greater share of freight has been predicted (Brown and Allen, 1997), and has been observed over the last decade (DfT, 2009). The Netherlands demonstrate the ability to reduce freight intensity by encouraging modal shift towards rail and inland waterways through greater integration (Haq and Bolhuis, 1998). Recent examples in the UK include Eddie Stobart which now transports freight for Tesco by rail between England and Scotland and has also started rail deliveries of refrigerated goods from Spain, both of which were previously delivered by truck.

Given transport's role as a leading CO_2 contributor to climate change (see Chapman, 2007), it is highly likely that modal split will be an important determinant of future exposure, with a key factor in this importance being the extent to which the British government will promote a shift towards other modes in the coming decades. Much research has been conducted on promoting greater use of rail freight. Forkenbrock (2001) shows the external costs on society involved with rail freight, (including accidents, noise, particulate pollution and greenhouse gases) to be around three times lower than those associated with road freight. For instance the greenhouse gas externalities for road freight are estimated at 0.15 cents per ton-mile compared to 0.2 cents for rail freight (Forkenbrock, 1999). However, it must be remembered that this is a US study where road freight vehicles and distances travelled are considerably different to those in Great Britain. A British study has demonstrated that freight trains can remove approximately 50 to 120 HGVs from the road per day (DfT, 2008).

Although the decision-making process surrounding modal choice by an individual organisation is complex and not solely determined by cost (Gray, 1982), it seems likely that the internalisation of transport externalities will be the main instrument with which governments will attempt to lower the volume of freight carried on the road. For instance Nijkamp et al (1997) used a neural network of decision making to forecast the effect of eco taxes on modal choice across the Trans Alpine routes in Austria and Switzerland. The projected reduction in traffic flows resulting from these taxes shows the likely behaviour of transport managers when a mode becomes less attractive due to cost, and offers a potential policy route to promoting a shift to less polluting forms of transport such as rail freight.

Several other studies have attempted to forecast the likely impact of efforts to promote modal shift within the freight sector. For instance, Piecyk and McKinnon's (2008) expert Delphi of the environmental impact of road freight predicts a fall in road's share of the freight market from 64% to 59.9% by 2020. The study also predicts rail's share increasing from 9% to 11.3%, inland waterways and coastal shipping from 23% to 24.4% and pipeline's share from 4% to 4.4%. However, it must be noted that freight traffic volumes were forecast to increase by around 25% from 257 billion tonne-kilometres in 2005 to 322 billion tonne-kilometres in 2020; hence the total exposure of road freight vehicles to meteorological hazards is still likely to rise.

Modal choice is one aspect of transport included in the UKCIP02 scenarios, but only for passenger transport (UKCIP, 2001). However, that study does provide a precedent for converting qualitative storylines of contrasting socio-economic scenarios into quantified indicators of future modal split via expert opinion. For instance, the World Markets and National Enterprise scenarios where environmental concerns are minimal sees road transport's share of passenger kilometres at 85% by 2050, similar to the mid-1990s baseline of 87%. Where environmental concerns are key to governance, such as the Local Stewardship and Global Sustainability scenarios, road's share falls to 70% and 64% respectively by 2050, with rail seeing an increase to 15% in both scenarios along with large increases in bus and coach transport.

4.3.4. Reduction in number of links in the supply chain

The number of links in the supply chain is an important determinant of freight transport growth. Although there was a slight reduction during the 1997-2004 period, prior trends were predominantly towards a greater number of links impacted by the wider geographical sourcing. Historically, this move towards larger and more complicated supply chains has been enabled by lower transport costs and faster travelling speeds, termed as a reduction in the 'friction of distance' (Sessa, 2009). This is particularly noticeable with 'food miles', the increasing amount of transport that occurs in the farming and processing of foods stuffs (e.g.

Böge, 1995). However, in scenario building over periods of 20-50 years it is quite conceivable to imagine scenarios where changes in socio-economic values and governance promote changes which are inconceivable in the short to medium-term. For instance the research by (Böge, 1995) suggesting that the total vehicle-km involved in strawberry yoghurt production could be reduced by 67% if the nearest suppliers were used but would be at the expense of customer choice and higher prices make it an impractical choice in the present-day. However, under the local stewardship scenario of the UKCIP (2001) and BESEECH toolkits (2006), it is exactly this type of production which is promoted due to greater community values and a more regionalised economy and government.

Anderson et al (1999) stress the importance of the European Commission's (EC) Packaging and Packaging Waste Directive and the subsequent 1997 UK Producer Responsibility Obligation requiring companies to take responsibility for the recycling of their packaging. An increase in the number of links in the supply chain in vehicle kilometres of 14% was estimated to have resulted from this, hence contributing to exposure during the 1997-2004 period. Increased home delivery freight driven by e-commerce journeys also act to increase the number of links in the supply chain. It can also be argued that this shift in operational practice increases exposure to winter-related hazards, as a significant proportion of freight transport may increasingly be moved away from the trunk road network and onto minor roads, which are less likely to be gritted. However, McKinnon (2007) mentions that home delivery by vans to some extent merely replaces car journeys that previously delivered the 'last mile' in the supply chain. This development also has significant environmental benefits if deliveries are routed efficiently (Edwards and McKinnon, 2009). Hence, when taking road transport as a whole, this move should act to reduce total exposure.

4.3.5. Diminishing rate of spatial concentration

Spatial concentration refers to the trend towards centralisation of production and distribution, as transport costs fell and average travel speeds increased during the second half of the 20th Century, allowing firms to serve a wide geographic region from fewer locations (Quarmby, 1989; McKinnon 2007). This had the effect of increasing the average leg length of journeys, therefore increasing exposure. The effect of this process can be seen in the large-scale increase in European freight transport after the liberalisation of freight markets allowed firms to concentrate production and distribution into a small number of sites serving large parts of the continent.

It also has to be remembered that the road network of Great Britain is to a large extent fixed in its current form, with little scope for major reorganisation. As a result, certain logistical changes become difficult to implement, especially further logistical centralisation. For example, the cost savings estimated from a lowering of distribution depots can only be implemented with concurrent improvements to the road network (Quarmby, 1989). However, environmental issues may also emerge as a key driver for changes in the location of distribution centres within the existing road network. For instance, Browne and Allen (1997) concentrate on reducing energy use by freight in cities through a range of measures, including raising vehicle payloads, reducing empty running and the use of urban transhipment centres. This would shift the exposure outside of the city towards the countryside, which as Edwards shows (1996, 1998), increases accident rates.

4.3.6. Efficiency of freight transport

Exposure may also be reduced as freight becomes more efficient. Several components of the 1997-2004 decoupling explored by McKinnon (2007) relate to this. A useful way of introducing these concepts is through the work of Samuelsson and Tilanus (1997) who defined efficiency in terms of actual transport output compared to the theoretical maximum output, the case that would exist if goods were moved non-stop from origin to destination along a minimum distance travelling at maximum speed. They suggest that actual efficiency (E) is determined by four dimensional efficiencies; Time (T), Distance (D), Speed (S) and Capacity (C) so that;

$$\boldsymbol{E} = \boldsymbol{T} \times \boldsymbol{D} \times \boldsymbol{S} \times \boldsymbol{C}$$

Time refers to the percentage of available time that a vehicle is utilised, the theoretical maximum being non-stop 24-hour utilisation. Distance efficiency describes the extent of the deviation away from an idealised minimum radial distance. The speed efficiency is a measure of the travelling speed against the maximum allowable speed and the capacity efficiency, referring to the weight or space used in trailer compared to the maximum weight/space capacity. A future scenario that promotes an improvement to any of these ratios should result in a more efficient freight. Although this may not result in less exposure per tonne kilometre (for instance a large increase in vehicle capacity without a reciprocal increase in lifted freight would lower the ratio), in practice a decrease is likely.

Better vehicle routing and improvements in vehicle utilisation as a by-product of increased freight cost are the two components mentioned by McKinnon (2007), which relate most to Samuelsson and Tilanus's (1998) concept of efficiency. Improved vehicle routing through computerised methods show significant reductions in distance travelled. As McKinnon (2007) shows, although investment in infrastructure was at a low level during the period of decoupling, the way the existing road network was navigated became more efficient due to the use of computerised vehicle routing and scheduling (CVRS) packages. It is estimated the use of these packages can cut vehicle kilometres by 5-10%, with even greater reductions in travel times achieved by bypassing known congested areas (McKinnon, 2007).

As mentioned in Section 4.3.1, increases in the real cost of road freight led to more efficient vehicle utilisation. The empty running of trucks has been reducing in the UK due to a number of factors including the obligation for operators to collect return loads (McKinnon, 1996). This includes own account (vehicles owned by the company) returning waste products and recyclables as well as stock, and third part logistics companies picking up loads on an ad hoc or agreed arrangement. This third party movement has been especially aided by electronic systems, allowing companies to obtain a suitable backhaul.

However, statistics suggest little change in the percentage of vehicles running empty between the years of 1998 and 2008, with a small increase from 27.5% to 29% (DfT, 2009). McKinnon (2000) shows evidence that just-in-time replenishment (the reduction of buffer stock and lead times in the supply chain; e.g. Garreau et al, 1991) has not encouraged under-utilisation of truck space, with companies taking extra measures to add consolidation to loads at different points in the supply chain. One problem in vehicle utilisation studies is that most countries record load factor by weight rather than volume, which is important as some vehicles are full before their weight limit is reached, leading to an underestimation of vehicle utilisation (McKinnon et al, 2002).

Increasing vehicle weight and size limits can also reduce the number of vehicles on the road (McKinnon, 2007). The use of 'double deck' or 'high cube' trailers is unique to the UK due to the higher clearance under bridges. This clearance of 4.9 metres compared with the European standard of 4 metres allows taller trailers to be used, having the effect of decreasing exposure, as a greater volume of freight can be carried by the same length of trailer. However, this also has the effect of exaserbating the problems of high-sided vehicles operating in windy conditions previously discussed by Baker (1993).

There are also calls to increase the weight and length and weight limits on UK freight towards those seen on mainalnd Europe. The current weight limit is 44 tonnes, with the length limit being 16.5. Knight et al (2008) discuss the impact of raising these limits up to a maximum of 82 tonnes and 34 metres. It was hypothesised that road wear would increase, vehicles may be trapped by road geometry, bridges would need to be strengthed and parking facilities altered. Again this would have the effect of decreasing exposure and increasing sensitivity, due to the greater surface area presented to crosswinds.

Penman (1997) highlights the potential improvements in utilisation simply through using more efficient pallet load systems. For instance, it was shown that by using higher pallets it is possible to utilise more of the available trailer space in grocery vehicles. The potential impact of this if implemented across Europe would be a reduction of 15% of the vehicles used in the sector. McKinnon and Campbell (1998) demonstrate that similar efficiency gains can be made by double-decking loads. The environmental reasoning behind regulations targeting packaging would suggest that the Global Sustainability and Local Stewardship scenarios of the UKCIP toolkit (2001) would promote higher levels of vehicle utilisation than the World Markets and National Enterprise Scenarios. Of course, vehicle utilisation also has a bearing on handling under high wind conditions (Summerfield and Kosior, 2001) and is a useful point on which to enter the discussion on sensitivity.

4.4. Sensitivity

Sensitivity is not a commonly forecasted characteristic, nor is it one which has a relationship with the overlying economy that can be easily modelled. Ongoing improvements in vehicle braking technology, telematics, vehicle body design as well as anticipated future technologies such as automation are all likely to reduce accidents. Furthermore, sensitivity will also be determined by the quality of infrastructure on which freight vehicles operate. Much of any future change in road freight transport safety may come about by as yet unknown 'disruptive technologies', developments which have the potential to fundamentally alter the nature of a given industry. Unlike fuel technology whose take-up is often hastened in response to price shocks (Sessa et al, 2009) the introduction of safety technologies often follow a gentler curve, where economies of scale reduce the price. This is especially true where technologies need to reach a critical mass before their true safety gain is seen, such as automated vehicles. However this section attempts to draw links with the economy. Although difficult to predict, this section reviews the current understanding how sensitivity changes within the freight sector, and highlights a number of potential developments in both the short and long-term.

4.4.1. Technology and vehicle design

As shown in Table 4.1, many of the aspects determining sensitivity are concerned with the design of heavy goods vehicles. Foresight (2002) provides an interesting example of how the future vehicle design can be assessed in a structured process. Figure 4.6 shows the trends and drivers used by Foresight (2002) to determine changes in the road transport system. These are expanded in Figure 4.7 to show the likely timing of significant developments within each of these dimensions between 2002 and 2022.

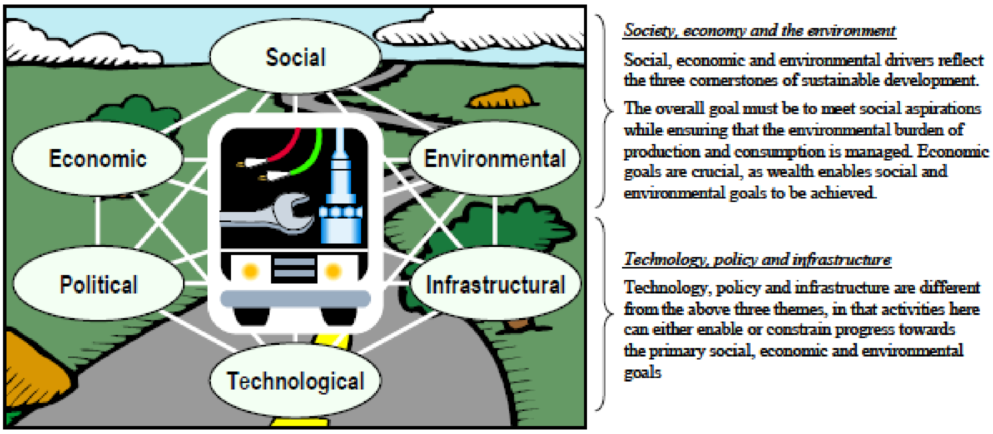


Figure 4.6. Trends and drivers that influence the road transport system (Foresight, 2002)

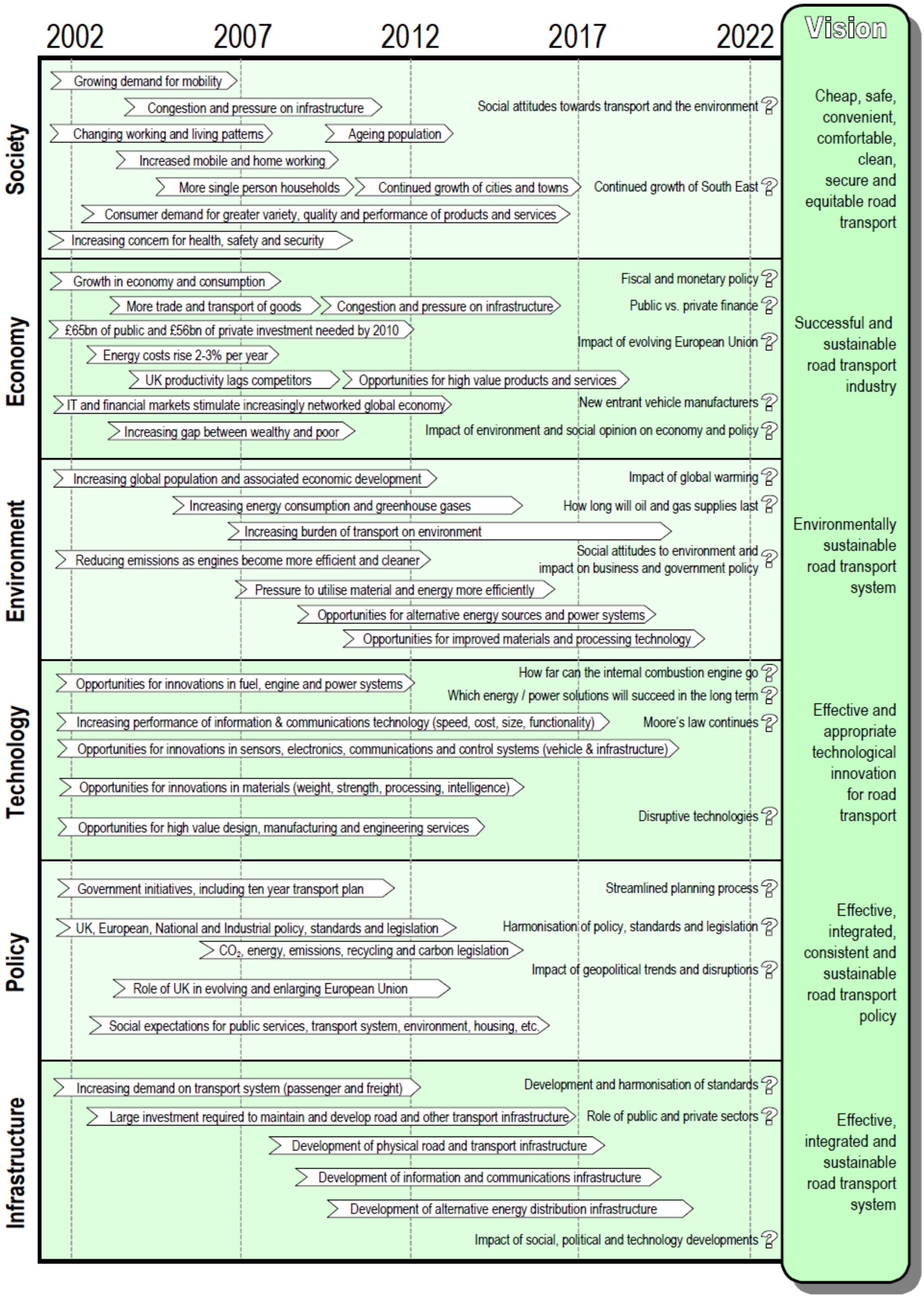


Figure 4.7. Industry market trends and drivers (Foresight, 2002)

These trends can then be mapped onto various technologies to determine how the overlying economy may promote or impede its development. An interesting example for this thesis is the integration of software into road vehicles. Duff (2006) has previously postulated that drive-by-wire and brake-by-wire are possible future developments as well as sensor technology that will determine distances between vehicles and ensure speed limits are kept to. Even aspects like tyre wear could be monitored electronically (Duff, 2006), which again has impacts on braking distances in adverse weather.

However, this methodology of that Foresight (2002) utilised has several limitations. Firstly, it is based on a single scenario of socio-economic change over a 20-year period. This does not allow for potentially divergent trends in governance and values over this period. Secondly, the scenarios are based on backcasting. This is where a desirable outcome in the future is selected, and the necessary steps to achieve this end-point are envisaged. Lastly, these scenarios provide little scope for clear breaks with the past. Disruptive technologies are only envisaged at the very far end of the timeframe Figure 4.9.

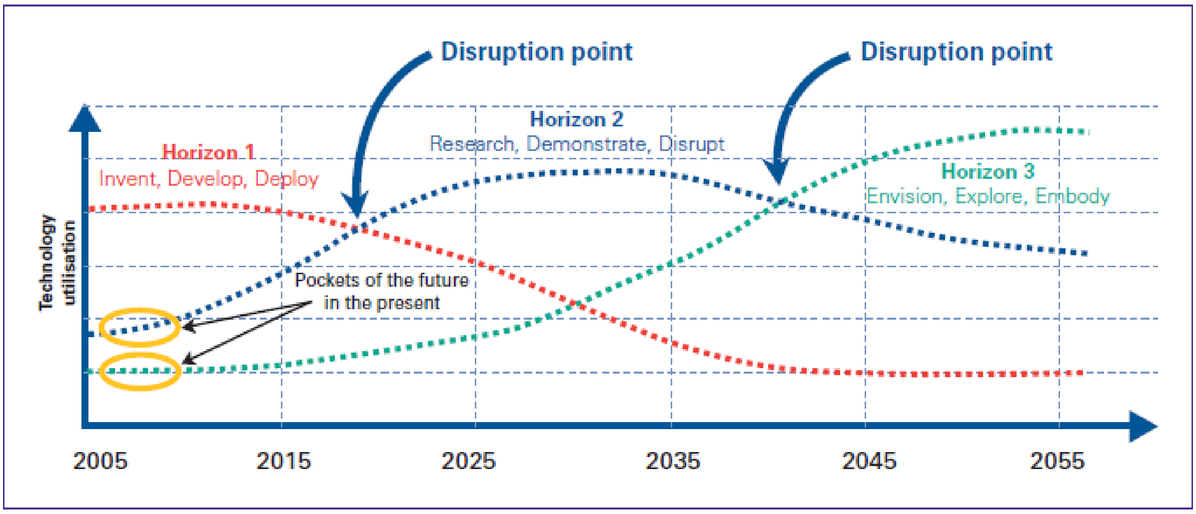


Figure 4.8. Three time horizons in anticipating technology developments (Foresight, 2006)

The Foresight group's (2006) later approach looks at three time horizons (Figure 4.8), allowing for both innovations in existing and new, as yet unknown technology to be considered. The first horizon describes a continuation of the present, with the introduction of new but understood technology, with fairly predictable innovation. An important point about this second phase is that even when the trend of innovation is clear, the form it is achieved in can be unpredictable. An example they use to illustrate this is the Internet, as researchers and business were predicting a global information network in the 1980's, but did not know the model it would take. They suggest similar broad advancements can be predicted within transport, such as automation, which is highly anticipated even though the technology does not yet exist.

4.4.2. Longer-term developments and sideswipes

As mentioned in Chapter 2, scenarios are often too conservative and do not include sideswipes: unexpected breaks with the past (Berkhout et al, 1999). Many forecasting and visioning techniques such as the previously mentioned Foresight (2002) study do not allow for the consideration of low probability high impact developments. Part of the reasoning for this is that the process of constructing scenarios often involves building consensus among a group of experts. In reference to the Delphi methodology Linstone and Turoff (1995) argue that consensus-based techniques often produce conservative views of the future. In suppressing radical views such methods have the effect of reinforcing existing paradigms.

However, thought-provoking insights can be found by consulting individual experts in the industry. For example, the Chartered Institute of Logistics and Transport UK (CILTUK, 2006) elicited future transport visions at an 80-year horizon, extending from its implementation in 2006 to an anchor year of 2086. McKinnon (2006) suggests both positive and negative scenarios for this timeframe. The positive scenario sees the introduction of a market based approach to network allocation, with electronic auctions being used to determine use. This demonstrates the importance of disruptive developments on levels of freight exposure. The positive scenario also sees the automation of most freight, which would have huge and largely unknown impacts in the relationship between weather and freight accidents. Interestingly both the positive and negative scenarios suggest a point where freight growth will cease, either due to miniaturization and more efficient freight, or through economic collapse brought about by climate change and restrictions put in place on reactionary environmental grounds.

Interestingly, Sessa et al (2009) mention that as a result of a Delphi survey, safety was reported as one of the most predictable factors, whilst paradoxically technology is perceived as one of the most difficult. This is probably an issue of detail, as respondents will have lived through an era of improving technology, which they are confident of persisting into the future, without necessarily being able to identify the specific technological improvements through which this increased safety will be achieved. This is similar to Moore's Law in computing (1965), where aspects such as processing speed and memory capacity can be accurately predicted to multiply at a standard rate, without knowing the advancements that will lead to this.

4.4.3. Vehicle usage

As mentioned in section 4.3, exposure and sensitivity are often linked. For example, the increase in reverse logistics of packaging waste may have a detrimental effect on the sensitivity of a vehicle to wind. Compared with drivers running empty vehicles who can tie back the side curtains to reduce the chance of overturning during heavy wind events, drivers operating on a backhaul would not have this option, and as a result would potentially be operating partly loaded, leaving the vehicle more vulnerable to crosswinds (Summerfield and Kosior, 2001). Interestingly it has been suggested that an increase in pressure to find backloads usually happens during recessions due to the intense competition in the road haulage industry, potentially adding a cyclical aspect to wind vulnerability. Congestion charges could lead to more night-time deliveries (Duff, 2006) which could increase the effect of adverse weather due to low light conditions.

A significant recent trend in the UK freight and logistics sector has been the increased pentration by foreign-registered operators. For example, in 1997 52% of all freight vehciles arriving at British ports were foreign registered, in 2004 this rose to 75% (department for Transport, 2005; in Mckinnon, 2007). Cabotage, the transport of deomestic freight by foreign operators has also increased. Differences in driver training, vehicle standards and maintainance as well as the driver's unfamiliarity of driving on the left-hand side of the road could all theoretically contribute to increased sensitivity. Socio-economic scenarios often include levels of EU integration, a potentially useful measure when discussing future rates of cross-border operations.

Certain scenarios promote better expenditure on infrastructure. Some proposed techniques involve bypassing surface transport altogether, such as hydraulic tunnels (Howgego and Roe, 1998; Taniguchi and van der Heijden, 2000), would reduce exposure and sensitivity to meteorological hazards to zero. Similar underground tunnels have been suggested by Browne (2006) as a potential solution to future distribution demands as well as tighter planning and aesthetic restrictions. This would solve many of the problems of city logistics including congestion mentioned by Ogden (1984). Although seemingly far-fetched, several examples of enclosed and subterranean freight systems have already existed, including the Post Office's automated railway which transported mail along a 23 mile network between sorting offices in London until its closure in 2003 (Aldhous et al, 1995; Howgego and Roe, 1998). The involvement of British architect Norman Foster in the planned Masdar City project in Abu Dhabi is an example of the concept of enclosed transport applied to an entire city, with all transport being confined to guided electric vehicles on a subterranean level.

4.5. Conclusion

This chapter highlighted the complexities involved in moving from a simple physical based CIA towards a more holistic assessment incorporating concurrent socio-economic change. The concept of severe weather is relative and mutable, and is determined largely by the exposure and sensitivity a society or sector to that hazard. By reviewing the existing research on the causes of past changes to the components of freight important to exposure and sensitivity, the likely impact of future changes can be hypothesised. These links are generally stronger for exposure. A paradox of attempting to forecast sensitivity is that while the general path of vehicle safety has been shown to be predictable, the specifics advances that bring these benefits are harder to predict (Sessa et al, 2009). Although the Foresight Vehicle Technology Roadmap project offers a suitable structure for forecasting components of sensitivity in the medium-term, the timeframes involved with climate change increase the likelihood of sideswipes; significant technological developments which are inherently unexpected.

As with vehicle technology, attempts to forecast freight growth are also concerned with the medium-term. It is obvious that a shift to greater timescales necessitates the consideration of potentially divergent socio-economic outcomes as discussed in Chapter 2. A key question is whether the factors that have affected exposure and sensitivity in the previous two decades will change in their importance during the timeframes involved with climate change? It is clear that environmental issues, especially climate change, will have an increasingly important role in freight and logistics. Diverging scenarios for the British government and society's response to this challenge are imaginable, and will have a large bearing on the shape of the transport sector of the future, just as the level of climate change they promote will determine the extent of the potential impacts on the physical operating environment of freight discussed in Chapter 3. These two dimensions of change are strongly linked. The following two chapters build a framework within which these can be integrated.

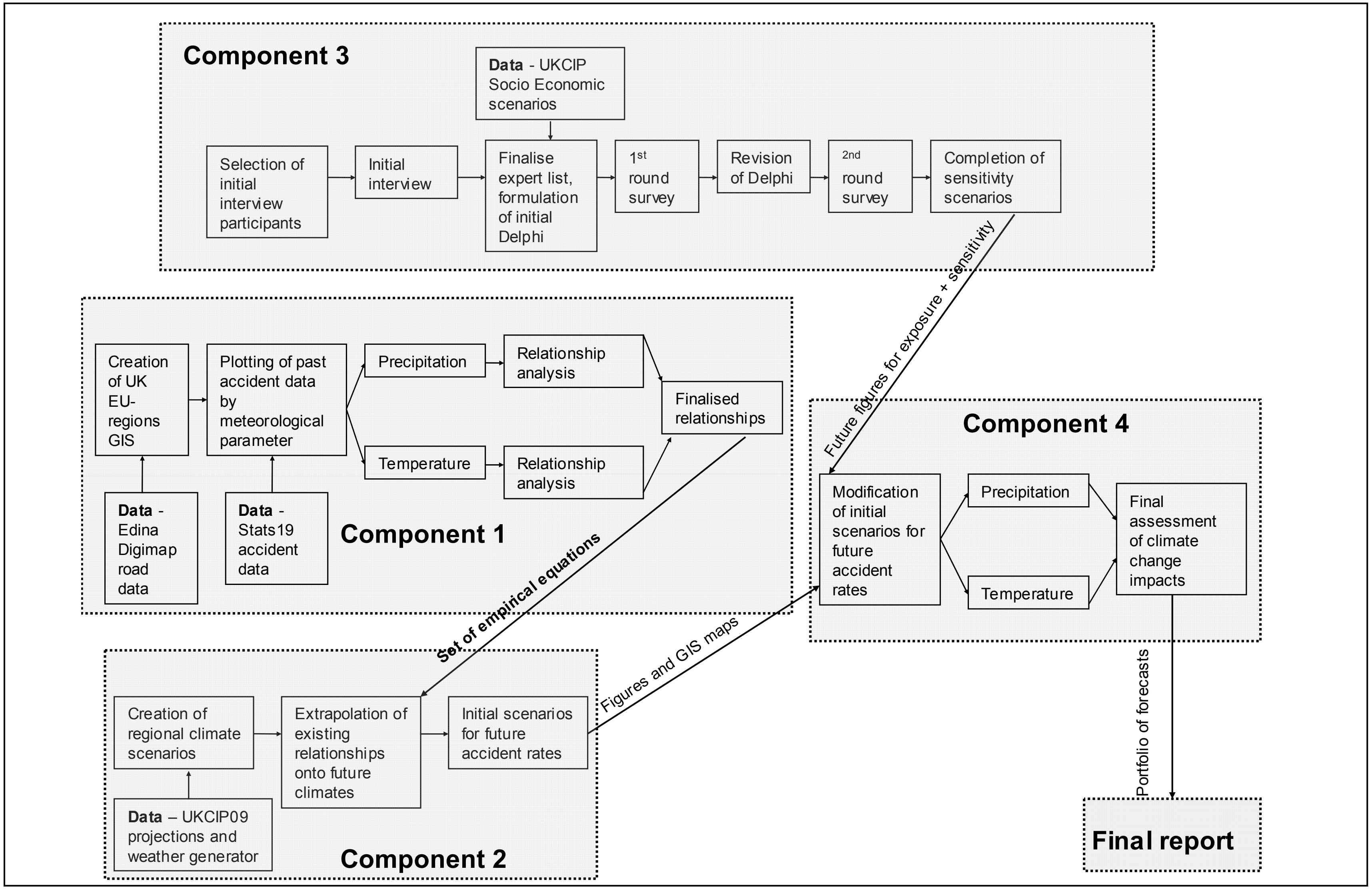
Chapter 5 - Methodology 1: The Physical Assessment of Climate Change

5.1. Introduction

The following two chapters present the methodological framework of this thesis. Central to conceptualising and constructing this framework was the exploration of CIA (Chapter 2), which presented a set of guidelines that informs the organisation of this project (e.g. Tol, 1996; Füssel and Klein, 2006). The first section of this chapter uses the sector-specific knowledge from Chapters 3 and 4 to arrive at a broad framework within which changes in the climatic and socio-economic environment can be examined, quantified and integrated.

Of key importance is Figure 5.1, which displays how the four components of this project interact with each other to achieve the ultimate aim of an integrated assessment. The justifications and reasoning for the methods adopted in this thesis are highlighted throughout. The remainder of the chapter details the approach taken in estimating the impact of climate change on road freight transport accidents. This includes the determination of relationships between key meteorological parameters and accidents and the use of probabilistic climate scenarios and generated weather time-series to extrapolate these relationships onto future climates. The methodology presented in this section can be thought of as the base of the climate change impact assessment, similar to the 1st generation CIA examined in Chapter 2 (Füssel and Klein, 2006). In this way it provides a starting place for the more sophisticated and holistic assessment methodology reached in Chapter 6.

Figure 5.1. The methodological framework



5.2. Project overview / road map

The design consists of four distinct yet interdependent components (Figure 5.1). Relating to the base of the physical assessment, Component 1 deals with the determination of a set of relationships between meteorological events and road freight accidents. Component 2 uses these relationships, along with existing climate change scenarios, to extrapolate an initial projection of future freight accidents based on an unchanged freight network. Component 3 deals with the construction of expert led forecasts for the future sensitivity and exposure of the freight network based on a set of underlying socio-economic drivers. Component 4 utilises the potential meteorological risk and future sensitivity and exposure to reach a final assessment of the possible climate impacts on the road freight sector.

5.3. Methodological framework

The interaction of physical stressors with a constantly evolving sector requires an interdisciplinary framework within which an estimate of future impacts can be derived (Tol, 1998). Much work within the climate research community has focussed on formulating a set of guiding principles for implementing such assessments (e.g. UKCIP, 2001). However, there has been confusion over what constitutes a climate change impact assessment (CIA), and what distinguishes this from vulnerability and adaptation assessments. As stressed in this thesis, these ideals are purposely mutable, with the requirements of the framework being determined by several factors inherent to the sector in question.

Füssel and Klein's (2006) classification of the different generations of CIAs based on their level of sophistication and incorporation of interdisciplinary techniques (presented in

Chapter 2) is useful for identifying a suitable framework for this project. It is helpful to consider the most basic framework available, determine which components of that framework will be appropriate to this study and then move forwards through the more advanced frameworks to include as many physical and socio-economic concepts as is feasible within the bounds of this thesis. For example, the study by Dawson et al (2009) on coastal risk (discussed in chapter 2) is an example of a sophisticated CIA, incorporating aspects from the more advanced generations of CIA mentioned in Füssel and Klein's (2006) classification, in that it determined both how sea level rise may impact on coastal erosion and how concurrent development along the coast may increase economic and human exposure. This process applied to this study therefore produces a set of interdependent components, both physical and social, within which the aim of this assessment can be achieved.

As with all CIAs, the base component is an assessment of the physical impacts that climate change will impose on a sector identical to that of today (Tol, 1998; Füssel and Klein 2006). This means that initially, possible changes in freight traffic volume, the geographical concentration of freight activity, the economic costs involved with accidents, and vehicle design and safety are not taken into consideration. As quantitative relationships between meteorology and road freight accidents have not previously been determined in the literature, this project adds an additional step to those of the frameworks previously discussed. This first component investigates the impact of meteorology on road freight accident rates in similar ways to those examined in Chapter 3 (e.g. Eisenberg, 2004; Andrey et al, 2003) and provides the necessary empirical relationships (in the form of a set of equations) to be used in the second component. This second component utilises these empirical relationships along with climate scenarios for the UK in a similar way to previous assessments such as the REGIS project (Holman and Loveland, 2002) to produce a simplistic climate extrapolation.

This gives a future forecast for the number of accidents caused by different meteorological hazards and also indicates how climate change alone may affect the geographical distribution of these incidents, expanding on the preliminary discussion around the UKCP09 climate maps in Chapter 3.

The next level of complexity involves forecasting the non-climate factors that will influence the sensitivity and exposure of the road freight sector to meteorological hazards. Relevant issues include how the size of the UK road freight industry may change (thus determining the number of vehicles exposed to meteorological events), how the distribution of the freight network may be spatially altered and how the sensitivity of vehicles to meteorological events may change. This component utilises the literature examined in Chapter 4 along with interviews and questionnaires with freight experts to identify key variables, and uses appropriate forecasting techniques to hypothesise how these may change in the future. Due to the uncertainties involved, several forecasts are made, based on possible scenarios for socio-economic development in the UK, similar to the approach of UKCIP (2001) discussed in Chapter 2. The formation of expert consensus is a key part of this process, and is sought using the Delphi methodology (e.g. Linstone and Turoff, 1975). The use of non-climate drivers of sensitivity places this part of the project within a 2nd generation vulnerability assessment framework according to Füssel and Klein's typology (2006). The output of this component is in the form of quantified forecasts of certain indicators and qualitative storylines for others.

Component 4 uses the physical and socio-economic futures formulated in the Components 2 and 3 to reach an integrated assessment of the impacts of climate change on potential future road freight networks. Using the knowledge of the accident rates expected under various possible climates from Component 2 and the possible future exposure and sensitivity information from Component 3, integrated scenarios are created which attempt the level of sophistication of recent CIAs, including the previously mentioned work by Dawson et al (2009). A matrix of the various climate scenarios and sensitivity/exposure scenarios is used to examine the range in magnitude of the impacts and gives an indication of best and worst case scenarios as well as to identify the most likely outcomes. Component 4 marks the upper bounds of the assessments complexity.

5.4. The relationships between meteorological events and road freight accidents

The first component is concerned with the determination of a suite of empirical relationships between meteorological parameters and road freight accident rates. These relationships are developed as tools to be extrapolated onto climate scenarios in Component 2. Several relationships are already established in the literature as discussed in Chapter 3 (e.g. Andrey, 1992; Qiu and Nixon, 2009). This chapter examines the techniques used in these studies and assesses whether they could be appropriated to achieve the research objectives of Component 1. This component also aims to present a broad overview of the current spatial and temporal patterns of weather-related road freight accidents in the UK, both for comparison with previous research on general road transportation (Edwards, 1994; 1996, 1998, 1999) and to provide a baseline to contrast future projections with. The methodological framework of this component is presented in Figure 5.4 towards the end of this section.

5.4.1. Research objectives of Component 1

- To formulate a methodology for determining empirical relationships between meteorological events and freight accident rates.
- To ensure that these relationships are in a form that is compatible with the climate scenario tools used in the second component.
- To identify existing sources of UK vehicle accident data.
- To filter accident details by vehicle type and descriptive meteorological conditions.
- To link accidents to reliable meteorological observations.
- To produce an overview of the current spatial and temporal patterns of weather-related road freight accidents in the UK.

5.4.2. Accident relationships for CIA

Currently there is no definitive set of relationships between meteorological events and road freight accident rates, hence no methodology exists which can easily be applied to this thesis in its existing state. Barriers to the formation of empirical relationships existed as current methodologies tend to be:

- Applied on a relatively small scale to urban areas.
- Based on an analysis of all vehicle types with no distinctions being made for freight transport.
- Concerned with one meteorological parameter, in most cases precipitation.
- Often not linked to reliable meteorological observations.
- Not quantified in a way which is compatible with climate change scenarios.

One of the fundamental differences between this thesis and many studies in the literature is the requirement for a specific form of quantification in the formation of relationships imposed by the climate tools. For example, the 6-hour spatial resolution used by Keay and Simmonds (2006) for observations of precipitation is not possible on most climate models, so a lower temporal resolution must be used. However, this does not mean an inherent simplification in all aspects of the analysis used in this thesis compared to studies not concerned with climate change. For instance, where in previous studies impacts were often related simply to the presence of a certain type of meteorology regardless of its intensity and magnitude (Andrey et al, 2003), this study seeks more complex dose-response relationships where possible. It is clear that a compromise must be made, as techniques that use ‘wet days’ as a variable (such as Edwards, 1998, 1999) would not be able to capture the true nature of climatic change for parameters such as precipitation which, unlike ice, show no threshold value (Eisenberg, 2004).

It is also clear that the spatial resolution of the majority of studies examined in Chapter 3 cannot be retained. The scale at which climate and socio-economic scenarios are presented, and the scale deemed most useful in sector dissemination, is regional, whereas the scale often presented in previous studies is the individual city. However, the enforced shift towards regional relationships (similar to those studied by Eisenberg 2004; 2005) in this thesis presents a useful methodological benefit. Different regions respond differently to meteorological hazards, and cities present different additional factors (lighting, lower speeds) to rural areas (lower road lighting levels, higher speeds) (Edwards, 1996; 1998). The level of complexity these factors present (Fridstrom et al, 1995) renders them impossible to model properly, so by determining separate relationships for a range of regions, much like the work of Eisenberg (2004; 2005) and to an extent Edwards (1996; 1998; 1999), it is arguable that the influence that the relative proportions of urban and rural road sections would be accounted for, rather than explicitly modelled. This has the disadvantage that the methodology is not instantly compatible with other countries, as new relationships will have to be determined for any new region, instead of the adoption of a more universal equation. However, in practice such an equation would be unfeasibly complex and the data requirements so intense that they would be unworkable.

The focus on climate change also determines the temporal resolution at which relationships are built. It is clear that the demand for hourly meteorological and traffic data of studies based in the present day often cannot be met by the current climate and socio-economic tools. The relationships must be in a form that can easily be extrapolated for future climates. This is problematic, as the daily or hourly meteorological data used in previous studies are not compatible with climate change scenarios which are often given in annual, seasonal or monthly averages (Murphy et al, 2009). Hence a shift towards monthly and seasonal relationships, again similar to Eisenberg (2004), is necessary. As daily predicted accidents are no longer required, other considerations such as the influence of day of the week or time of day are also less important. More important confounding factors such as the differences in daylight hours are accounted for by the formation of individual seasonal relationships for winter and summer, rather than the modelling approach of Fridstrom et al (1995).

Edwards's (1999) analysis does not take into consideration the trends in accident rates over the study period. It is plausible that improvements in overall vehicle safety, similar to those highlighted by the Department for Transport (2009), could have influenced the vehicle's response to meteorology. This is also a concern in this thesis, as changes in the safety of vehicles during the control period could produce a false baseline. This is exemplified by Qiu and Nixon (2009) who in their meta-analysis demonstrated the changing relationship between weather and accidents. For example, the percentage change of crash rates during snow showed a decrease from 113% during the period of 1950-1979 to 47% between 1990-2006. Preliminary examination of the UK data shows a similar decrease between 1985 and 2006, which is discussed in Chapter 9. This limits the sample period in which a relationship can be formed, as safety improvements during the past 20 years have changed the relationship between weather and accidents. The sample period should be as static as possible to reduce the effect of this confounding factor.

5.4.3. Selection of hazards

Chapter 3 clearly determined that the extent to which different climatic parameters are handled by climate models varies wildly. Whereas temperature and precipitation are covered extensively and authoritatively by the climate tool available in the UK, others such as snow and fog are not included (Jones et al, 2009; Murphy et al, 2009). This severely limits the amount of useful analysis that can be performed. The projection of fog-related accidents is already hampered by the lack of quantitative studies in the literature. However, the lack of climate scenarios for snow is a greater disappointment, as a strong literature on the relationship between snow and accidents already exists and would be amenable to a UK study (e.g. Andreescu and Frost, 1999; Eisenberg and Warner, 2005; Sokolovskij, 2007). The lack of anything more than broad estimates of the future scenarios for these two parameters rules out their inclusion in the quantitative components of this CIA. They are, however, included as a key discussion point in both the socio-economic scenarios in Chapter 9 (in which they emerge as a perceived high risk within the industry), and their potential future impact is examined qualitatively in the final assessment in Chapter 10.

However, of the three weather types not brought forward into the quantitative stage, the most disappointing case is wind. Although scarce, the little literature that does exist on statistical relationships between wind and observed accidents (Edwards 1999; Young and Liesman, 2007) suggest that they could be produced for the UK. Unfortunately, the lack of any clear consensus of the magnitude and sign of future changes in wind speeds and directions (Rockel and Woth, 2009; Jones et al, 2009; Murphy et al, 2009) has prevented any useful climate scenarios being produced. Hence, arguably the most visible impact of weather on freight transport cannot be investigated to the level hoped. However, several steps, both qualitative and quantitative are discussed in Chapters 7 and 10. These focus on the current impact of high wind events such as 'Windy Thursday' 2007 (e.g. Eden, 2007; Highways Agency, 2008), the 'Burn's Day Storm' of 1990 (e.g. Baker and Reynolds, 1992), and the 'Great Storm' of 1987 (e.g. Shine, 1987). This lays the foundation for the creation of relationships between extreme events and accidents, in lieu of projections for future frequencies of such events.

The climate scenarios currently available in the UK determine that precipitation and temperature-related accidents can be brought forward to the quantitative stage. These are two significant hazards, with precipitation alone accounting for more weather-related accidents than all of the other weather types combined (Edwards, 1999). The predicted changes in the precipitation regime of the UK produced by UKCP09 are extensive and in some cases extreme (Jones et al, 2009; Murphy et al, 2009). In particular, the shift to greater precipitation amounts during the winter will likely result in a confluence of dangerous driving conditions during a time of the year with high vehicle exposure levels (Department for Transport, 2009) and low lighting conditions (Fridstrom et al, 1995). The case of ice is equally compelling, as temperature is the best forecast parameter in the UKCIP models (Murphy et al, 2009), and like precipitation is set for potentially dramatic changes. However, in this case the impact will be, at least on the surface, beneficial to road freight safety, as the literature examined in Chapter 2 showed the potential for reductions in average frost days to single figures for much of the country under the highest emission scenarios (Jones et al, 2009). Furthermore, the statistical analysis of ice-related accidents has been largely neglected in the literature, providing an opportunity to produce a tailored methodology.

5.4.4. Accident data

The successful determination of useful relationships is contingent on reliable and spatially identifiable accident data. In this sense, the design of Component 2 is largely driven by the available data. Edwards (1999) suggests three main sources of road traffic accident data; hospital, insurance and police records. Hospital records are discounted in this case as there is no linkage to the weather conditions at the time of accident. Insurance claims offer a greater level of detail in terms of the circumstances of the accident, but again are discounted by Edwards (1999) due to difficulties in obtaining the data from insurance companies. Of the three data sources, police records are the only feasible option, due to the supporting weather condition details. It was decided that the most appropriate dataset is the STATS 19 archive of road traffic accidents. The reasons for this selection include:

- The ability to identify individual accidents and relate these to a rough description of the meteorology at the time.
- The data offers high spatial resolution.

- This type of data has a relatively strong research history in the existing literature which can inform the methodology.
- Although not in a form readily amendable to the necessary quantification required for this project, the weather reports allow linkage to other more detailed sources of meteorological information.

All road accidents in the UK that cause injury are recorded by the police around the time of the incident and take into account, among other factors, the type of vehicle and the meteorological conditions present at the site. Continuous records exist for all UK regions since 1979. This provides a long potential study period in which the relationships can be determined, and also helps to avoid the problems mentioned by Thomas (1996) regarding the size of datasets. The types of observations recorded in these reports include:

Accidents

- severity of the accident
- number of vehicles involved
- number of casualties involved
- time and location
- road class and number
- speed limit
- weather and road conditions
- carriageway hazards

Vehicles

- type
- location and manoeuvre at time of accident

Casualties

- Age
- injury
- severity
- Whether a driver, passenger or pedestrian

The pertinent fields for this project are vehicle type, location and most importantly weather and road condition. STATS 19 report weather under the following categories:

1. Fine without high winds
2. Raining without high winds
3. Snowing without high winds
4. Fine with high winds
5. Raining with high winds
6. Snowing with high winds
7. Fog (or mist if hazard)
8. Other
9. Unknown

The caveats of using Stats 19 and similar datasets for transport meteorology studies have been touched upon by Edwards (1992, 1998, and 1999) and Andrey et al (2003), in several papers which serve as a foundation for this part of the methodology. Much of the criticism involved with this type of data relates to the subjectivity in classifying weather and road conditions. As the police observations are often based on the weather at the time of the report, not at the time of the accident, the influence of meteorology in cases of short duration precipitation events may be misreported. In these circumstances, Edwards (1998) suggests that the conditions at the site of the accident would be recorded as wet road surface, as the precipitation event would have ended. This error would imply that the accident was caused by reduced road surface friction rather than the potential additional cause of reduced driver visibility (Shinar et al, 1983). The same problem applies to misreporting snow lying on the ground as 'snowing' even in clear sky conditions.

As the STATS 19 data is concerned with accidents that cause injuries, another problem that arises is the certainty that the records do not represent all freight accidents caused by meteorological events. The previously mentioned meta-analysis by Qiu and Nixon (2008) shows that the number of accidents causing injury is slightly smaller than the overall number of accidents. The extent of underreporting is dependent on the weather type, for example, underreporting would be expected to be low for wind-related road freight accidents because of the near certainty of injuries due to the physical severity of overturning events (Young and Liesman, 2007). Others such as precipitation may cause accidents without injury. It may be the case that precipitation has a slight negative impact on reporting as people will be less likely to want to wait in the rain for the police to arrive (Edwards, 1999).

5.4.5. Accident data manipulation

The STATS19 data for the years 1998-2007 was obtained from the UK Data Archive in the form of 10 sets of 3 zipped table files. The ten year period was based on a similar length of period used by Edwards (1999) and provides a suitable number of accidents whilst limited the changes in vehicle safety which could be seen over longer study periods (e.g. DfT, 2009). It was also informed by Qiu and Nixon's (2008) observation of the changing relationship between weather and accidents and the broader preliminary study of this thesis which elicited the weather-related accident trends between 1985-2006. These results are presented in Chapters 6 and 9 as a component of the questioning techniques used in the Delphi study. Overall, 3,947,063 accidents were considered. Of the three table files ('accident', 'vehicle' and 'casualty'), the two containing information on the description of the accident site and details of the vehicle were opened and the unique accident code was used as a key to link the records of the two files. A query was designed to elicit the pertinent information. The fields of interest were as follows:

- Year of Accident
- Accident Day
- Month
- Day of Week
- Easting and Northing
- Weather Condition
- Road Surface Conditions
- Vehicle Type
- Accident Code

The records were first sorted for vehicle type, with codes 19 (Goods vehicle under 3.5 tonnes), 20 (Goods vehicles between 3.5 and 7.5 tonnes) and 21 (Goods vehicles 7.5 tonnes and over) being those of interest (code 113 was used for the later two categories for 1998 and 1999). The query also sorted for the weather type and then for road condition. This was done for all ten years, with all freight vehicle accident records being transferred to Microsoft Excel and SPSS for analysis. In total, 304,620 freight accidents were identified.

An initial examination was performed on the data to produce an overview of freight accidents in the UK. This included a breakdown of the weather conditions observed at the site of the accident, which is useful for determining the relative influence of weather types compared to those observed by Edwards (1999) for the general road fleet. It was also important to examine the temporal distribution of the accidents caused by different weather types, to see if the unique nature of the freight sector's operations plays a role in its accident rates, as hypothesised in Chapter 3.

The two main accident causes studied in this thesis, precipitation and road ice were then processed further. Individual Excel files were created, separated into the months of June, July and August (JJA) and December, January and February (DJF) for each year for precipitation-related accidents and DJF for ice-related accidents. JJA and DJF are used for precipitation as this is the main axis in which patterns are expected to change (Murphy et al, 2009). Although not capturing the entire road ice season of the UK (Thornes, 2001), DJF best fits the available climate scenarios of UKCP09. These were then plotted onto a GIS map of the UK on ARCGIS using the easting and northing information. Each plot was spatially-joined with a GIS layer of the European Union (EU) defined regions of Great Britain (Figure 5.2). This allowed monthly and seasonal accident totals to be elicited, which could then be related to the corresponding monthly and seasonal meteorological data. It should be noted that the density of the road network varies in each region, with regions such as the North West and South East having a relatively dense concentration of roads compared with regions such as Wales or the North East.

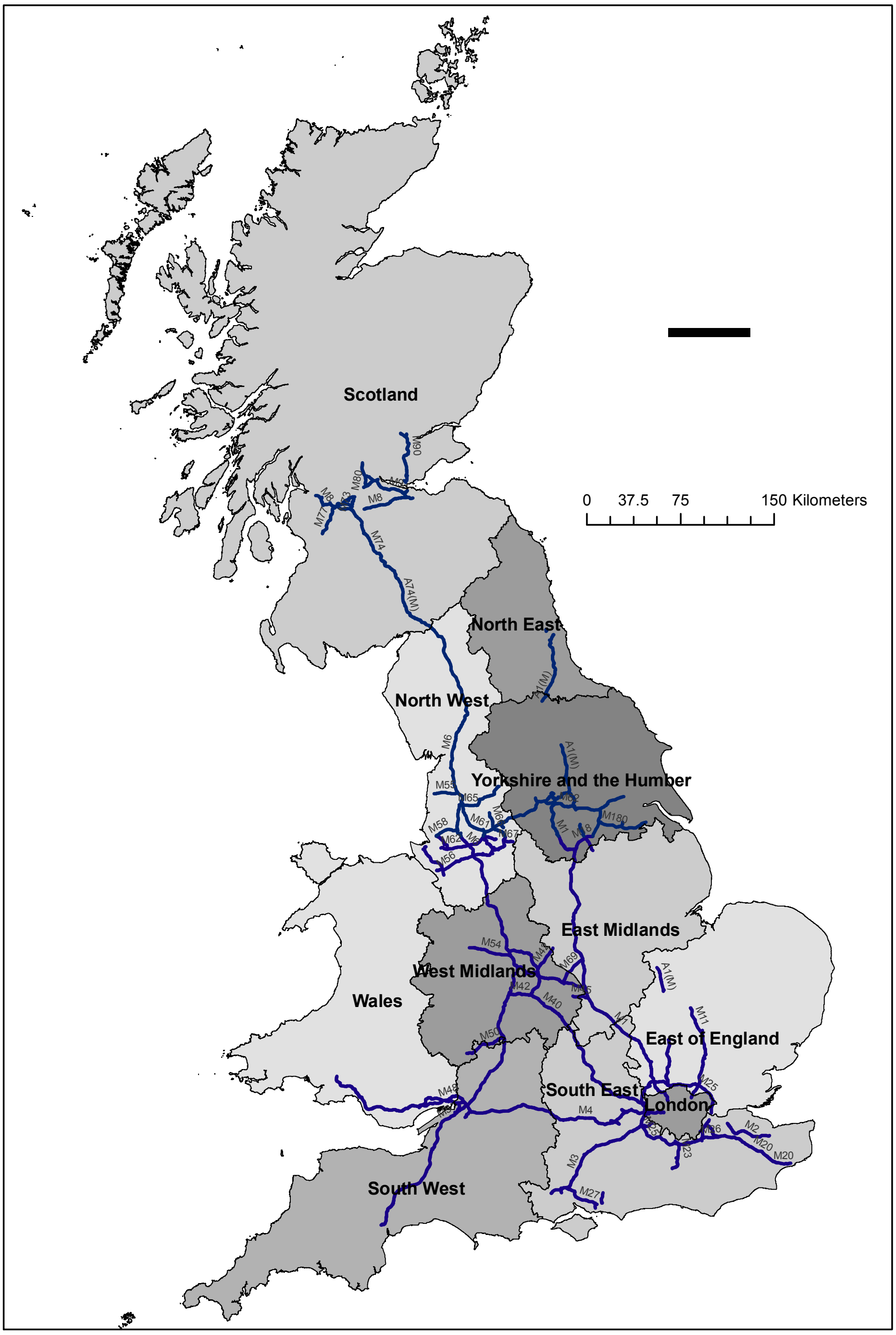


Figure 5.2. EU regions and motorway network in Great Britain

5.4.6. Meteorological data

This study adopted a similar approach to that of Eisenberg (2004) for the quantification of precipitation. This required a measure of monthly precipitation values. Several sources of potential meteorological data, including individual station data from the British Atmospheric Data Centre (BADC), the Met Office and the summary monthly Weatherlog from the Royal Meteorological Society were examined. Monthly area averaged precipitation records from the Met Office were chosen, as the regions used map fairly well with the EU regions used for the accident counts, although certain compromises were made where an exact fit was not possible (Table 5.1). The monthly nature of the data also fits well with the monthly and seasonal UKCP09 climate data. The long term nature of the records also meant that a 1961-1990 average could be made for comparison with the 1998-2007 data used in this project.

Table 5.1. EU regions and corresponding Met Office rainfall region

EU region	Rainfall region
East Midlands	Midlands
Eastern	East Anglia
London	England SE / Central S
North East	England E and NE
North West	England NW / Wales N
Scotland	Scotland
South East	England SE / Central S
South West	England SW / Wales S
Wales	Wales
West Midlands	Midlands
Yorkshire and the Humber	England E and NE

For the output of this component to be useful in component 2 it was required to be in a format which would be compatible with the parameters given by the climate change data. Several transformations had to be made so that the meteorological data matched with the format of the data provided by the UKCIP. The most important was converting the monthly area-averaged precipitation records from quantities into anomalies against the 1961-1990 averages. This allowed a greater measure of comparability with the UKCP09 precipitation data which is given in anomaly form at the regional scale.

Conversely, the threshold of 0°C for ice formation dictated a separate approach. A similar method to that proposed for wind by Edwards (1996) was adopted, using a measure for the number of days in a season where ice is present, or a frost-day index. Due to the relative low occurrence of ice compared to precipitation, relationships were built at a lower spatial and temporal resolution. This included using seasonal accident numbers rather than monthly, and also prompted a move towards larger collection areas similar to Dobney et al 2010. It was also necessary to chose representative stations for larger regions, again, similar to the method used by Dobney et al (2010). This method was imposed by the move towards using the UKCP09 weather generator to deal with threshold projections, which does not present data in an area-averaged format. These stations were chosen from the Royal Meteorological Society's Weather Log, which details the monthly number of air frost days. The more preferable surface frost figure given in the Weather Log could not be used, as the UKCP09 weather generator is not capable of projecting for this parameter. As shown in Figure 5.3, four larger areas were created; 'North' consisting of Scotland, the North West, the North East and Yorkshire and the Humber EU regions; 'Central, consisting of the Eastern region, East Midlands and the West Midlands; 'West' consisting of the South West and Wales and 'South East' consisting of London and the South East. The representative stations are similar to those used in Dobney et al (2010), with Heathrow representing the South East, Lyneham representing the West, Waddington representing the Central region and Leuchars representing the North.

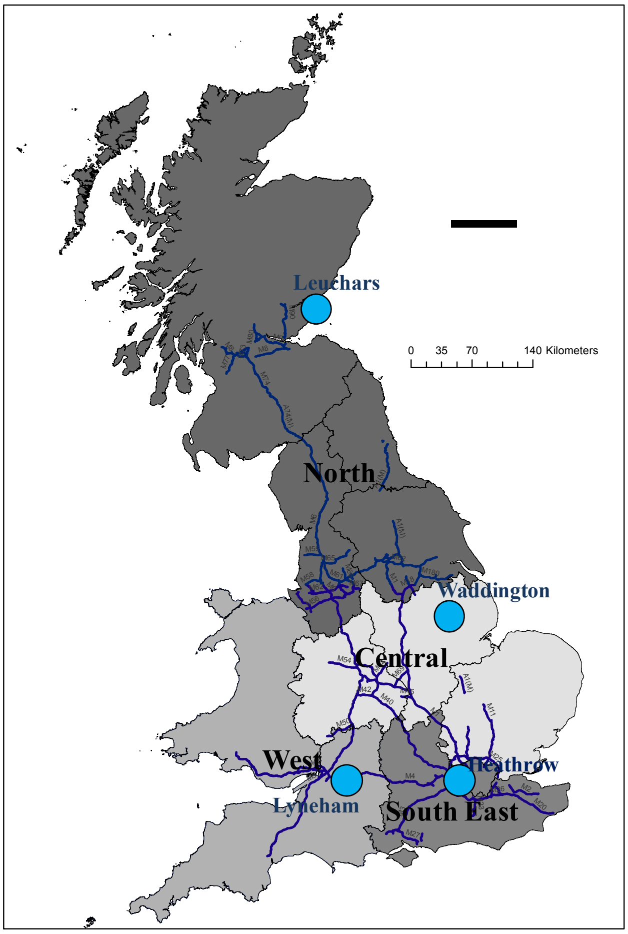
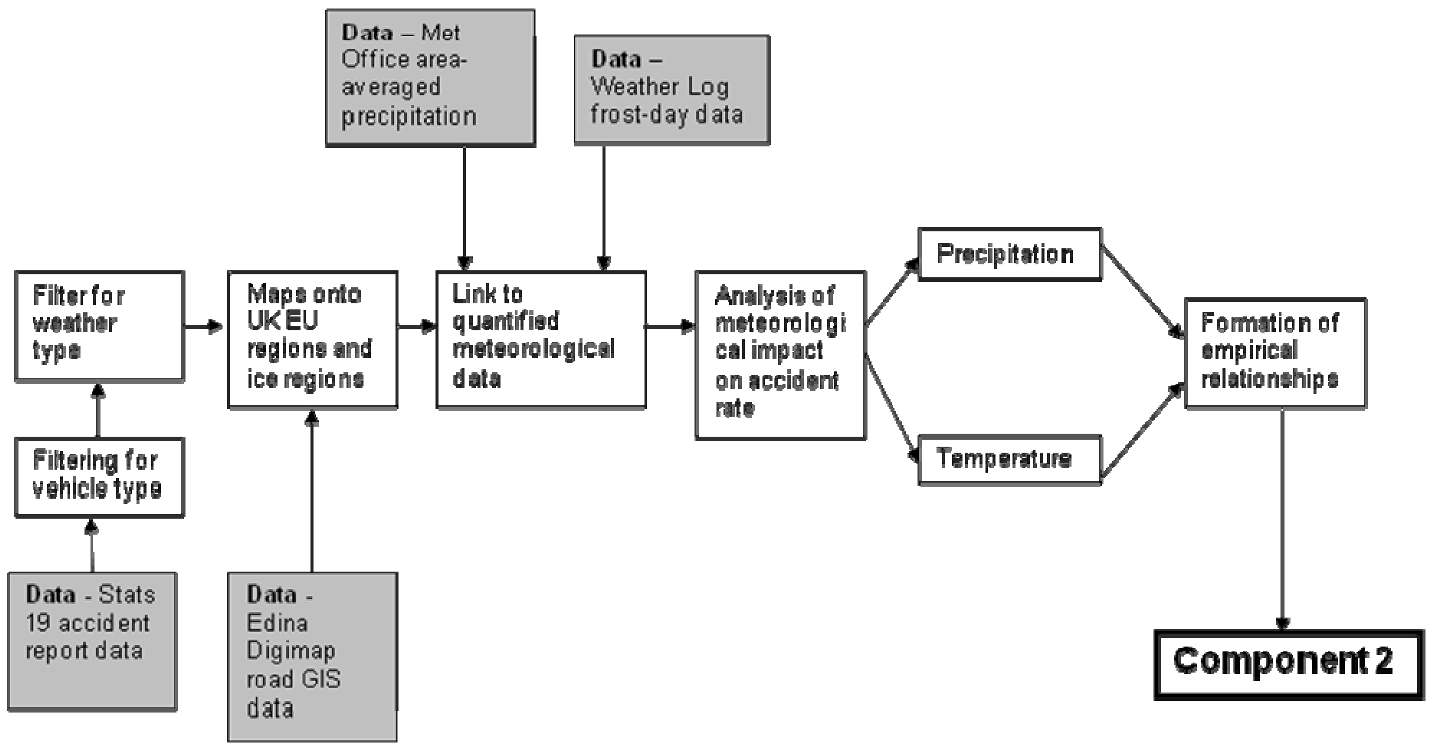


Figure 5.3. Combined EU regions with corresponding weather stations

5.4.7. Determination of relationships

Linear regression was used to determine the nature and strength of the relationships between monthly precipitation anomaly and precipitation-related accidents and seasonal frost-days and ice-related accidents. These were created for summer and winter for precipitation and winter for ice. These were produced in graphical form, with equations being determined for used in the climate extrapolation in component 2. The methodological framework for Component 1 is given in Figure 5.4.

Figure 5.4. Extended methodological framework for component 1



5.5. The physical assessment of climate change

This section details the methodological approach of assessing how climate change may potentially affect road freight accident numbers, constituting a first generation CIA under Füssel and Klein's categorisation (2006). This part of the methodology comes at a transitional time for climate scenario tools in the UK, and this section details how attempts were made to incorporate recently introduced probabilistic projections. The output from this component forms part of the integrated assessment in Component 4. The methodological framework of this component is presented in Figure 5.10.

5.5.1. Research objectives of Component 2

- To select an appropriate set of climate scenarios
- To use these scenarios to extrapolate the accident rates from Component 1
- To determine the changing influence of precipitation and temperature
- To assess the impacts under various emission scenarios for a range of time-steps
- To determine any geographical changes in accident distributions purely as a result of climate change
- To produce a set of figures for seasonal and annual accident rates, both nationally and regionally
- To incorporate probabilistic projections
- To produce graphical representations of these figures in the form of GIS maps

5.5.2. Climate scenarios

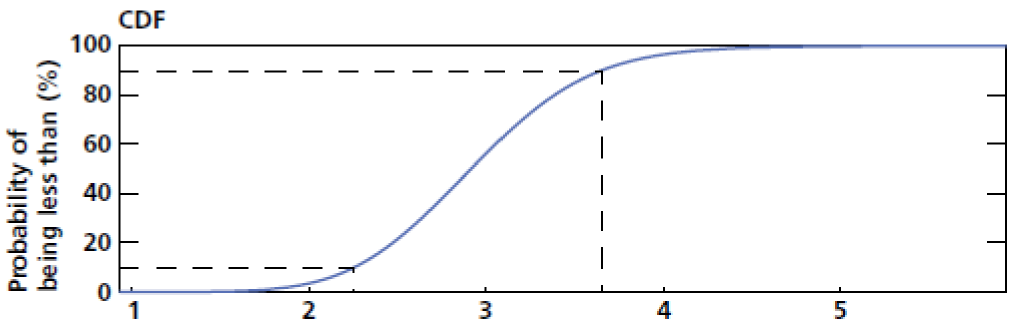
The assessment of climate impacts on transportation requires a unique set of climate parameters based on the existing knowledge of transport meteorology. The selection of appropriate climate scenarios that reflect these physical relationships was essential for the successful assessment of future freight accident rates. As will become apparent, several compromises had to be made, as no one dataset could satisfy all of the criteria.

To cover the uncertainty of climate forecasts, several scenarios were required to give a range within which judgements about probabilities can be made. This helps to account for the inherent uncertainty caused by the non-linear and non-deterministic climate system (e.g. Lorenz, 1976.). Ensemble models which utilise many model runs are best placed to deal with these issues. The increasing importance of uncertainty in assessments explored by Patt et al (2005) and Dessai et al (2007) has been mirrored in the evolution of recent models which present a spectrum of low and high probability projections to better inform stakeholders of the range of risk. In comparison, less sophisticated deterministic models such as UKCIP98 and UKCIP02 produce scenarios based on a limited number of model runs, and are much more rigid device, offering a limited ability to explore low-probability, high-impact scenarios.

5.5.3. UKCP09

The latest iteration of the UKCIP tools (UKCP09) was used to produce the climate scenarios in this thesis. As well as the central estimate, this model assesses the full range of projections used in the ensemble, giving a measure of the extent to which the modelled evidence supports a given amount of climate change. This is demonstrated in Figure 5.5, showing hypothetical probability and cumulative distribution functions (PDF, CDF) for future temperature rises. By reading the CDF it shows that the central estimate is 2.8 degrees, with a 10% probability of the rise being less than 2.3C and a 90% probability of this being less than 3.7C. This can also be read as there being a 10% probability of temperature rising by more than 3.7C. This is useful information, as previous models would have only presented the central estimate. However, it must be noted that the wide range of possible scenarios produced by ensemble models can sometimes be considered a caveat when discussing climate change with stakeholders, as discussed in Chapters 8 and 10.

(a)



(b)

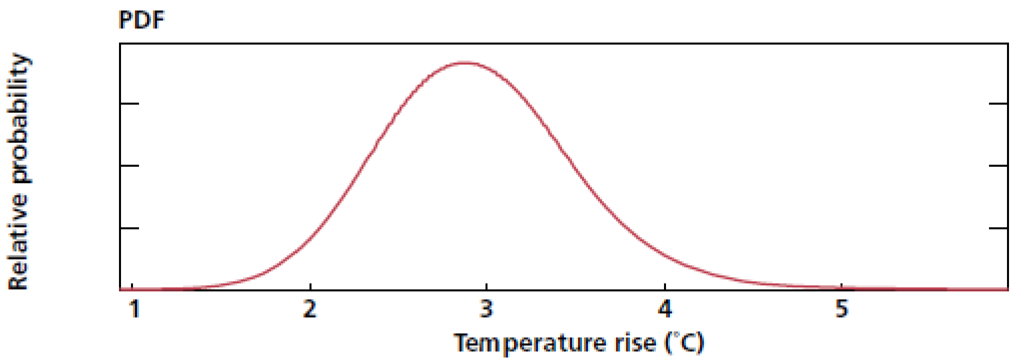


Figure 5.5. Graphs showing the concept of cumulative distributive functions (a) and probability density functions (b). (Murphy et al, 2009)

Due to the integrated nature of this assessment, the upper bounds of the timescale were largely dependent on the scope of the socio-economic component. As the socio-economic scenarios that underpin these assessments are mainly limited to the first half of the 20th Century, any climate data needed to be available up until 2050. The UKCP09 scenarios calculate climatic change over seven overlapping 30-year periods. For example, the commonly used time period of the 2080s represents the average climate between the years of 2070 and 2099.

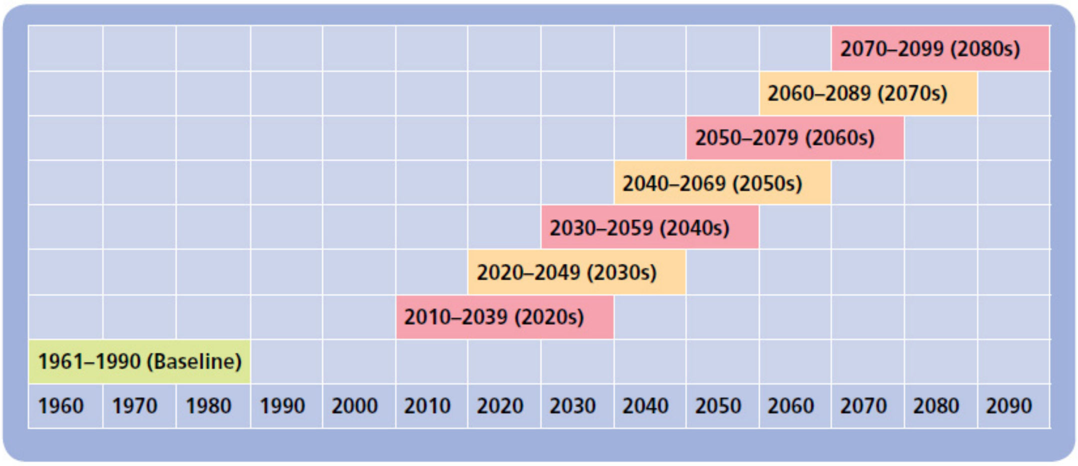


Figure 5.6. UKCP09 time periods (Murphy et al, 2009)

This thesis uses the following time periods for the assessment of impacts;

- 2020s (2010-2039)
- 2050s (2040-2069)
- 2080s (2070-2099)

The model uses three 'emission scenarios' of future level of GHGs. These are 'low' 'medium' and 'high, and are displayed in Figure 5.7. As with the socio-economic scenarios described in Chapter 2, probabilities are not assigned for future emissions.

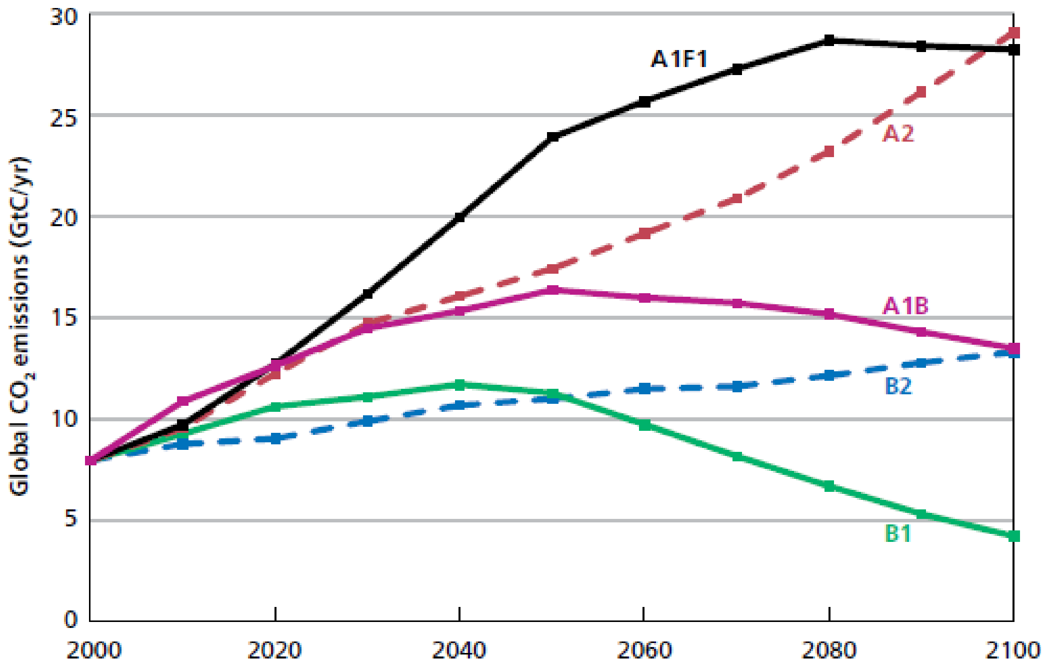


Figure 5.7. UKCIP global annual CO2 emission, based on three IPCC SRES scenarios, A1FI (black: high emissions), A1B (purple: medium emissions) and B1 (green: low emissions), as well as two SRES scenarios used in UKCIP02, A2 (red: medium-high emissions) and B2 (blue: medium-low emissions). (Murphy et al, 2009).

Temperature projections for the previously mentioned time-steps and emission levels were produced using the online portal. These were given at an area-averaged regional scale, shown in Figure 5.9. The administrative regions used by UKCIP are the same as the UK EU regions used to collate accident rates, apart from Scotland which is split into three smaller regions. Eastern Scotland was used in this thesis due to the concentration of major roads in this area.

Figure 5.8. The administrative regions over which area averaged climate projections are available from the UKCIP (Murphy et al, 2009)

5.5.4. UKCP09 weather generator

The production of frost-day projections involved a far greater level of technical complexity and direct data manipulation compared with the precipitation projections. The UKCIP Weather Generator includes several post production tools to examine the raw datasets, including a threshold detector. This can be used to project how many times a certain meteorological threshold will be reached in a year, season or month in a projected climate. However, unlike the UKCP09 scenarios, the weather generator tools lack the inbuilt ability to present probabilities for anything apart from the central estimate, therefore omitting the low-probability extreme scenarios which are of high importance to stakeholders and policy-makers.

An alternative methodology was devised in order to recreate the level of detail found in the precipitation projections. As the ‘probabilities’ previously mentioned for precipitation are a measure of the extent to which the evidence (produced by many different model runs) supports a given future climate (Murphy et al, 2009), it was expected that by examining the climates produced by individual weather generator runs, distributions of more common or extreme climates could be found, similar to the distribution functions of Figure 5.5. For each location, climate was examined for the 2020’s, 2050’s and 2080’s under low, medium and high emissions. For each of these nine combinations 100 model runs were produced. Each of these model runs contain a 30-year static (i.e. fixed-climate) time-series of daily weather, providing just under 11,000 generated weather observations per run. Macros were devised to count the number of days the minimum temperature dropped below 0ºC over the DJF period for each of the 100 runs. The climate scenarios for precipitation and temperature were then fed into the regional relationship equations in Component 1 to produce projections of future accidents for the 2020s, 2050s and 2080s.

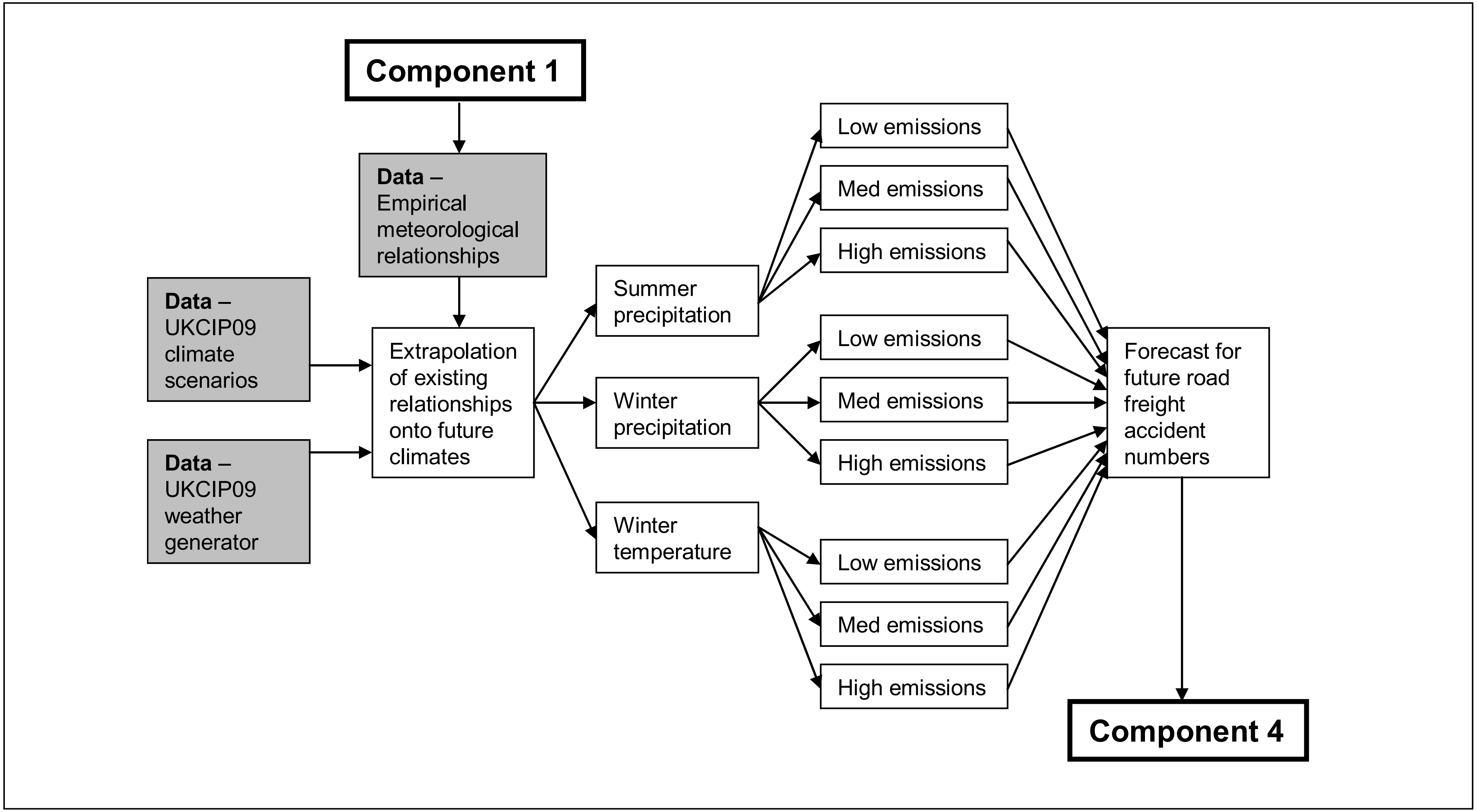


Figure 5.9. Extended methodological framework for Component 2

5.6. Conclusion

This has chapter presented the methodology of the base components used in this CIA. This included the formation of relationships between recorded road freight accidents and area-averaged meteorological records. Climate extrapolation was performed using the UKCP09 climate toolkit for winter and summer precipitation and the UKCP09 Weather Generator for winter temperature. Scenarios were given for the 2020s, 2050s and 2080s at low, medium and high emissions. A further level of detail was given by using probabilistic data at a range of probability levels. The two components were then combined to produce an initial set of accident projections. The next chapter describes the methodology of assessing concurrent socio-economic change.

Chapter 6 – Methodology 2: Future Resilience and the Integrated Assessment

6.1. Introduction

From the results of the initial climate assessment in Component 2, a picture of the impacts of various future climates on an unchanged transport network can be determined. Component 3 provides the next stage of complexity, and addresses the impact of the concurrent development in Great Britain's socio-economic environment. This was done by producing quantified and qualitative forecasts for changes in sensitivity and exposure, thus enabling a more realistic impact assessment. This chapter details the construction of a Delphi study to elicit views on current and future trends within the freight sector. Potential socio-economic scenarios are then used to extend these trends further. The methodological framework for this component is presented in Figure 6.3 towards the end of this section. This chapter concludes with a description of Component 4, a methodology for integrating the socio-economic and climatic projections of this thesis.

6.2. The assessment of future exposure and sensitivity

This section describes the methodology used in this thesis to assess potential changes in the freight and logistics sector of Great Britain. This includes a background of the Delphi methodology, a description of the initial interviews and question design, a breakdown of the socio-economic scenarios and the selection of experts.

6.2.1. Research objectives of Component 3

The objectives of Component 3 were as follows:

- To investigate changes in sensitivity and exposure under a number of socio-economic scenarios during the next 50 years
- To determine the future size of the road freight network
- To forecast changes in vehicle safety
- To forecast the geographical distribution of the future UK road freight network
- To investigate the institutional treatment of weather as a hazard
- To examine industry views of climate change

6.2.2. The Delphi methodology

'(The Delphi is) a method of structuring a group communication process, so that the process is effective in allowing a group of individuals, as a whole, to deal with complex problems'.
Linstone and Turoff (1975)

One such technique that has been used both in past scenario elaboration and within the freight literature is the Delphi method. The Delphi methodology is an iterative questioning technique used to elicit a consensus judgement on future forecasts by experts. Its main application is in circumstances where a problem does not permit the application of precise analytical techniques (Linstone and Turoff, 1975). In these circumstances the problem in question can benefit from subjective judgments on a collective basis. Linstone and Turoff (1995) also state its applicability when the relevant specialists are in different fields where communication is limited, and when the number of specialists is too large to effectively interact in face-to-face communication. This has relevance for the freight and logistics sector. A distinguishing feature of this methodology is the great emphasis that is placed on structuring the flow of information between participants.

A Delphi is conducted by sending out a round of questions to a group of experts in the field. The answers to their questions are sent back to the group coordinator who identifies areas of consensus and disagreement. A second round questionnaire includes a measure of the responses from Round 1 and asks participants to review their answers in relation to the opinions of the rest of the panel. By this process of iteration the panel of participants (who are anonymous) move to a point of consensus of view around each area of questioning.

Although initial Delphi studies sought consensus on future forecasts, several other methods exist where a range of scenarios are required. These include Turoff's Policy Delphi (1970) which is a specialised tool to elicit the strongest group of opposing views to a new policy. Turoff's view was that there is no such thing as an expert when talking about policy. Another non-consensus approach, and one that originated from transportation studies, is Tapio's (2003) disaggregative Delphi. The aim of this approach is to form distinct viewpoints on future development, grouping like-minded experts using cluster analysis. Although a split of opinion is always possible with any Delphi, it is Tapio's opinion that if this is deemed likely the coordinator should set out to obtain a split consensus from the offset. This approach could be seen as having problems involving bias depending on its application. One major benefit of the Delphi is its history of use within transport and logistics including McDermott and Stock (1980), Cranfield School Management (1984), Cooper (1994), Monticelli and Carrara (1999) and McKinnon and Forster (2000). Brown and Allen's (1997) demonstrate a study where both consensus and polarization were found for different issues with the transport sector.

However, the interpretation of the results is plagued by difficulties. In their seminal text, Linstone and Turoff (1995: in McKinnon and Forster, 2000) list the criticisms the Delphi methodology has been subject to. These include:

1. *Delphi surveys can exaggerate the concept of expertise.*
2. *The composition of the panel is seldom random, reflects the personal biases of the researchers and is not necessarily representative of specialist knowledge in the field.*
3. *Anonymity relieves panel members of accountability and hence can lead to careless responses.*
4. *By seeking consensus, Delphi surveys promote a conservative view of the future, discourage original thinking and suppress radical views. They can have the effect of reinforcing existing paradigms.*
5. *They offer little insight in the reasoning underlying the panel members' responses and give no opportunity for their arguments to be tested in face-to-face discussion.*
6. *As Delphi questions are intrinsically very difficult to answer, they elicit, at best, a series of 'guestimates'. The quantification and averaging of these 'guestimates' give a spurious sense of scientific accuracy.*
7. *The iterative nature of Delphi surveys makes them slow and time-consuming.*

Further to this criticism, Linstone and Turoff (1975) also highlight the eight basic pitfalls of implementing the Delphi methodology:

1. Discounting the future
2. The prediction urge
3. The simplification urge
4. Illusory experts
5. Sloppy execution
6. Optimism – pessimism bias
7. Overselling
8. Deception

These criticisms and pitfalls were taken into consideration during the construction of the methodology. Most pertinent to this study were the selection of appropriate experts, the elicitation of reasoning, quantification and the possibility of reinforcing existing paradigms. These influenced the interview stage and questionnaire design.

6.2.3. Delphi design

An initial interview stage was carried out with managing directors of small and medium sized third party logistics companies. The interviews were conducted both in person and over the phone, and set out to gather the following insights:

- An assessment of the type of questions required to elicit forecasts for sensitivity and exposure

- The underlying reasoning and thought processes likely to be involved when answering these questions
- The format of the questions and how best to avoid issues with sensitive and confidential financial information
- The type of socio-economic information necessary to answer these questions
- Whether these scenarios should be presented as qualitative storylines, quantitative indicators, or a mixture of the two
- An improved typology for the selection of the final Delphi panel

This process also contained questions on change within the freight and logistics sector, meteorological risk, climate change, safety, and technology. The use of the initial interviews prior to the Delphi is an attempt to allow for the creativity and spontaneity of individual views that can often be filtered out during the consensus phase. Cards were used to arrange factors contributing to freight growth and safety in order. Further details are contained in the interview structure in Appendix 1.

The question list for the first iteration of the study was completed with the guidance from the interview group and can be split into the following four topics:

1. Impacts and perception of weather
2. Current and future trends in safety
3. Current and future freight growth
4. Socio-economic scenarios

It was assumed that discussing day-to-day experiences with meteorology would be a suitable route into the questioning process, before dealing with the more abstract concepts of future change and socio-economic scenarios. The responses to the perception of weather as a hazard would also allow insight into the current institutional treatment of meteorology. This was achieved by rating the relative risk associated with weather types on a 5-pont Likert scale, an approach also used in later questions.

It was then asked to score the possible reasons for recent reductions in road freight accident rates. This allowed the concepts of change, and more importantly the drivers of change to be introduced. Future developments in safety were then rated for their likelihood. Other questions required the experts to indicate how they felt a certain parameter, such as vehicle accidents, would change by 2020. Their answers were given as a percentage move away from the present day figure. This approach was repeated for growth in the freight sector, with potential drivers of growth being indicated, likely developments being rated, and percentage change forecasts being made. Finally, the 'World Markets' socio-economic scenario from UKCIP / BESEECH was presented, with participants being asked whether this would promote growth in the freight sector and improvements in safety. This questionnaire is presented in Appendix 2.

The final round of the Delphi was sent out after the initial results were collated. It was decided that not all aspects from the first round would be brought forward into the second. This was done to concentrate on aspects important to exposure and sensitivity, and to bring the length of the questionnaire down so that it could be answered in 20 minutes. As a consensus had been found on the impact of day to day meteorology on accidents it was felt appropriate to leave this out. The full survey can be seen in Appendix 3.

6.2.4. Socio-economic scenarios

As discussed in Chapter 2, the divergent trends of potential socio-economic development require several scenarios if long-term predictions are to be made. The socio-economic scenarios provided with the questionnaires came from the UKCIP (2001) and BESEECH (2006) projects. The BESEECH scenarios are an improved are more focused version of the UKCIP SES (Chapter 2, Figure 2.5), providing GDP forecasts under four scenarios (National Enterprise, Local Stewardship, World Markets and Global Sustainability). These also included general qualitative storylines of the resultant socio-economic landscape. The World Markets scenario was introduced to the experts in the first round of the Delphi, with a summary of both qualitative and quantitative information included with the questionnaire. During the second round all four scenarios were used, an extended summary of these being given in Table 6.1.

Table 6.1. Summary of UKCIP/BESEECH socio-economic scenarios

	National Enterprise	Local Stewardship	World Markets	Global Sustainability
VALUES AND POLICY Social/political values	• Concentration on meeting individual needs through private consumption with little concern for the environment	• Social values are community-orientated encouraging co-operation self-reliance and regional development	• People are concerned with material well-being, with the market rather than state presumed to best deliver this goal	• Communitarian and internationalist • Consensus on enhancing social equity and environmental quality
Role of the state	• Markets decide social and economic outcomes • Transfer of sovereignty to EU resisted • Slower pace of devolution	• Federal system of government with power devolved downwards	• Retreat of nation state • Fiscal, trade and defence policy increasingly transferred to EU • Limited devolution	• Governance becomes increasingly globalised • Transfer of monetary, defence, social and environmental policy to EU
Policy style	• Economic and political power consolidated in traditionally strong interest groups; law, the City, professionals • Top-down policy style	• Traditional regulation replaced by a more diffuse structure of governance involving stakeholders throughout society	• More open and deliberative decision making • Private sector and NGOs have stronger influence on public policy	• Participative, open democracy • Local governance • Strong partnership between government, industry and NGOs
Welfare and health	• State provision for healthcare and education decline and becomes more uneven. • Income disparities grow	• High level of public provision for health and social services which are open to all	• Declining state provision of healthcare, education and other public services • Inequality in access to social services	• Reconciliation of social values with economic growth • Adequate social safety net for disadvantaged
Environmental policy	• Little concern about environmental issues • Environmental policies that impede economic development do not succeed • People support measures which enhance their immediate local environment	• Conservation of resources and the natural environment are strong policy objectives • Environmental policy succeeds as a result of structural and behavioural changes as much as technological innovation	• Heavily reliant on economic instruments focussed on problems which immediately affect the population e.g. noise and air pollution • Longer term issues such as climate change tend to be neglected	• Sustainable development is a political priority • Development of external regulation and internal environmental management • Mix of market-based and regulatory instruments

	National Enterprise	Local Stewardship	World Markets	Global Sustainability
ECONOMIC DEVELOPMENT Economic policy	• Economic growth is a political priority • Little state-intervention, except for support against foreign competition • UK remains outside European Monetary Union	• Smaller-scale production of goods and services is encouraged • International trade less important	• Liberalised national and international markets • Dismantling of trade barriers and retreat of the state • Income distribution widens	• Balancing of commercial and social/environmental objectives. • Innovation via investment in research and technology development
Economic development	• Economic growth falls below long-term UK average • Export-orientation sectors growth relatively slowly • Increased consumerism	• Small and medium-sized enterprises in the manufacturing sector and co-operatives prosper • Economic growth is slow relative to the long-term average	• Rapid growth by historical standards • Further integration of financial markets • Service sector dominates overall economic activity • Manufacturing falls	• Growth continues at long-term average rates. • Growth in role of services • Emphasis of quality and non-price value in most markets • Export orientated
GDP annual growth rate	2.2%	1.5%	3.4%	2.8%
GDP (in 2001 £ million)	3,668,473	2,483,186	7,288,536	5,347,931
GDP per capita per year	58,805	41,289	103,986	78,834
Regional trends	• London and South East dominate • Peripheral regions suffer from underdevelopment and rely on traditional activities	• Economic growth more evenly spread • Greater importance on regional development to achieve sustainability • More regional autonomy	• All regions benefit from growth from 'spill over' • Regions offering knowledge based services grow fastest • Regional specialisation	• Evenly distributed through planning controls and transfer payments • Previously heavily industrialised areas require restructuring
Manufacturing	• Low innovation • Manufacturing stabilises • Sectors operating in global markets suffer	• Low rates of investment in manufacturing • Innovative new applications of IT and biotech enable	• High innovation and growth, with IT and biotech driving change • Traditional manufacturing	• Highest growth in sectors providing eco-goods • Polluting industries phased out • Increased eco-efficiency

Table 6.1. continued - Summary of UKCIP/BESEECH socio-economic scenarios

Table 6.1. Continued - Summary of UKCIP/BESEECH socio-economic scenarios

	National Enterprise	Local Stewardship	World Markets	Global Sustainability
SETTLEMENT AND PLANNING Population	• Population numbers increase slowly due to low inward migration and birth rates	• Population is stable • Household numbers decline slightly and urbanisation stops	• Population grows more rapidly • Net internal migration towards the South East	• Population grows more rapidly • Net internal migration towards the South East
Population (2050s)	63 million	61 million	70 million	68 million
UK passenger transport (%) Air Rail Road (public) Road (individual)	 1% 7% 7% 85%	 0.5% 15% 14.5% 70%	 3% 10% 2% 85%	 1.5% 15% 19.5% 64%
Transport infrastructure	• Continuing reliance on private transport • Car fleet grows slowly due to low GDP • Roads operate at full capacity due to lack of investment • New technologies such as informatics are introduced at the very top end • Air traffic increases no more quickly than other modes • Without new developments in rail, freight continues to be mainly by road • Quality of public infrastructures is poor	• Slowdown in the growth of trade and demand for mobility • Transport costs rise sharply due to high energy prices and policies to internalise environmental costs • Private transport dominated by car, but public rail and road services extended • Low emission vehicles are commonly used • Low investment in infrastructure	• New roads are built to meet the increased demand for passenger transport • Traffic is efficiently managed using new control systems • High investment in the built environment drastically improves the quality of transport infrastructure • Large increase in transport demand	• Modernisation and restructuring of freight and passenger transport is started, with the longer-term aim of building an integrated system with an increased proportion of public road and rail • Tension between transport demands of a mobile society and environmental concerns • New roads, rail and airport infrastructure are developed, with a priority on limiting environmental impact

6.2.5. The selection of experts

"There is therefore a dual benefit to participatory approaches – they provide the narrative resources for scenario elaboration (policy learning); while also generating critical self-reflection and preparing the conditions for change (organisational learning)" (Berkhout et al 2001)

The selection of participants is perhaps the most important part of the Delphi study and without adequate expertise the process would be flawed from the start (Linstone and Turoff, 1975). It was therefore useful to gather the views of a number of individuals representing different parts of the sector. As mentioned earlier, freight is interesting as a large number of the vehicles on the road come from small companies often operating out of a single depot. This is shown in the summary statistics from the Department for Transport in Figures 6.1 and 6.2, which show the a stable average fleet size over the 1998-2008 period and a predominance of companies operating with one or two vehicles.

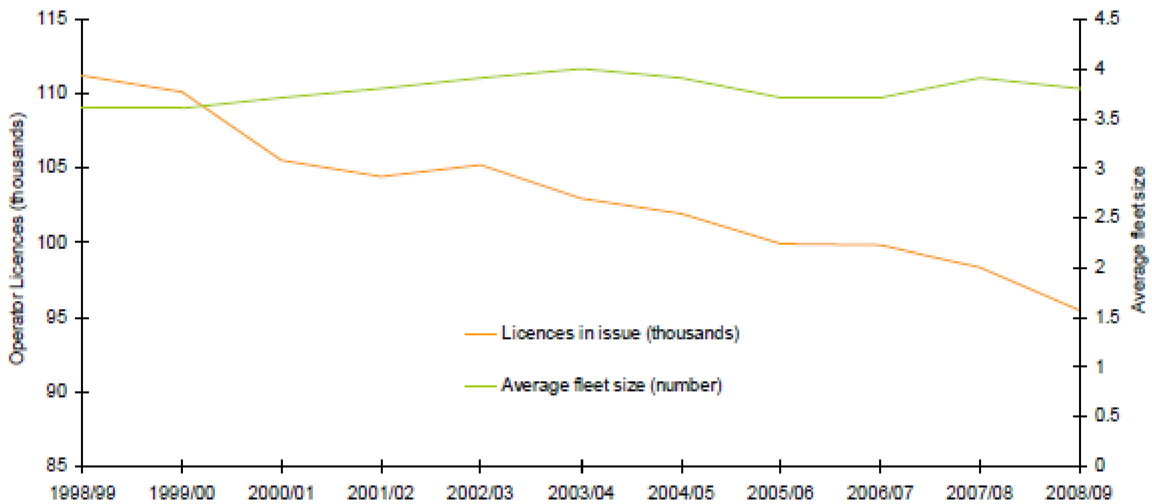


Figure 6.1. Operator licenses issued and average fleet size in Great Britain between 1998-2008 (DfT, 2009)

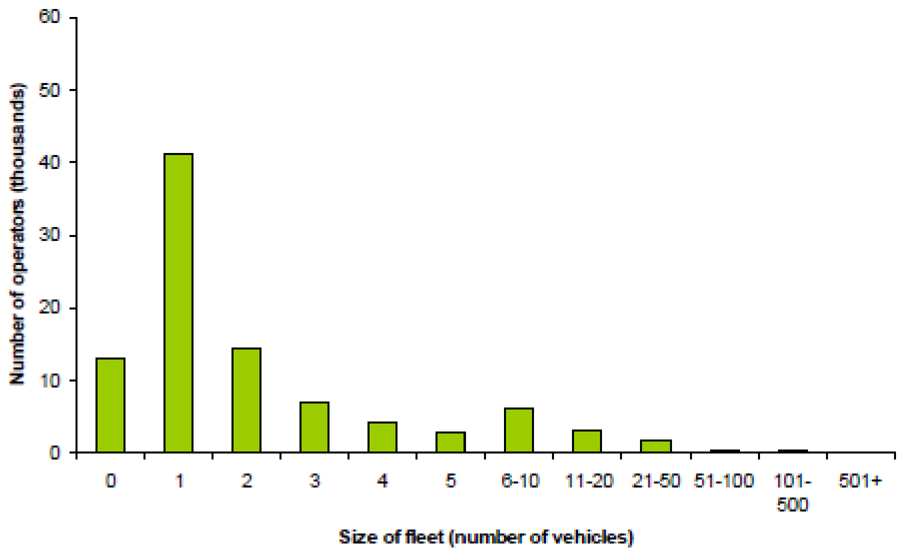


Figure 6.2. Number of operators by size of fleet in Great Britain in 2008 (DfT, 2009)

It was therefore decided that small companies would make up a significant proportion of the respondents. Within this bulk of small companies are a number of highly specialised and niche companies. Of interest in this study were so called 'green-logistics' companies, who use biofuel as a replacement for diesel. It was thought that these environmental 'leaders' (in the sense of Welford, 1997) would have a different view on socio-economic development and climate change owing to the nature of their businesses.

Table 6.2 shows the list of interviewees and Delphi participants. Although the primary output of the Delphi is aggregative in nature, confidentiality agreements were given to allow the use of specific viewpoints given in the questioning process. It was also hoped that anonymity would allow the participants to speak candidly about their companies' safety procedures during severe weather. All participants were managing directors of their firms, apart from Martin of Large TPL A, who was a general manager.

Table 6.2. Interviewees and Delphi participants

Code name	Company code	Company Type	Location	Interview	Delphi
Stephen	TPL A	Third party logistics	West Midlands	x	x
Brian	TPL B	Third party logistics	West Midlands	x	x
Henry	TPL C	Third party logistics	West Midlands	x	
Paul	TPL D	Third party logistics	East Midlands	x	
Frank	TPL E	Third party logistics	West Midlands	x	
James	ECO A	Green-logistics	Greater Manchester	x	x
Robert	ECO B	Green-logistics	North West		x
David	TPL F	Third party logistics	West Midlands		x
Chris	TPL H	Third party logistics	Greater Manchester		x
Darren	TPL I	Third party logistics	West Midlands		x
Jonathan	TPL J	Third party logistics	South East		x
Harry	TPL K	Third party logistics	South East		x
Martin	Large TPL A	Large logistics	North West		x

6.2.6. Iterations

The questions were sent by email and post depending on the preferences of the participant. The first round of the Delphi was undertaken at in November 2008. Due to a poor initial response further participants were recruited though to March 2009 (See Chapters 9 and 10 for further details). The responses from these questionnaires were collated and helped to inform the construction of a second questionnaire. This second questionnaire was sent out in March 2009.

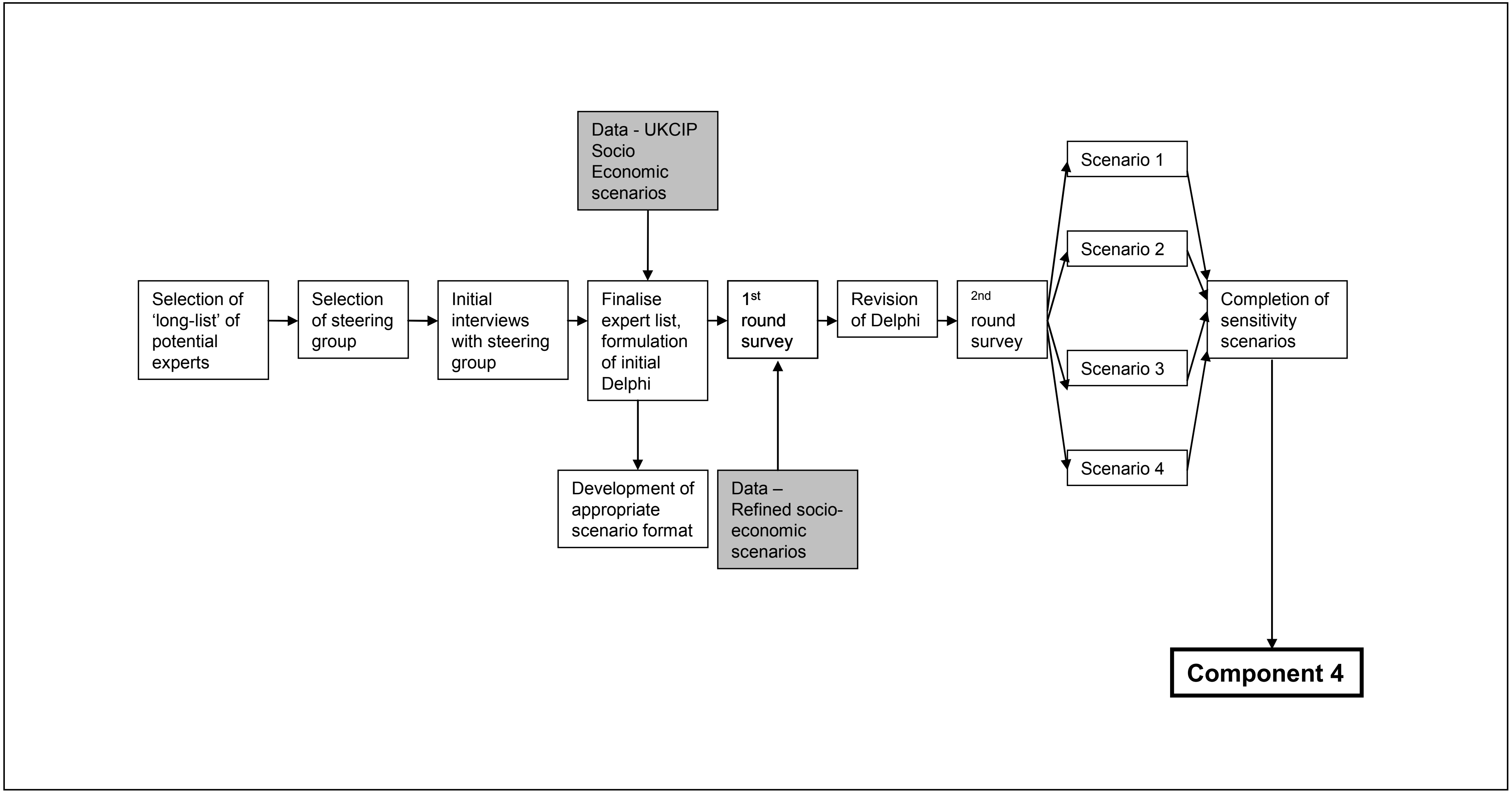


Figure 6.3. Extended methodological framework for component 3

6.3. The integrated assessment

The aim of Component 4 was a full exploration of the range of impacts given different combinations of climate and socio-economic scenarios. The probability of any given integrated scenario was the sum of the probabilities of the constituent scenarios used in its formation.

6.3.1. Objectives of Component 4

- To integrate the climate change assessments with those for sensitivity and exposure
- To provide a guide as to which combinations of scenarios present the greatest impacts
- To give a relative measure of probability and uncertainty of the resultant scenarios

6.3.2. The integrated assessment of climate change

A comparative approach was adopted for this study, comparing the impacts of various climate scenarios against the modifying effects of socio-economic development. Not all combinations of scenarios were as likely as each other. As emissions are dependent on the socio-economic environment it is unlikely that certain combinations would be possible. For example, it would be unlikely that a Local Stewardship scenario would promote high emissions. This concept is described in Table 6.3.

Table 6.3. A combination of the UKCIP climate and socio-economic scenarios. (UKCIP, 2001)

Emission Scenario	Global Sustainability	Local Stewardship	World Markets	National Enterprise
Low	✓			
Medium-low		✓		
Medium-high		✓	✓	
High			✓	✓

From these comparisons it was possible to hypothesise the best and worse case scenarios, as well as the most likely. It also gave a guide to whether the raw road freight accident projections of Component 2 would need to be revised upwards or downwards. A modified version of the UKCIP possibility space was created to display these concepts.

6.4. Conclusion

This chapter demonstrated a methodology within which the future exposure and sensitivity of Britain's road freight sector can be assessed. The collaborative nature of the Delphi methodology has been emphasised, as well as the need to include direct interviews which allow for spontaneity and more radical ideas. The integrated assessment completes the wider methodological framework presented in Chapter 5, allowing the climatic and socio-economic dimensions of changed to be assessed in holistic approach. The following chapter presents the results of the first component of this assessment; the relationship between meteorology and road freight accidents.

Chapter 7: The Relationship between Weather and Road Freight Accidents

7.1. Introduction

This chapter presents the results of the first component of the freight transport safety CIA, detailing the examination of recent spatial and temporal patterns of weather-related freight accidents in Great Britain and the construction of a suite of empirical relationships to be extrapolated onto future climates in Component 2. The first part of this chapter is concerned with the examination of the STATS 19 road accident dataset for the sample period of 1998-2007. This includes the relative contribution of each weather type to the total accident count, the temporal variation of each weather type's contribution throughout the year, the pattern of spatial distribution of freight accidents across the regions of Great Britain, and comparisons between the nature of the hazard presented by each weather type (e.g. the chronic nature of precipitation (Andrey et al, 2003) as opposed to the intermittent but severe hazard presented by high winds (Edwards, 1996)). Attention is paid to differences in freight accident patterns compared with those observed in Edwards' earlier studies on weather-related accidents in England and Wales (1994, 1996, 1998, 1999), with potential explanations based on the nature of road freight transport examined in Chapters 1-4. The second part of this chapter presents a detailed analysis of the statistical relationships between precipitation and temperature and freight accident rates, presented at a seasonal resolution for the regions of Great Britain. Potential reasons for differences in the nature and strength (especially seasonal variations) of the relationships and the sensitivity of the various regions are given. These relationships are then extrapolated onto projected future climates in Component 2 (Chapter 8).

7.2. Overview of weather-related road freight accidents

Table 7.1 shows the recorded meteorological and road-surface conditions at the scene of weather-related road freight accidents as a percentage of all road freight accidents for the study period of 1998-2007. Note that this exploration includes the additional hazard of icy road-surface conditions, absent in most similar studies (e.g. Edwards, 1999). Even when including this additional hazard, the breakdown shows a broadly similar total contribution of the atmosphere to recorded road freight accidents to that of the 1999 study by Edwards, which was based on 1980-1990 data and included all road vehicle types. The overall figure of 22.2% of accidents being related with weather (or, more accurately in the case of this study, the atmosphere) is close to that of 21.8% found by Edwards (1999).

Table 7.1. Atmospheric and road-surface conditions recorded at the site of road freight accidents in Great Britain between 1998-2007 as a percentage of all accidents, with breakdown from Edwards (1999) in parenthesis

Hazard	Percentage
Fine without high winds	77.8% (78.2%)
Raining without high winds	13.8% (13.5%)
Snowing without high winds	0.4% (0.7%)
High winds	3% (3.7%)
Fog or mist	1% (1.1%)
Ice	1% (N/A)
Other	1.7% (2.1%)
Unknown	1.2% (0.5%)

However, caution is required when comparing these datasets. Edwards' 1999 study is based on an earlier period (1980-1990), and includes all modes of road transportation. The addition of ice also means that the two sets of percentages are not fully comparable. The similarity in the overall proportion of accidents associated with weather in the results of this thesis should not necessarily be taken as evidence for a similar sensitivity of the freight fleet to atmospheric hazards as the general road fleet. As mentioned in Chapter 3, as Edwards (1999) did not distinguish between vehicle types it is possible that the percentage of freight accidents associated with weather during the earlier 1980-1990 period was higher or lower than the broad figure of 22.2% found in this study. For instance, it is possible that weather caused a higher proportion of freight accidents in the earlier study period, and that this has been brought down to the current level by improvements in training, vehicle design and weather warnings (discussed further in Chapter 9). Indeed, the longer-term weather-related accident numbers presented in Chapter 9 (Figure 9.2) show a decrease since 1985.

An overall reduction in all road vehicle accidents has also been seen across a similar time period (DfT, 2009; see figure 4.1). This leads to the possibility of unequal improvements in weather-related safety during the intervening period, affecting the way in which freight vehicles and the general fleet react to weather differently. As this thesis does not examine the proportion of accidents associated with weather across the general road fleet it is not possible to say whether this is true. However, exploratory analysis suggests this may not be the case, at least for the broad measure of total vehicle accidents. For the most recent year in the analysis (2007), the percentages of weather-related accidents in the general and freight fleets are remarkably close, 20.7% and 20.8% respectively, indicating that their sensitivity to weather at this coarse measure is roughly equivalent, despite the inherent vulnerability dictated by the physical characteristics of freight vehicles (e.g. Baker and Reynolds, 1992).

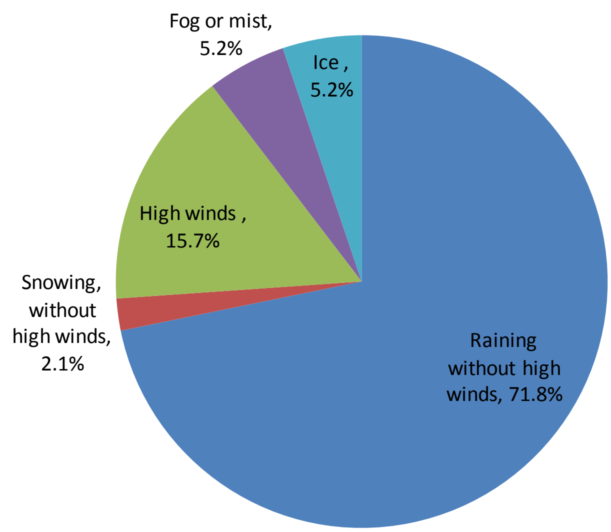


Figure 7.1. Breakdown of weather-related hazards reported at the scene of road freight accidents as a percentage of all weather-related road freight accidents between 1998-2007

The similarities with Edward's (1999) study run surprisingly deep. The contribution of each weather type towards the total accident count in the freight fleet (Table 7.1) is broadly similar to that of Edwards (1999), notably including wind. The fact that wind does not contribute a higher proportion of accidents in the freight fleet compared with other components of road transport is surprising, due to the large literature base on the susceptibility of freight vehicles to crosswinds (Baker, 1993; Chen and Cai, 2004), and the industry perception of wind as a key hazard to freight transport (Highways Agency, 2007). Although the second largest contributor to overall accidents (Figure 7.1) with 3% of all accidents and 15.7% of weather-related accidents, the relatively low numbers association with this weather-type runs contrary to this perception, an interesting finding which is discussed in more detail in Chapter 9.

Ice and snow also fit in with this, with relatively low contributions of 1% and 0.4% of all accidents and 5.2% and 2.1% of all weather-related accidents, yet retain a surprisingly high perception as a hazard (Chapter 9). One possible explanation is the predominance of rainfall in Great Britain, with frequent low intensity events meaning that precipitation is often present at the scene of the accident whilst not necessarily being the cause. Other explanations including the higher relative accident risk (Edwards, 1996; Eisenberg and Warner, 2005; Qiu and Nixon, 2009), as well as the related impact of disruption (e.g. Thornes, 2005) associated with these weather types are discussed in Chapters 9 and 10.

7.3. Temporal distribution

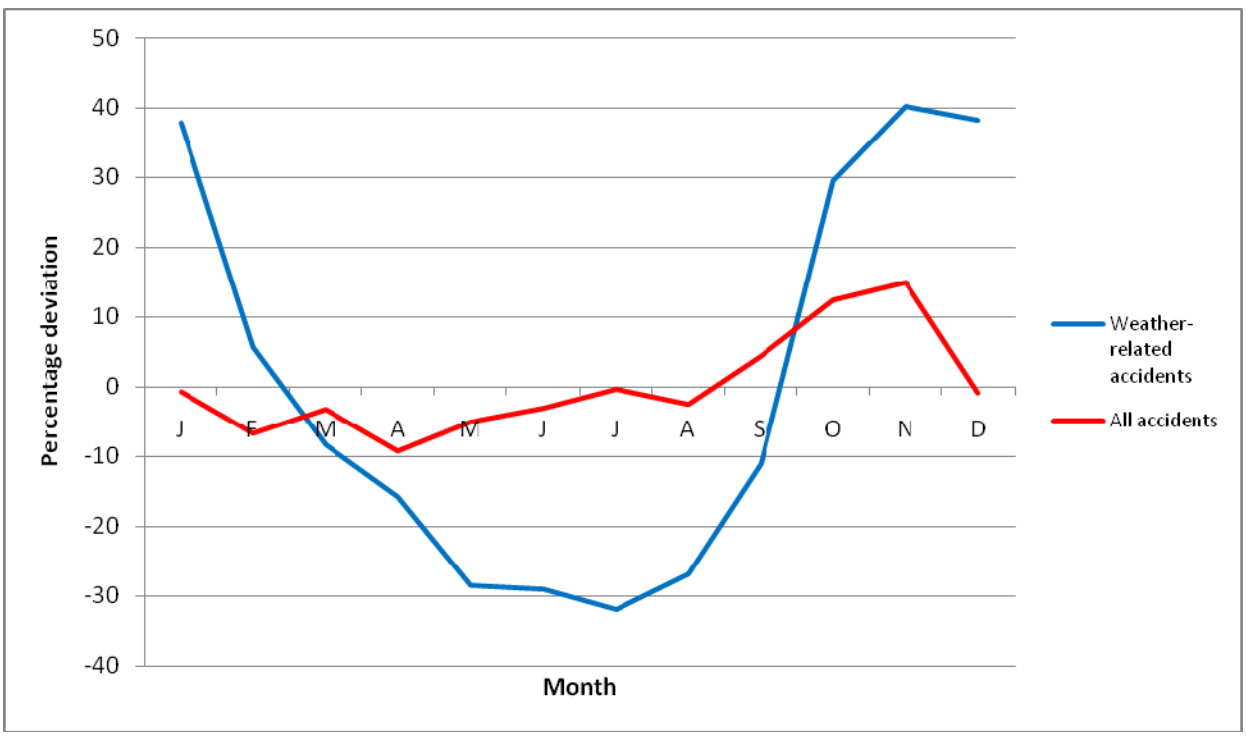


Figure 7.2. Monthly percentage deviation from annual average for all freight accidents and weather-related freight accidents

The temporal distribution of weather-related freight accidents displayed in Figure 7.2 shows a stark difference to the distribution of total freight accidents. The monthly percentage deviation of total freight accidents (in red) shows a similar pattern to the previously mentioned analysis of total road accidents determined by Edwards (1999), with a slight tendency towards more accidents in the final three months of the year, but a relatively small overall deviation. For example the greatest deviation is +14% in November, with a -9% deviation in April. This pattern is exaggerated to a far greater extent when considering only weather-related accidents (shown in blue). This ranges from +40% in November to -32% in July. Another difference between this analysis and Edwards (1999: Chapter 3, Figure 3.2) is the positive deviation in the first two months of the year. Although not as strong as the deviation in the final three months, it does suggest a greater propensity for weather-related freight accidents in January and February than for the rest of the road fleet. This adds weight to the hypothesis that the nature of freight activities and the reduced latitude to postpone or cancel travel increases exposure to weather-related hazards compared with other road users who have a greater ability to reduce their exposure to hazardous conditions (Koetse and Rieveld, 2009). A slight caveat to this analysis is the difference in study periods between this project and Edwards' (1999) research. The seasonally polarised distribution shown in Figure 7.3 is to be expected given the temporal patterns of accident rates given by the individual meteorological parameters of Figures 7.4 (a-e).

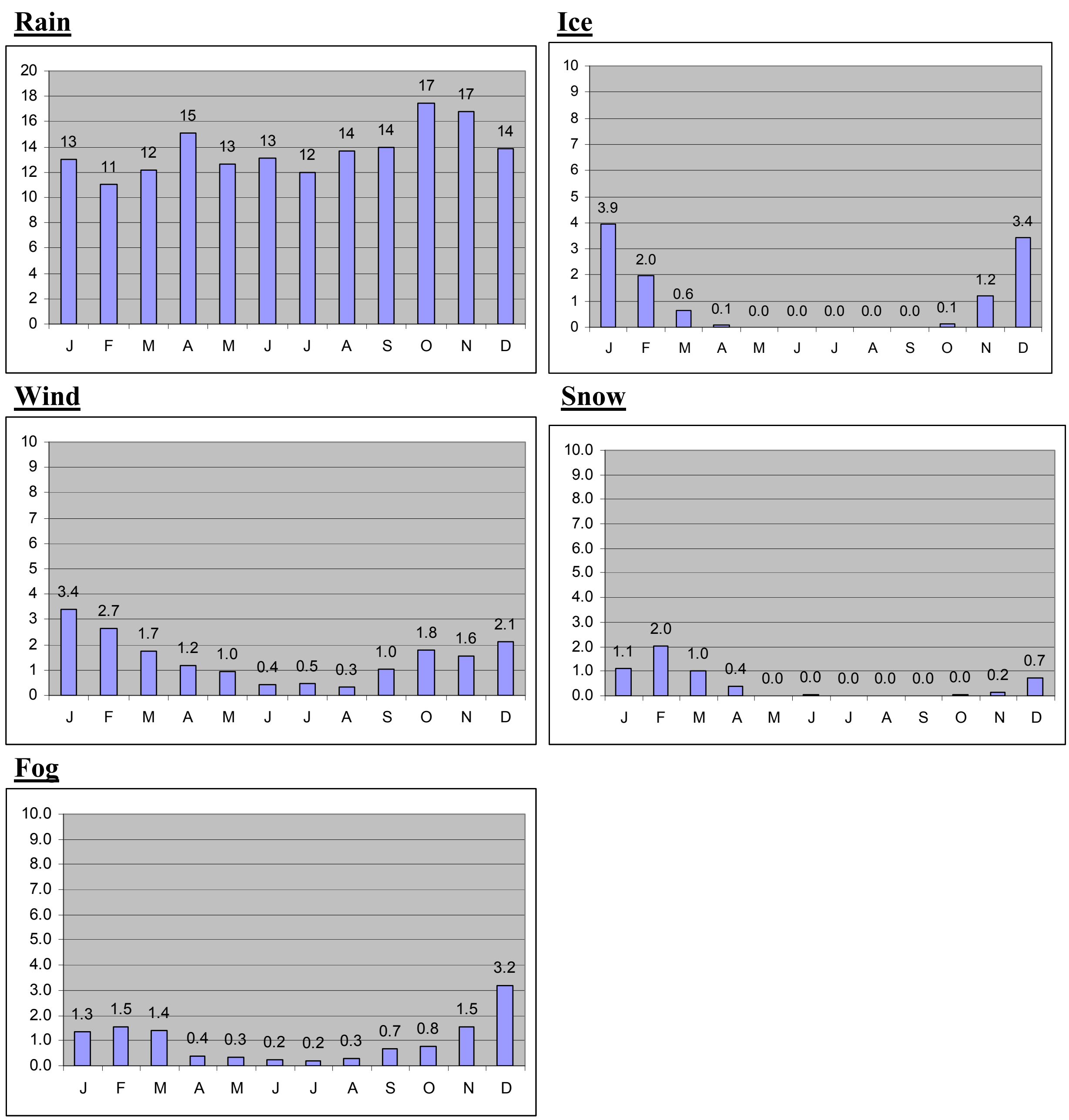


Figure 7.3. Monthly trends in freight accidents for rain, ice, wind, snow and fog as a percentage of all accidents for the period of 1998-2007

Apart from precipitation-related accidents, which show an increase towards the end of the year but are generally static, the patterns for ice, wind, snow and fog-related accidents all show a clear increase during the months of October through to March compared with the rest of the year.

The addition of ice as a studied parameter reveals its significance in accident causation. Although contributing only 1% of accidents on an annual basis, its influence is far more significant during the winter months, being involved with almost 4% of accidents during January. Like Edwards' (1999) study, wind shows a stronger influence in the autumn and winter, being present in 3.4% of accidents during January. Snow has a short period of influence, peaking in February where it accounts for 2% of all freight accidents. The effect of fog is greatest in the months between November and March, peaking at 3.2% of all freight accidents during December. The monthly contribution of precipitation shows the least variation of the hazards, ranging between 11% in February to 17% in October and November, potentially indicating the effect of greater rainfall totals (Met Office, 2010) and reduced hours of daylight (Fridstrom et al, 1995). However, these proportional figures do not reveal whether the actual number of precipitation-related accidents drops in February, or whether the rate stays fairly static while the additional accidents caused by ice, wind, fog and snow dilute its contribution to the total, seen in the spike in weather-related road freight accidents during the winter months in Figures 7.2 and 7.4.

When viewed in real terms (Figure 7.4) it is clear that the pattern of precipitation-related accidents does not wholly determine the pattern of the total weather-related accidents. The rate varies between just under 700 accidents per month in October through to January to under 400 during the summer months. Again, the distribution of ice, snow, wind and fog-related accidents shows a clear increase in the winter, due to the seasonal nature of the hazards. The monthly rates are significantly lower than those for precipitation, each contributing less than 100 accidents per month. However, the cumulative effect of these hazards adds significantly to the total number of weather-related accidents during these months, creating the distinctive U-shaped annual pattern (Figure 7.4, red dashed line), especially in the months of December, January and February, where precipitation-related accidents fall from their peak.

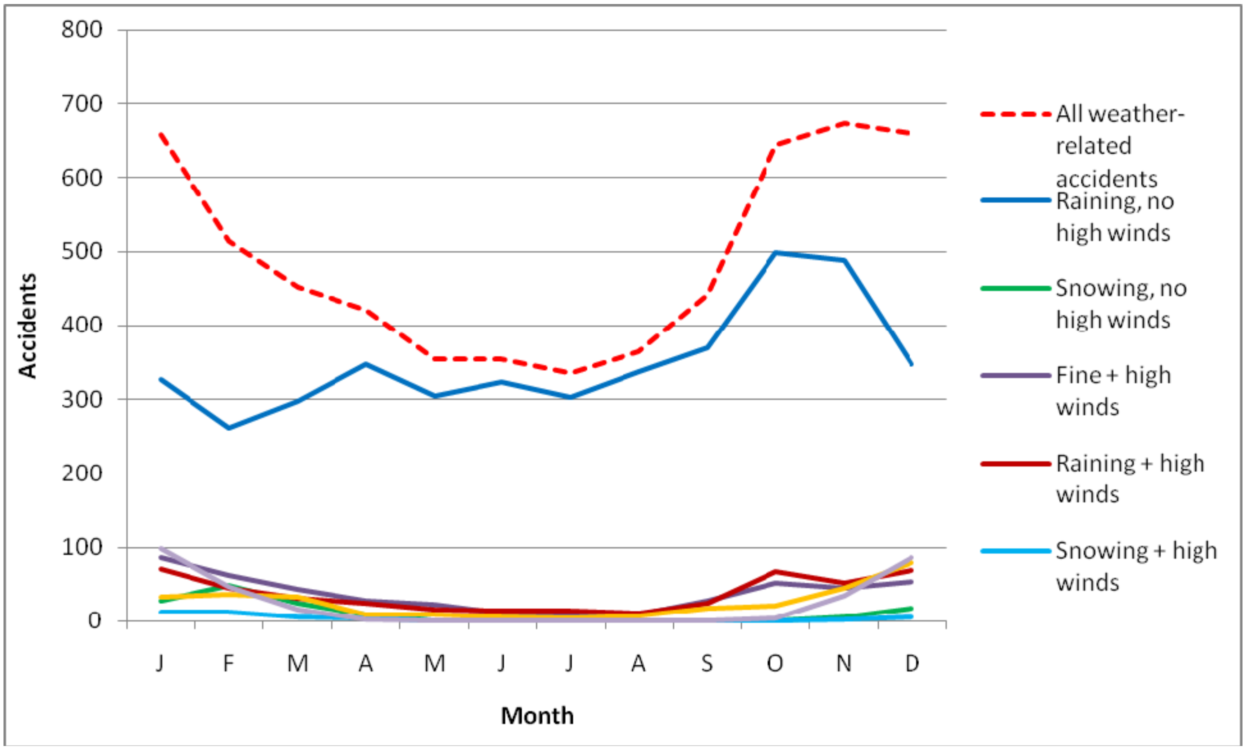


Figure 7.4. Average monthly accident numbers for fine weather, rain, fog, ice snow and wind-related freight accidents for the period of 1998-2007

The number of precipitation-related accidents tallies with the average precipitation data (Figure 7.5; Met Office, 2010) apart from in December. Despite having the greatest monthly rainfall total across Great Britain, there is a clear reduction in accidents. This may be due to the reduction in traffic during the Christmas and New Year break, and fits in with the graph of total freight accidents (Figure 7.6) which also sees a decline in December. This suggests that the period of reduced freight acitivity during December, along with the reduction in traffic volumes during January and February (Department for Transport, 2009), serves to reduce the impact of the winter weather hazards, and suggests that their relative risk (including that associated with ice and snow) is higher than that suggested by Figure 7.4.

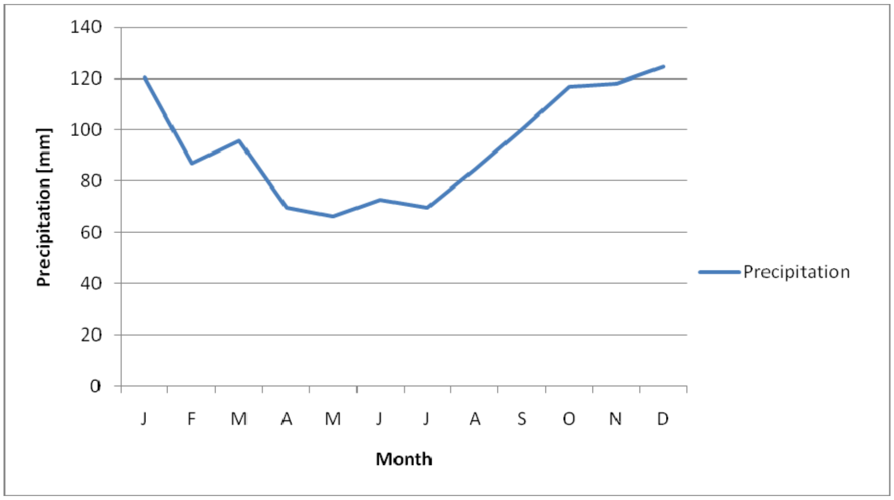


Figure 7.5. UK area averaged precipitation amounts by month for 1971-2000 (Met Office, 2010)

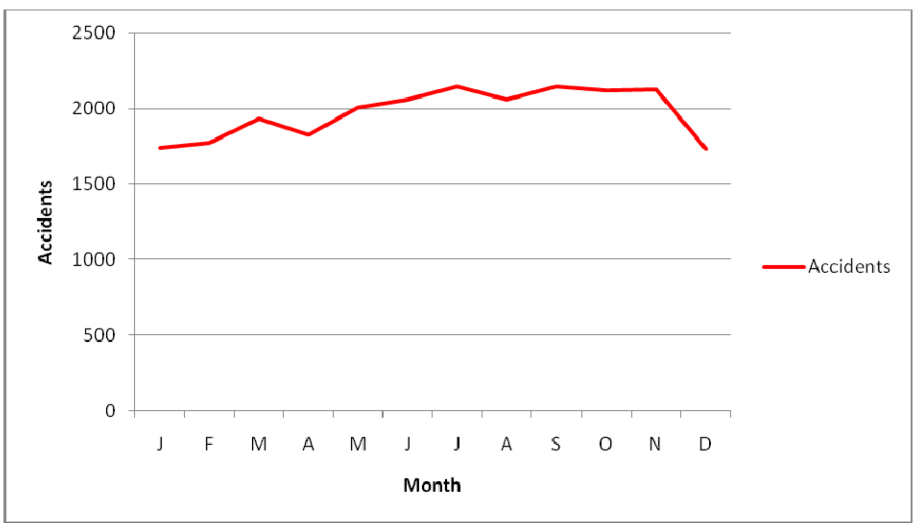


Figure 7.6. Total GB freight vehicle accidents by month for the period of 1998-2007

Another interesting aspect of the data is the inter-annual variation in accident rates. The varying influence of a number of factors, most notably recorded weather, but also trends within the sector, act as potential confounding factors in relationship building. As precipitation is the most common weather hazard it provides a good test bed for examination. Figure 7.7 shows year to year differences in precipitation-related accident numbers between 1998 and 2007. Reference is also made to area-averaged UK precipitation records (Met Office, 2010). Although the ten year period of 1998-2007 was chosen to reduce the influence of changes in vehicle safety technologies and traffic volume (Edwards 1999), the data do show a possible trend, the cause of which is ambiguous.

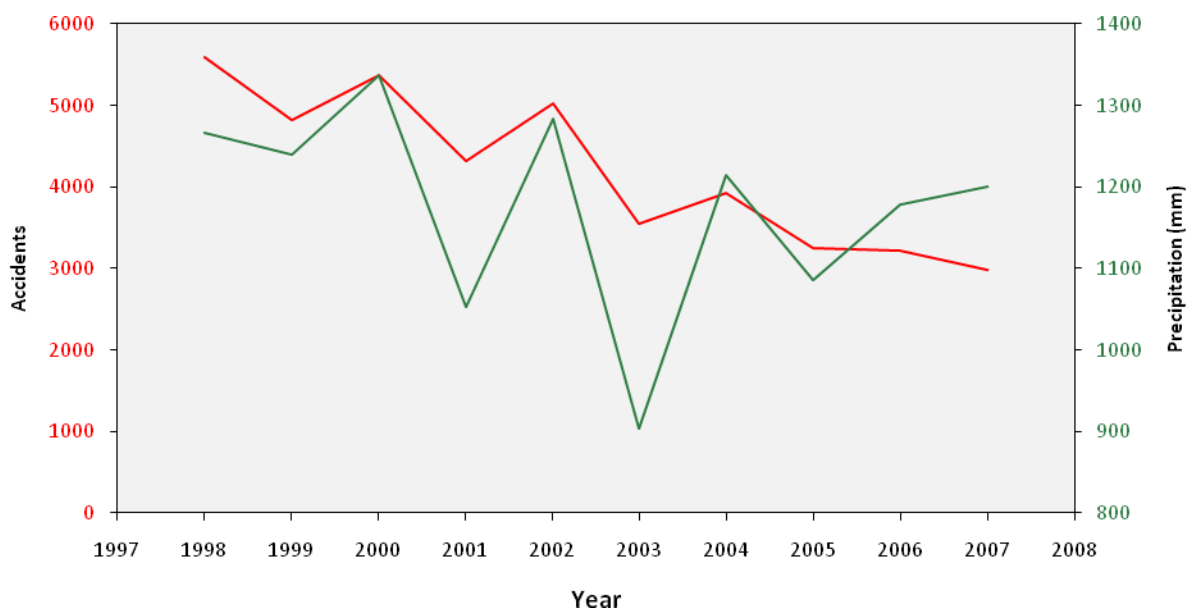
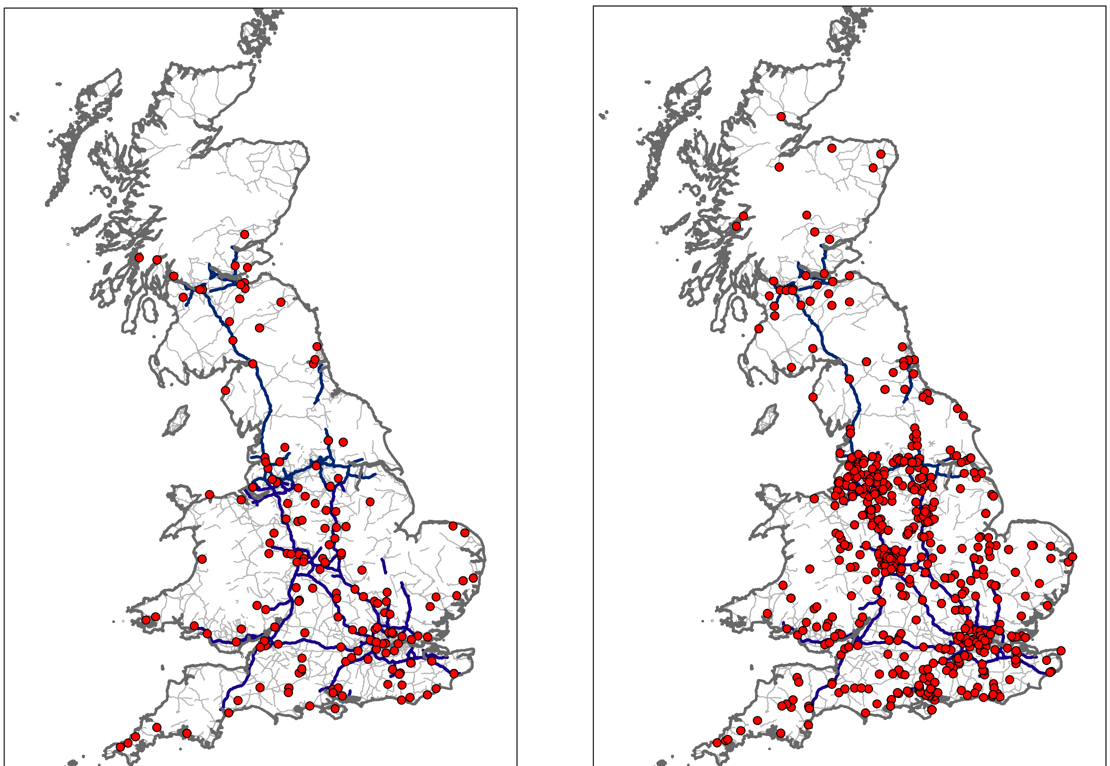


Figure 7.7. Precipitation-related accidents (red line) against UK area-averaged precipitation (green line; Met Office, 2010) for 1998-2007

On first glance there seems to be a trend towards lower accidents, as the first five years of the test period contain the five highest accident counts, with the lowest five occurring in the second half of the period, potentially indicating the influence of improvements in safety. However, the first five years also contain four of the five wettest years between 1998 and 2007 (1998, 1999, 2000 and 2002). The second half of the period has less annual rainfall (four of the five driest years; 2003, 2005, 2006 and 2007) and contains the five lowest years for accidents. This indicates the expected relationship between rainfall and accidents rates, hence de-trending of the data was seen as inappropriate. However, there is still the potential that changes in traffic volume, training and safety technology contributed to the accident patterns in Figure 7.7. This is especially interesting due to the apparent decoupling of the relationship between precipitation and accidents in the final two years of the test period (2006 and 2007), giving evidence of potential influence of developments within the sector. The consultation with experts in the industry discussed in Chapter 9 was important in gauging the importance of these changes. Methodologically, it must be remembered that the use of annual UK average precipitation data in the above example is not an ideal predictor of accident rates as the distribution of precipitation in the Great Britain in any given year as well as the distribution of freight traffic is uneven (see Figure 7.8.), a point addressed in the regional relationships of Sections 7.3 and 7.5.

Much variation also occurs on a monthly and seasonal scale between years, an issue addressed by Andersson and Chapman (2010) in the search for temporal analogues of the potential impact of future climates. As part of the analysis process each month's precipitation and ice-related accidents were plotted onto GIS of Great Britain and separated into regions. Although not the focus of this project, these figures provide a resource to refer to for the potential impact of both extreme months and also future climate averages. This can be expressed clearly by comparing the plots of accidents for July 2006 and July 2007. July 2006 was the hottest calendar month on record across most of Great Britain, and despite several thundery downpours nationally averaged rainfall was 50.9mm (a 69% anomaly), with many locations in England receiving less than 10mm (Eden, 2006). In comparison, July 2007 was the fifth most cyclonic on record with the highest nationally averaged rainfall since July 1936 (138.0mm, a 188% anomaly; Eden, 2007).



(a) (b)

Figure 7.8. Plots of Precipitation-related road freight accidents for (a) July 2006 and (b) July 2007

The large difference in precipitation-related accidents between July 2006 (185) and July 2007 (601) highlights the importance of looking at the variance of meteorology around the annual, seasonal and monthly averages, something that is important to bear in mind with the projected average accident numbers in Chapter 8. This point can be highlighted by referring to the annual area-averaged UK precipitation records in Figure 7.7, showing the extreme wet month of July 2007 occurred in an overall drier year than the extreme dry month of July 2006.

This analysis has the additional benefit of demonstrating the clustering of accidents around the trunk road network such as the M1, M6, and M40, and the major conurbations such as Greater Manchester, the West Midlands and Greater London. This is especially clear in the plot for July 2007 (Figure 7.8). This relates directly to the distribution of accidents across the GB EU regions in sections 7.4 and 7.6.

7.4. Precipitation

As highlighted in the previous two sections, precipitation is the weather type most associated with road freight accidents (Table 7.1, Figure 7.2). Unlike wind (Section 7.4), precipitation is well suited for a quantified CIA assessment due to the nature of its relation with accidents (Andrey and Yagar, 1993; Keay and Simmonds, 2005 and 2006; Eisenberg, 2004) and the availability of robust climate projections for this parameter (Murphy et al, 2009). As mentioned in Chapter 5, the methodology of this CIA splits the construction of relationships for precipitation into summer and winter, informed by the current distinct differences in baseline seasonal precipitation (Jones and Conway, 2007), and the fact that changes in the precipitation regime of Great Britain are projected to be concentrated on the summer-winter axis, with limited change in the spring and autumn (Jones et al, 2009; Murphy et al, 2009).

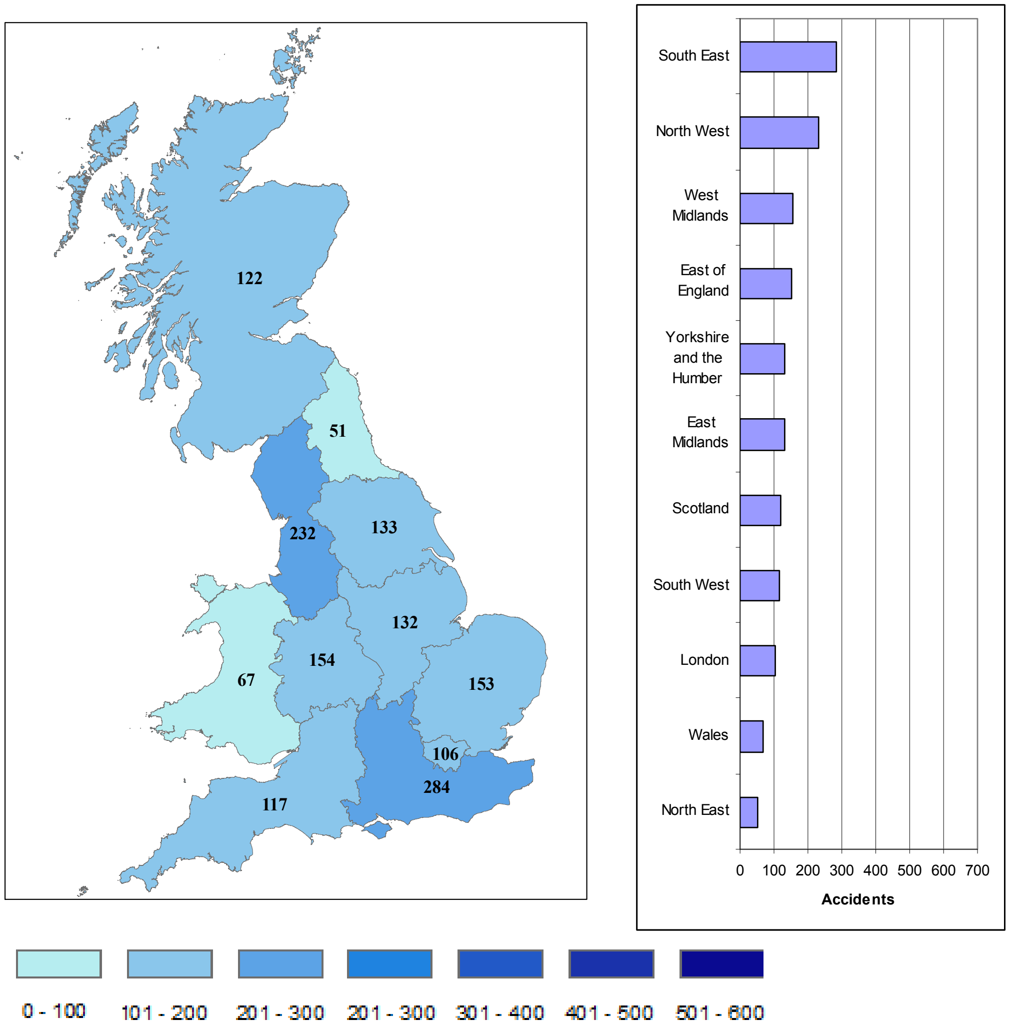


Figure 7.9 Regional distribution of summer precipitation-related road freight accidents, with corresponding graph of ranked totals

The regional distribution of summer precipitation-related accidents and the rank for each region are shown in Figure 7.9. It must be noted that these are total numbers and do not indicate the relative density of accidents against traffic volume in each region. For instance, the South East has the highest average number of summer precipitation-related road freight accidents (284), which is likely due to the heavy traffic flows in the concentration of arterial roads around London and flow-through from channel-crossings. This is also true for the North West region

(232 accidents) and the West Midlands (154). This can be compared with the lower seasonal accident counts in the more rural regions such as Wales (67) and the North East (51). In total the average summer precipitation-related accident average is 1550 across the Great Britain.

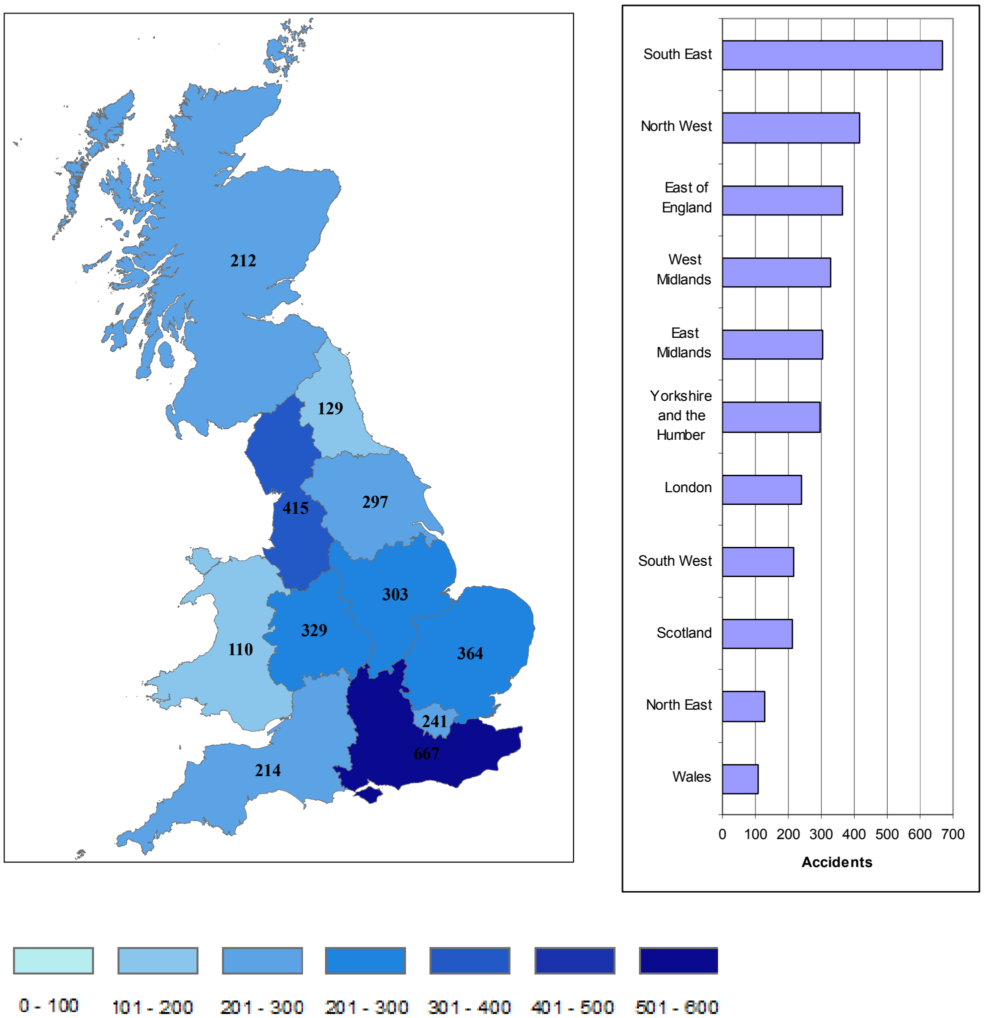


Figure 7.10. Regional distribution of winter precipitation-related accidents, with corresponding graph of ranked totals

Figure 7.10 shows the regional distribution of average winter precipitation-related accidents for 1998-2007. All areas show a significantly higher number of precipitation-related freight accidents compared with the summer, as would be expected from the temporal distributions shown in Figure 7.3a and 7.4. Overall there is a seasonal average of 3280 precipitation-related accidents across Great Britain, more than double that of the summer. Again, the distribution shows a clear relationship with the density of the trunk-road network and traffic volumes. Figure 7.10 shows higher accident counts along the North West (415) to South East (667) corridor, with a more visible concentration of accidents in the central region of Great Britain consisting of the East and West Midlands (303, 329) and the East of England (364), roughly corresponding with the areas of highest traffic. Although experiencing slightly fewer accidents, London (241) can also be included in this group due to the smaller size of this region. It is clear that the routes carrying heavy traffic volumes such as the M1, M3, M6, M25 and M40 increase exposure in these regions, clearly linking in with the distribution of precipitation-related accident plots shown in Figure 7.8. The nature of inter-urban travel between and within these areas may also be important, with factors such as the speed of the traffic and lighting levels being potential influences on accident rates (Fridstrom et al, 1995; Edwards, 1996). The importance of the six regions mentioned above and the impact of climate change in these areas is clear, they contribute to 70% of all winter precipitation accidents, despite accounting for just below 50% of the land area. Similarly to the summer statistics (Figure 7.9), the regions with the lowest average number of accidents are Wales (110) and the North East (129).

7.4.1. Precipitation Relationships

As mentioned in Chapter 5, the previously observed differences in relative accident rates between regions of varying nature (including urban/rural and climatological factors e.g. Edwards, 1996; Eisenberg, 2004) necessitates a set of individual relationships. These are presented in Figure 7.11 for winter precipitation-related accidents and Figure 7.12 for summer precipitation-related accidents.

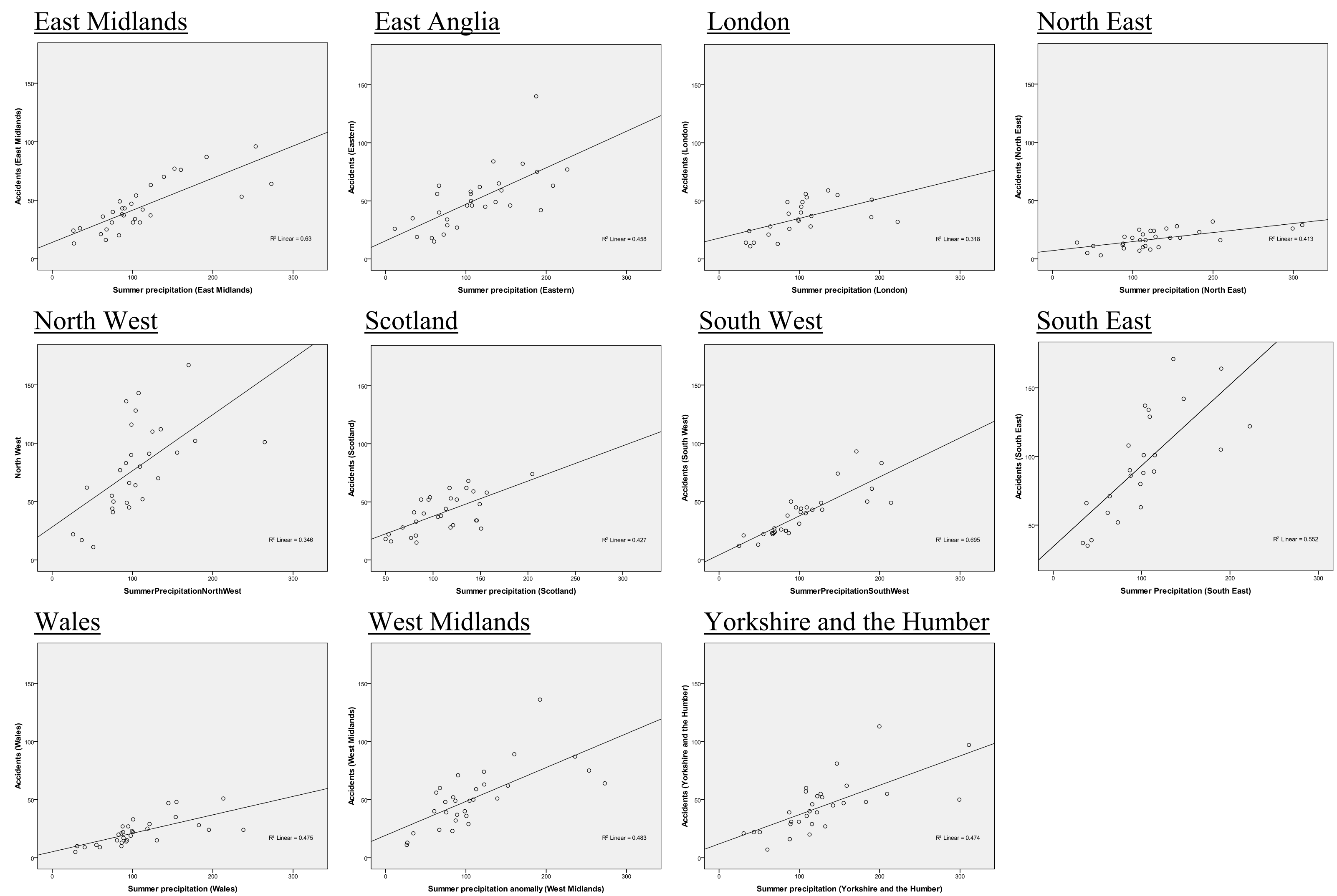


Figure 7.11. Summer plots for monthly accident numbers against precipitation anomaly with trend line and R^2 values for GB regions

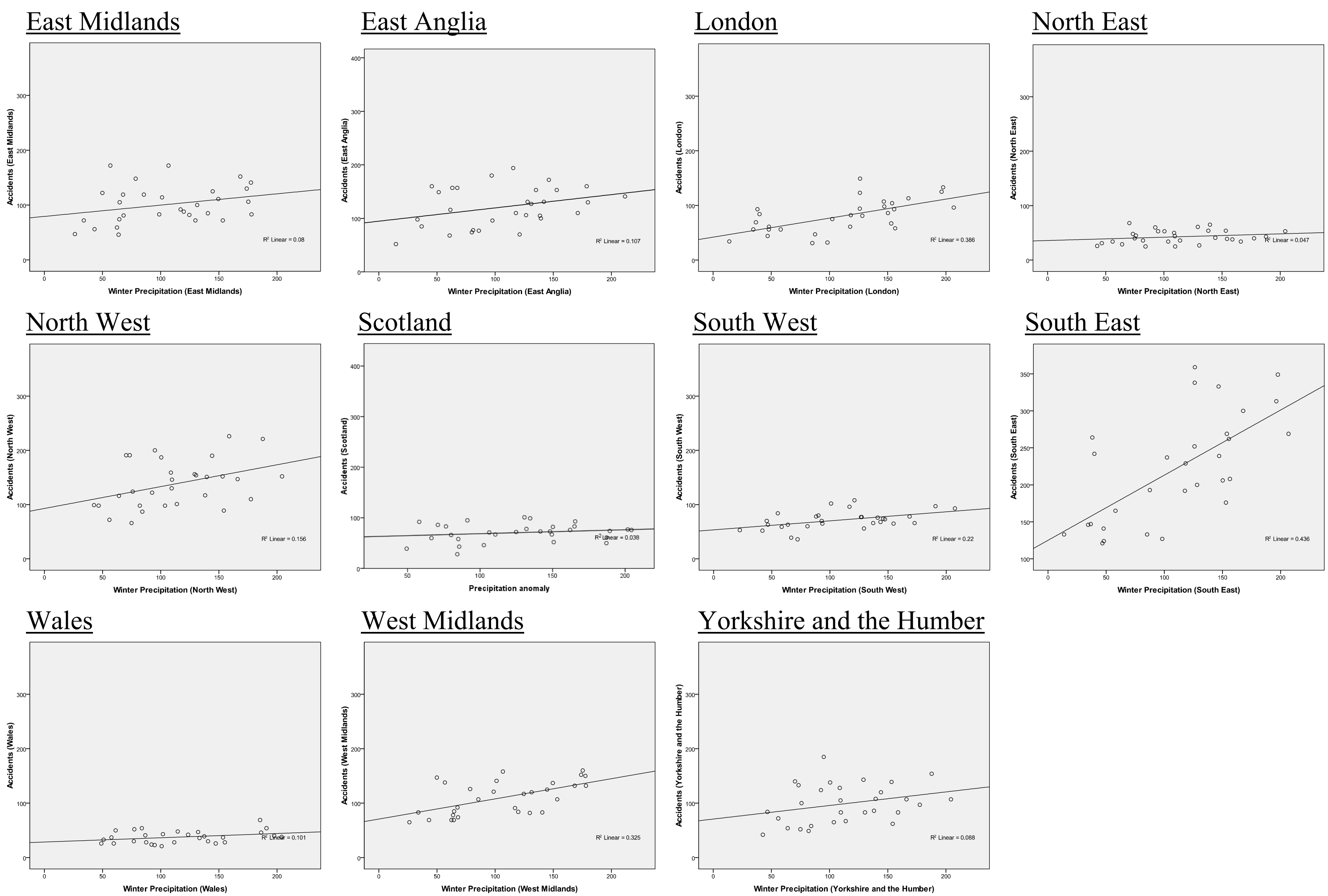


Figure 7.12. Winter plots for monthly accident numbers against precipitation anomaly with trend line and R^2 values for GB regions

The strongest summer precipitation relationships are found in the South West ($R^2 = 0.695$), the East Midlands ($R^2 = 0.63$) and the South East ($R^2 = 0.552$). Only two relationships had an R^2 value below 0.4; the North West ($R^2 = 0.346$) and London ($R^2 = 0.316$). The low score for the North West ($R^2 = 0.346$) is unfortunate due to the large number of accidents in this area (Figure 7.9). The relatively low R^2 value for London is likely due to the use of the wider Met Office South East area averaged rainfall region as a predictor of London traffic accidents. This was done for consistency between regions and for compatibility with the UKCP09 climate model, but the low regression score must be noted as the London area contributes disproportionately to the national accident figure. Although it was decided to use the relationship obtained from this methodology to avoid a mixed approach within the same analysis, an alternative would be to use a single station to represent the London area, although care would be needed to select a representative station, similar to the approach used for the wider regions of the ice analysis in section 7.5, as well as that used in the work of Andrey et al (2003) and Dobney et al (2009 and 2010).

Important for the response to climate change is the gradient of the relationship, with higher gradients having a greater response in terms of accidents. 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 study linking the severity of weather-related accidents to the nature of travel in different regions of the Great Britain. It also tallies with Elvik's (2006) laws of accident causation, as travelling at lower speeds may act to reduce the cognitive pressures put on the driver.

The relationships between winter precipitation and precipitation-related accidents rates given in Figure 7.12 show lower R^2 for most regions. This is unfortunate, given the greater number of accidents in the winter (Figures 7.4 and 7.10), along with the large potential changes in winter precipitation (e.g. Murphy et al, 2009; plume plots in Chapter 8). The strongest relationships are found in the South East ($R^2 = 0.436$), London ($R^2 = 0.386$; the only region to improve on its summer correlation coefficient), and the West Midlands ($R^2 = 0.325$). The fact that these regions have relatively strong relationships is beneficial, due to the contribution that they make to overall accident rates in Great Britain (Figure 7.10). These areas also show relatively steep gradients which, along with some of the highest projected increases in winter precipitation in Great Britain (Murphy et al, 2009), suggests that these areas may be particularly affected in terms of future accident rates.

The remaining regions generally show relatively weak relationships between winter precipitation and accident rates, along with small gradients. It is important to note that as precipitation rates are generally higher in the winter the relationship between precipitation and accidents at lower values of precipitation is difficult to uncover, due to the low number of observations at these values. In reality the relationship would tend towards zero as precipitation decreases, as this analysis is concerned only with accidents recorded under precipitation conditions. Although the linear trend line used in the above relationships is best suited for the part of the range studied in this thesis, it is likely that a non-linear curved trend line could be used to cater for the lower values. The equations of the relationships yielded from this analysis (and used for extrapolation in Chapter 8) are shown in Appendix 4.

7. 5. Wind

As mentioned in Chapter 5, the limitations of currently available climate projections, especially in the modelling of maximum gust speed (e.g. Murphy et al, 2009; Rockel and Woth, 2009) precludes a detailed analysis of relationships and climate extrapolation for this hazard. However, it was deemed useful to investigate the nature of the impact of extreme wind events as a means of discussing hypothetical changes in their frequency and intensity, important when dealing with a hazard that has a non-linear relationship with accidents (e.g. Summerfield and Kosior, 2001). A key difference between the hazards presented in this thesis is the frequency with which they occur. Unlike precipitation which occurs frequently, snow, wind ice and fog present a more sporadic hazard, and this has an influence on the nature of their impact. Although precipitation has the capacity for high impact spikes in accident rates, the higher baseline of precipitation-related accidents (Figure 7.3a) sets it apart from the other hazards studied in this thesis which generally show a much more pronounced pattern; this is especially true for wind (Edwards, 1994). Figures 7.13 shows the recorded daily wind-related accidents during months containing notable extreme storm events (October 1987, January 1990, January 2007) as well as a comparison to the total number of daily accidents (including wind-related accidents), allowing each events' magnitude to be put into context.

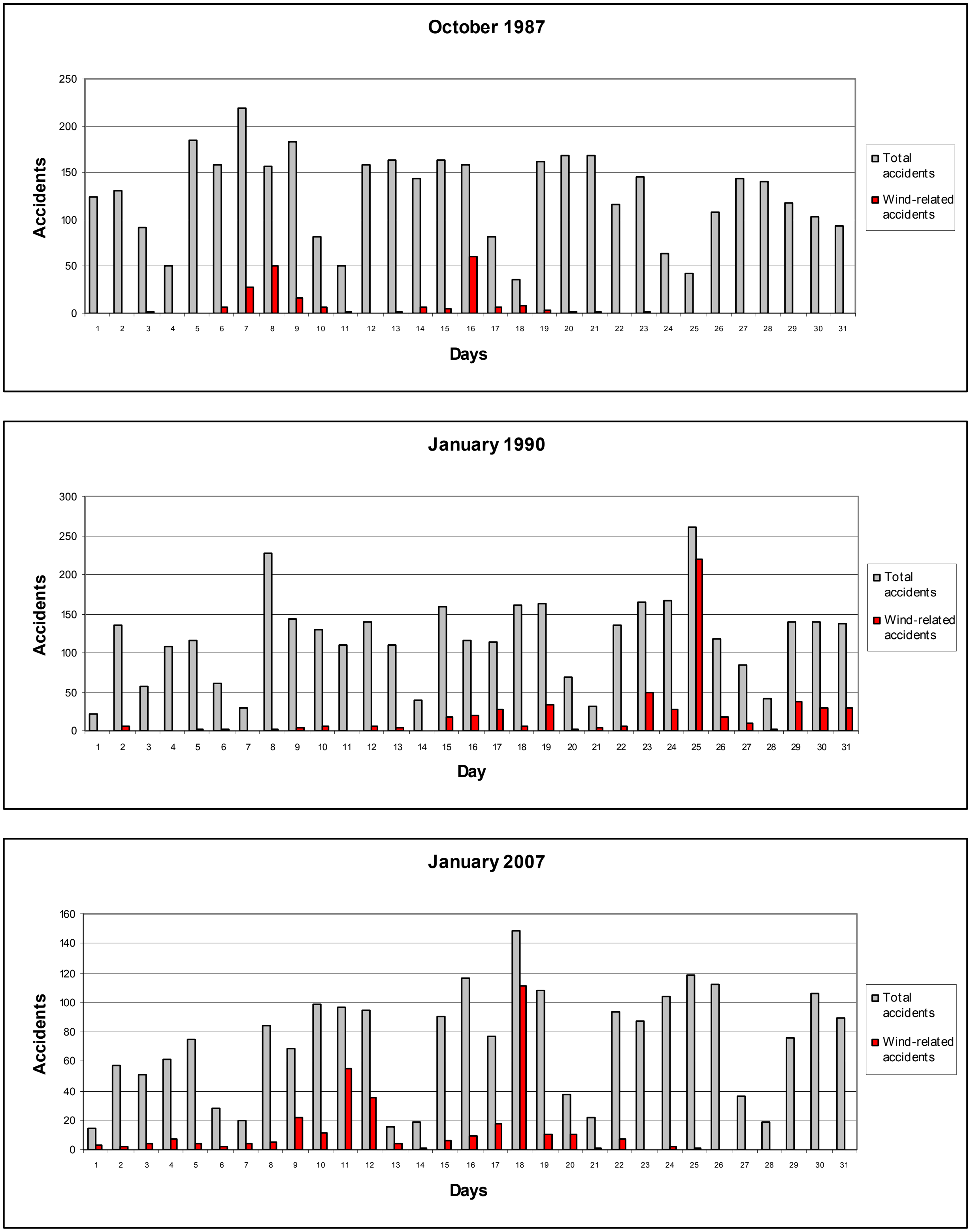


Figure 7.13. Graph showing total daily freight vehicle accidents (grey) and wind-related freight accidents (red) for months containing notable extreme events

All three months show a general low level baseline of wind-related accidents (typically less than 5 per day), accounting for a small proportion of overall accidents. However, during high intensity events wind has the capacity to generate a large share of the total freight accidents across the country. All cases show the disproportionate contribution of extreme wind events, with one or two-day storms contributing the majority of all monthly wind-related accidents. Also note the clear weekly pattern of general accidents, showing greatly reduced accidents during weekends (e.g 10^{th} - 11^{th} of October 1987; 13^{th} - 14^{th} of January 2007). This is important when viewing the impact of the 'Great Storm' of the 15^{th} - 16^{th} of 1987, which stands out less than the other two examples, mainly due to its occurrence on a Sunday night.

During the Great Storm gust speeds of over 80 knots (kn) were recorded across much of the South East England and East Anglia, with higher localised speeds also being recorded (Shine, 1987), causing 65 wind-related road freight accidents across Great Britain. In comparison the similarly powerful 'Burn's Night Storm' of 1990 (Baker and Reynolds, 1992) has a much greater effect than that of the Great Storm. This storm initially tracked across Southern Scotland, moving southwards and causing severe gales and storm force winds across large parts of England and Wales, with a maximum gust speed of 93 kn recorded at Aberporth (McCallum, 1990). Overall, 220 wind-related road freight accidents were recorded. A logical reason for this is that it occurred on a weekday, thereby increasing exposure to the hazardous driving conditions. The event of 'Windy Thursday' on the 18^{th} of January 2007 shows a similar increase in accidents from the baseline. Over this period an intense depression swept over large parts of England, Scotland and Wales with gusts of 65-75 kn (Eden, 2007). In total 111 accidents were recorded.

Interestingly, January 2007 shows a very low number of wind-related accidents following the events of Windy Thursday. Although the magnitude of the wind events that occurred in the remainder of January were much lower (Eden, 2007), it is conceivable that at least part of the reduction in accident rates (also seen after the Great Storm) may be the result of behavioural changes on the part of freight drivers and managerial decisions taken by the haulage companies, perhaps becoming more aware of the hazard and taking greater precautions. Again, this relates to the hypotheses of Elvik (2006), as the storm event likely acts to increase perception of the hazard and promote positive behavioural change to reduce risk. In a more practical sense, severe wind events may also reduce exposure of vehicles after the event due to road closures. For instance, it was reported that roads in some areas took up to 16 days to reopen following the Great Storm, mostly due to uprooted trees (Fishwick, 1990). Additionally, the overall lower level of general freight accidents in January 2007 (approximately 100 daily accidents) compared with the two earlier months (around 150) fits in with the general long-term findings of Edwards (1999) and the Department for Transport (2008), and most likely relate to the improvements in safety and vehicle design, discussed in relation to the Delphi study in Chapter 9. Implications of theoretical changes in the frequency of extreme wind events are discussed in Chapter 10.

7.6. Temperature

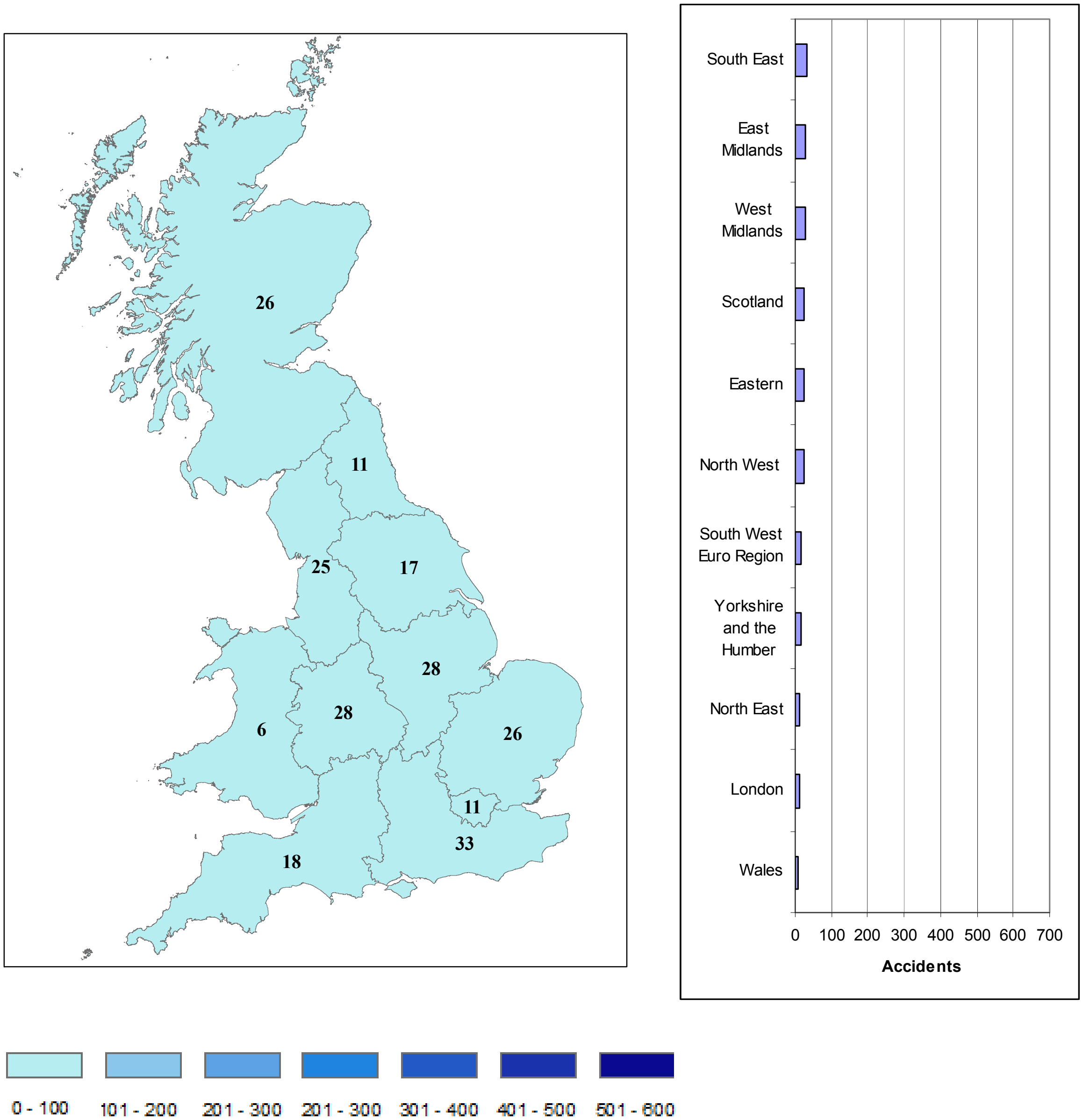


Figure 7.14. Regional distribution of winter ice-related accidents, with corresponding graph of ranked totals

Figure 7.14 shows the regional distribution of winter ice-related road freight accidents. It was deemed useful to look at the individual GB EU regions, even though the final regions used in this project are composites based on those used by Dobney et al (2010). The most striking aspect of Figure 7.14 is the significantly lower accident counts compared with the respective maps for summer and winter precipitation-related accidents. Overall there was an average of 229 winter ice-accidents over the 1998-2007 study period. The South West has a relatively high number of accidents (33) which belies its warm climate. This could be due to the lower number of frost nights, giving drivers fewer opportunities to learn how to deal with this hazard. This would be suggested from the work of Elvik (2006), and particularly the learning curve from Brüde and Larsson (1980; Chapter 3, Figure 3.1), although in reality the higher is more likely a reflection of the higher traffic volumes, and hence greater exposure in this region. However, this reasoning is slightly counteracted under this weather type Scotland (26) features highly in the ranking of regions, possible due to the colder climate. However, without traffic count data it is not possible to rank the risk per exposure unit, which would give a better measure of relative risk. The highest areas are again the South East (33), East Midlands (28), North West (25) and the East of England (26). The lowest averages are in the North East (11) and Wales (6). For the purposes of the analysis these areas are combined into the composite regions of the South East (44), West (24), Central (82) and North (79).

7.6.1. Temperature relationships

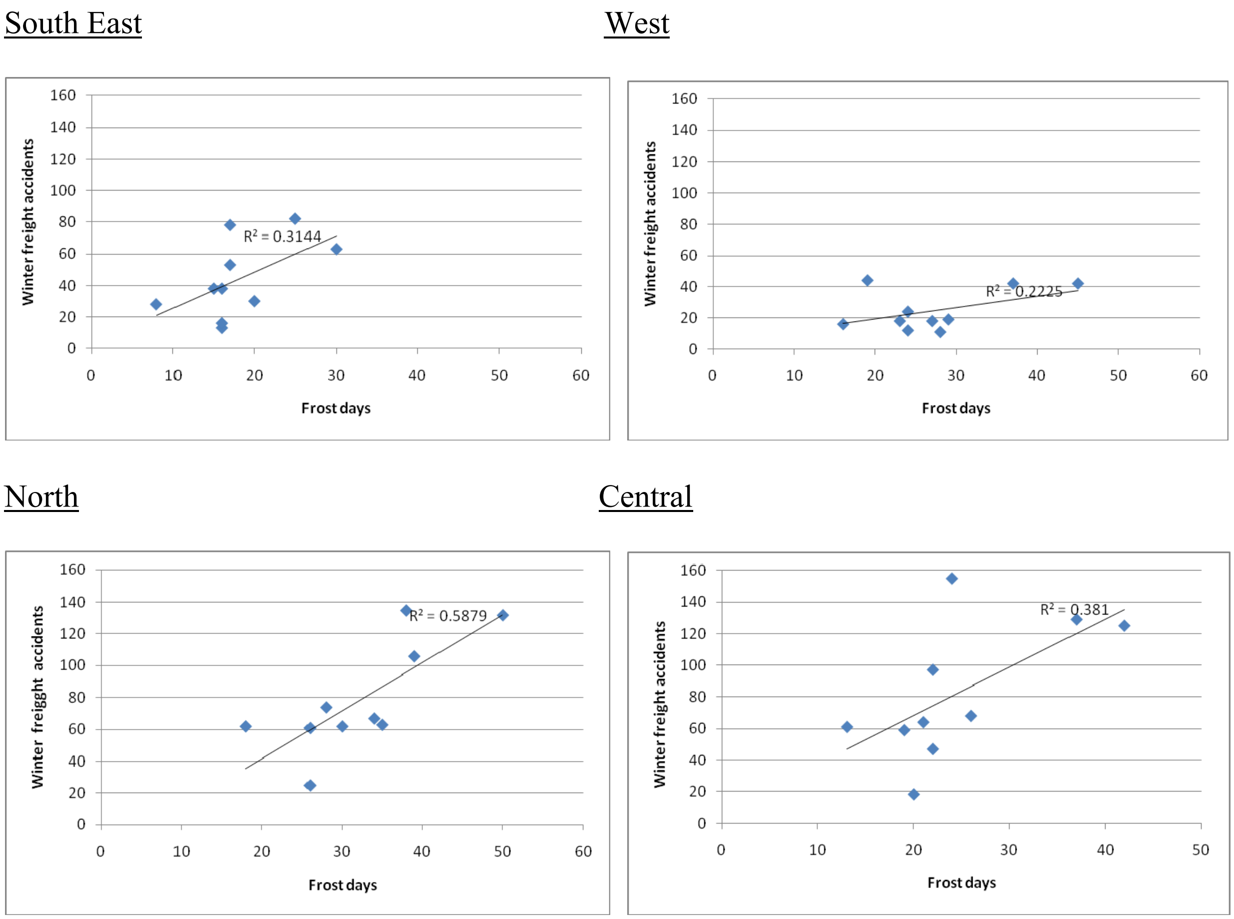


Figure 7.15. Winter ice-related road freight accidents against winter frost-days for the composite South East, West, Scotland and Central regions, 1998-2007

Figure 7.15 shows seasonal ice-related road freight accidents plotted against seasonal frost-days. As expected the number of winter frost-days is greater in the North (18-50) and Central regions (13-42) compared with the South East (8-30) and West regions (16-45). The R^2 values for the relationships were highest for North, with 0.588, with lower R^2 values for the Central region (0.381), the South East (0.314) and the West (0.223). It should be noted that even though some of the R^2 values are comaparable with precipitation relationships, the ice relationships were formed with annual figures to increase the accident counts, reducing the number of observations and therefore reducing the validity of the regression. The South East, Scotland and Central regions have comparable gradients, with the West having a lower gradient, suggesting that the first three regions are more sensitive to future changes in climate.

7.7. Discussion

A surprising discovery from the analysis of accident data is the relative similarities in both the contribution of different weather types to the overall accident counts and the temporal distribution of accidents between this freight-based study and the earlier more general study by Edwards (1999). This is especially surprising for wind, which shows a similar contribution to total accidents as well as a similar temporal distribution. It had seemed logical to hypothesise that the physical vulnerability of freight vehicles (e.g. Baker, 1992; Summerfield and Kosior, 2001), the reduced ability of freight drivers to postpone or delay travel during hazardous weather, and the fact that freight drivers are often exposed to additional risk factors such as low lighting conditions in early winter mornings may result in a higher proportion of freight accidents being associated with wind, and perhaps weather in general. One potential explanation is that the inherent vulnerability of freight vehicles may be partly offset by the benefits of trained and experienced drivers, as would be predicted by Elvik's laws of accident causation (2006). The fact that freight drivers encounter weather-related hazards far more often than the majority of other road users relates to the learning curve of Brüde and Larsson (1980) discussed in Chapter 3, where increased exposure reduces relative risk as drivers become better at dealing with hazardous conditions.

It is important to remember this concept when considering climate change, as the frequency of exposure is likely to change significantly, potentially increasing the severity of the impact of a given meteorological hazard as a result. For example, the spikes in accident rates for extreme wind events given in Figure 7.4 are partly determined by the ability of the driver to cope in those conditions, which in turn is partly determined by the number and frequency of times they have been exposed to similar conditions in the past. An increased frequency would likely reduce the prominence of the spikes in accidents seem in Figure 7.4, whilst a decrease in frequency would act to exacerbate them. The potential real-term net effect of these shifts in frequency of exposure is discussed in relation to the accident projections in Chapter 8.

7.8. Conclusion

This chapter developed the base level of understanding of the relationships between recorded weather and freight accidents needed for this CIA. The general overview of temporal patterns in weather-related road freight accidents in the GB is similar to those for all weather-related vehicle accidents found by Edwards (1999), with precipitation being associated with the largest number of accidents. However, there is a higher propensity for weather-related accidents during the first two months of the year than the earlier study, potentially indicating the fact that the ability to postpone or cancel travel is much lower for freight transport than other constituent components of the road. When viewed in real terms, precipitation is associated with around twice as many accidents in the winter than during the summer. As shown for several wind events, the nature of this hazard is quite different to precipitation, with a low underlying baseline of accidents and a particular importance of infrequent high-intensity events. The spatial distribution of accidents show significant clustering around the trunk road network and major conurbations, leading the North West, Midlands and the South East to have the highest recorded accident counts. Linear regression of precipitation and frost-days against accidents produced a suite of seasonal relationships, with the strongest being those for summer precipitation. The following chapter uses these relationships to project the potential impact of climate change on road freight accidents in Great Britain.

Chapter 8: Future Physical Environments for Britain's Freight Sector

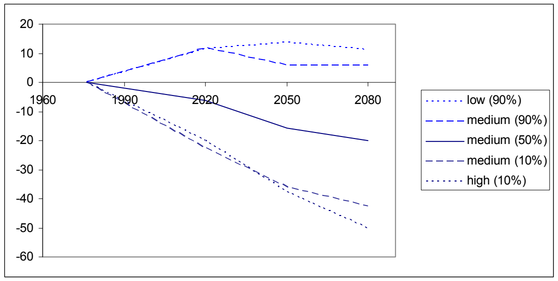
8.1. Introduction

This chapter extrapolates the accident relationships formed in Chapter 7 onto a set potential future climates describing both high and low probability scenarios. These cover the 2020s, 2050s and 2080s for low, medium and high emissions, and are given at a range of probabilities. The existing functionality of the UKCP09 climate model is used for precipitation projections in the form of plume plots, while additional attention is paid to the data manipulation used to extract tailored forecasts for future number of frost-days from the UKCIP Weather Generator. These are presented as cumulative distribution functions (CDFs). The resulting accident projections are presented in map form for summer and winter precipitation-related accidents and winter ice-related accidents for the various GB EU regions. GB-wide projections are shown in various graphical forms, in terms of percentage change and real numbers, and as a total combination of weather-related accidents and by season and weather type. This chapter concludes with a consideration of the behavioural impacts that a changed climatic environment may have on freight drivers and how this may act to modify the projections made in this thesis. The analysis presented in this chapter provides the base of the CIA undertaken in this thesis, constituting a 1st generation CIA under the definition of Füssel and Klein (2006).

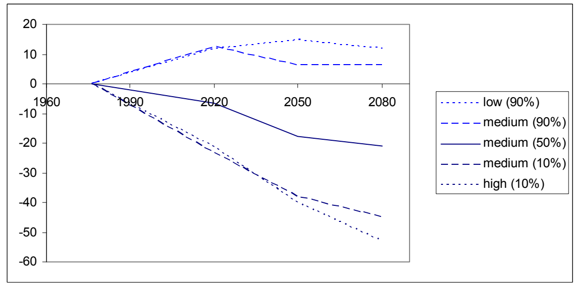
8.2. Climate projections for precipitation

As mentioned in Chapter 5, the projections for precipitation used the existing functionality of the UKCP09 climate model to produce a number of plume plots at different locations, time-steps, emission scenarios and probabilities. The plots presented in Figures 8.1 and 8.2 have been simplified from the raw output. The plots focus on the medium emissions scenario, giving the central estimate as well as the upper and lower probability bands of this projection, indicating that the model predicts there is a 90% probability of the climate will change within these bands, and a 10% probability that the change will occur outside of this plume. The upper bands under low and high emissions are also given.

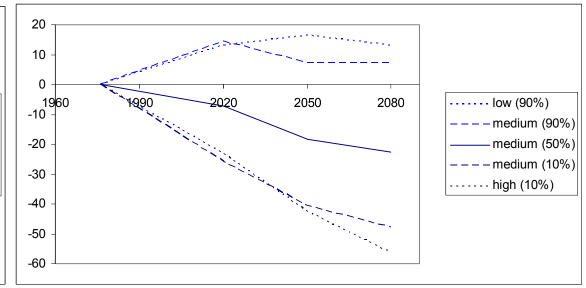
East Midlands



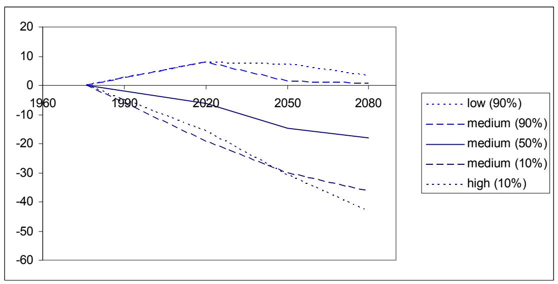
East of England



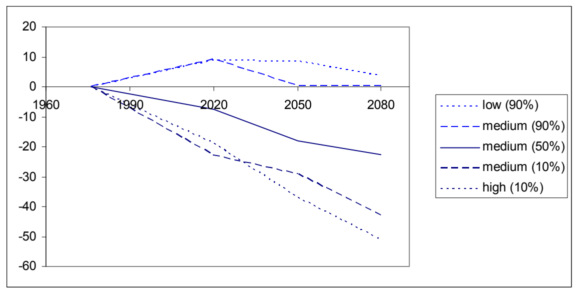
London



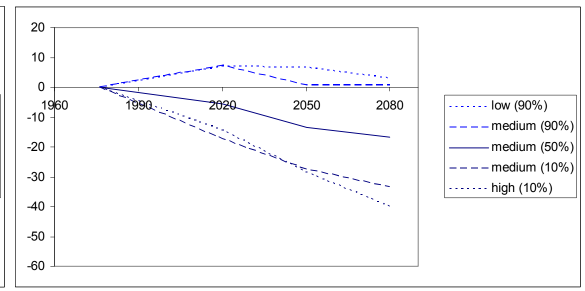
North East



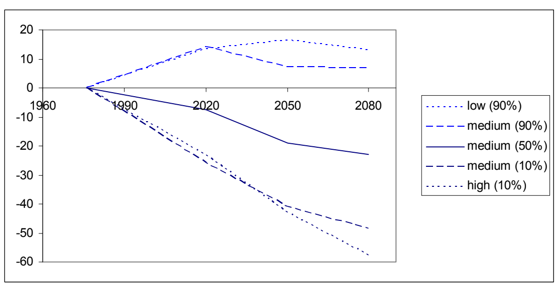
North West



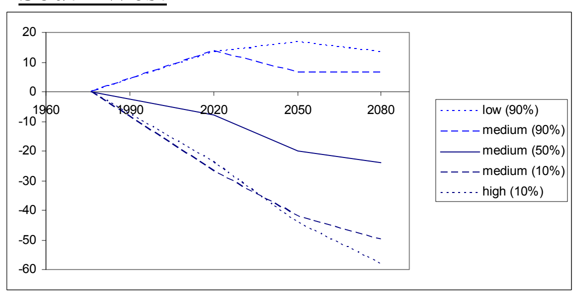
Scotland



South East



South West



Wales

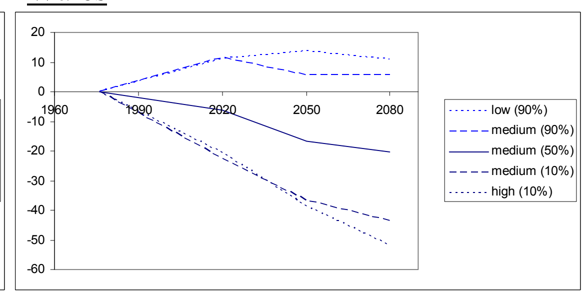
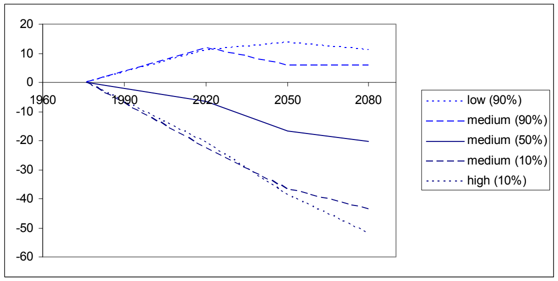


Figure 8.1. Regional plume plots for projected summer precipitation against 1961-1990 anomaly for 2020s, 2050s and 2080s at medium emissions (central estimate and upper and lowers 10% probabilities) and outlying projections for low and high emissions

West Midlands



North Yorkshire and the Humber

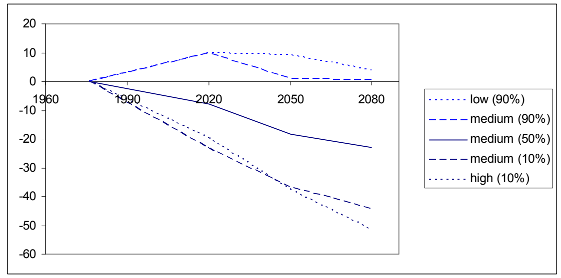
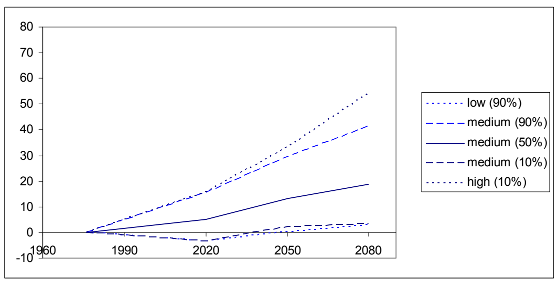
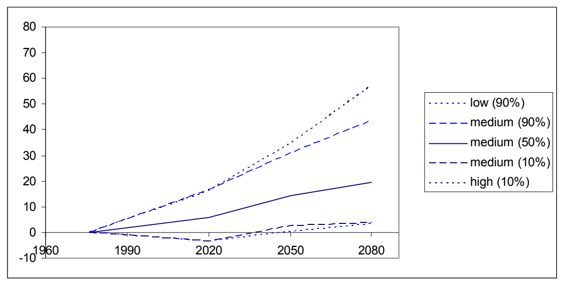


Figure 8.1. (continued)

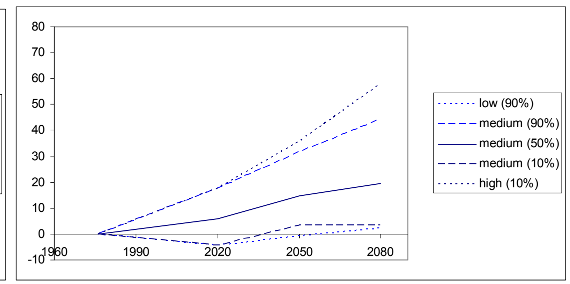
East Midlands



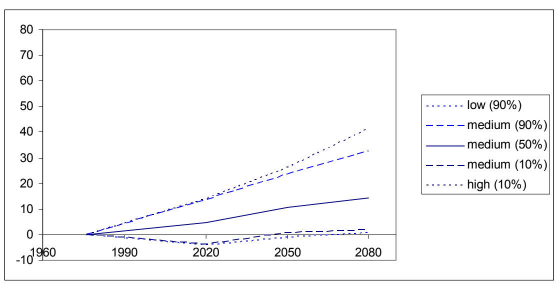
East of England



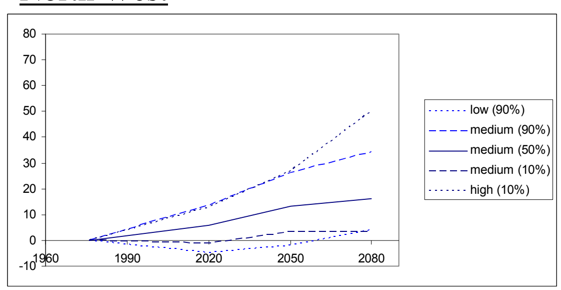
London



North East



North West



Scotland

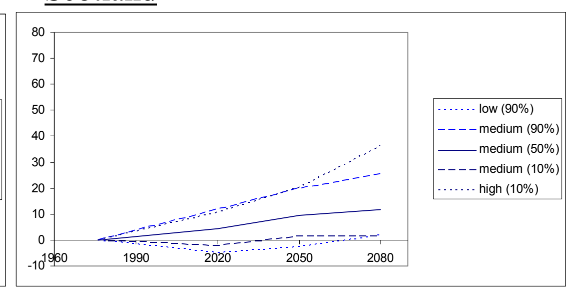
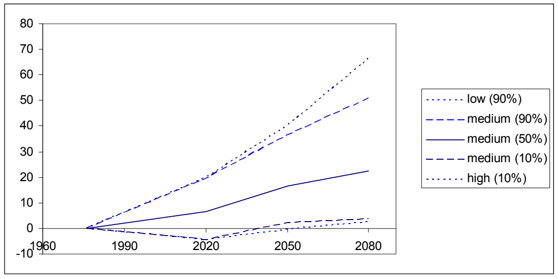
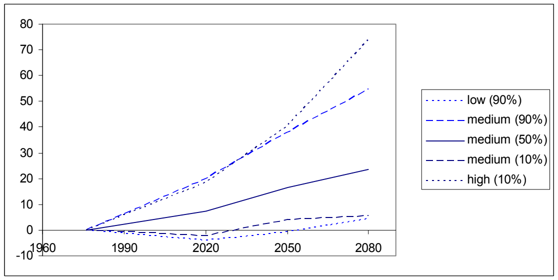


Figure 8.2. Regional plume plots for projected winter precipitation against 1961-1990 anomaly for 2020s, 2050s and 2080s at medium emissions (central estimate and upper and lowers 10% probabilities) and outlying projections for low and high emissions

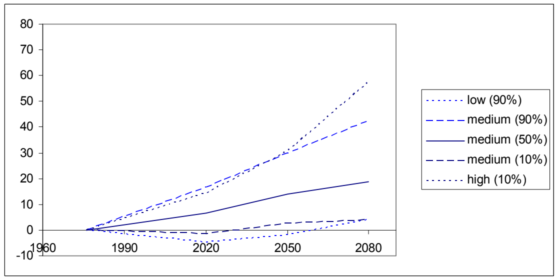
South East



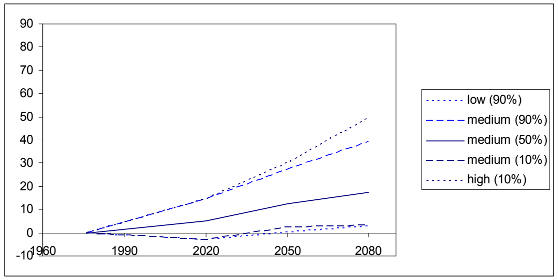
South West



Wales



West Midlands



North Yorkshire and the Humber

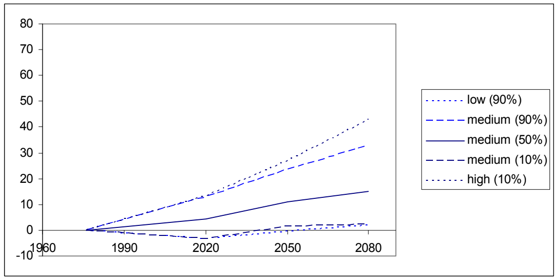


Figure 8.2. (continued)

Summer precipitation (Figure 8.1) shows a broadly decreasing trend under medium emissions at the central estimate, agreeing with the findings of Murphy et al (2009). For example the West Midlands shows a 6.5% decrease by the 2020s, a 16.7% decrease by the 2050s and a 20.2% decrease by the 2080s. The greatest decrease is given in the South West, projected at 20% and 24% by the 2050s and 2080s respectively. The smallest decrease is projected for Scotland, falling by 13.6% and 16.6% by the 2050s and 2080s. However, the summer precipitation projections show a large range of potential outcomes. For instance, under low emissions there is a 10% probability of increases in precipitation greater than 13.8% and 11.1% by the 2050s and 2080s for the West Midlands. Conversely under high emissions there is a projected 10% probability of decreases over 38.6% and 51.8% by the 2050s and 2080s. Overall the greatest decreases are suggested for the South West under high emissions, with a 10% probability of decreases greater than 44.3% (2050s) and 58% (2080s). The greatest increase is also projected for the South West, with a 10% probability of increases in excess of 16.6% (2050s) and 13.3 (2080s). There is an overall 71% spread between the greatest regional increase and decrease by the 2080s under low emissions.

Conversely, the winter precipitation projections show increases at most emission scenarios and for most probability levels, again agreeing with the findings of Murphy et al (2009). In comparison with the summer projections, the West Midlands shows stepped increases of 5.2% (2020s), 12.7% (2050s) and 17.3% (2080s) under medium emissions at the central estimate. The magnitude of regional increases range from 9.6% (2050s) and 11.7% (2080s) in Scotland to 16.7% (2050s) and 23.4% (2080s) in the South West, suggesting a potential North-South gradient of impact. Small decreases can be seen under low emissions at the 10% probability level, for instance a 2.7% decrease in the 2050s in Scotland. There is also the potential for much larger scale increases in winter precipitation under high emissions, with a 10% probability of increases greater than 40.5% (2050s) and 73.8% (2080s). The overall spread of change is 70% at the 2080s.

8.3. Climate projections for temperature

As discussed in Chapter 5, a separate methodology was used to project future number of frost days. The mean numbers of frost days projected by each 30-year model run are displayed in the form of a cumulative distribution function in Figures 8.3-8.6. The central estimate is read at 50% on the y-axis, with the x-axis showing the number of days where the minimum temperature is 0ºC or lower. For example, at Heathrow in the 2080s under high emissions there is a 10% probability of the number of frost-days being less than 1.6, a 50% chance of 6.6 frost days and a 90% probability that the number of frost days will be less than 13.7. Furthermore, there is a 95% probability of the number of frost-days being less than 18, the baseline found for the 1998-2007 study period used in this thesis, indicating that almost all of the models predict a decrease in frost days.

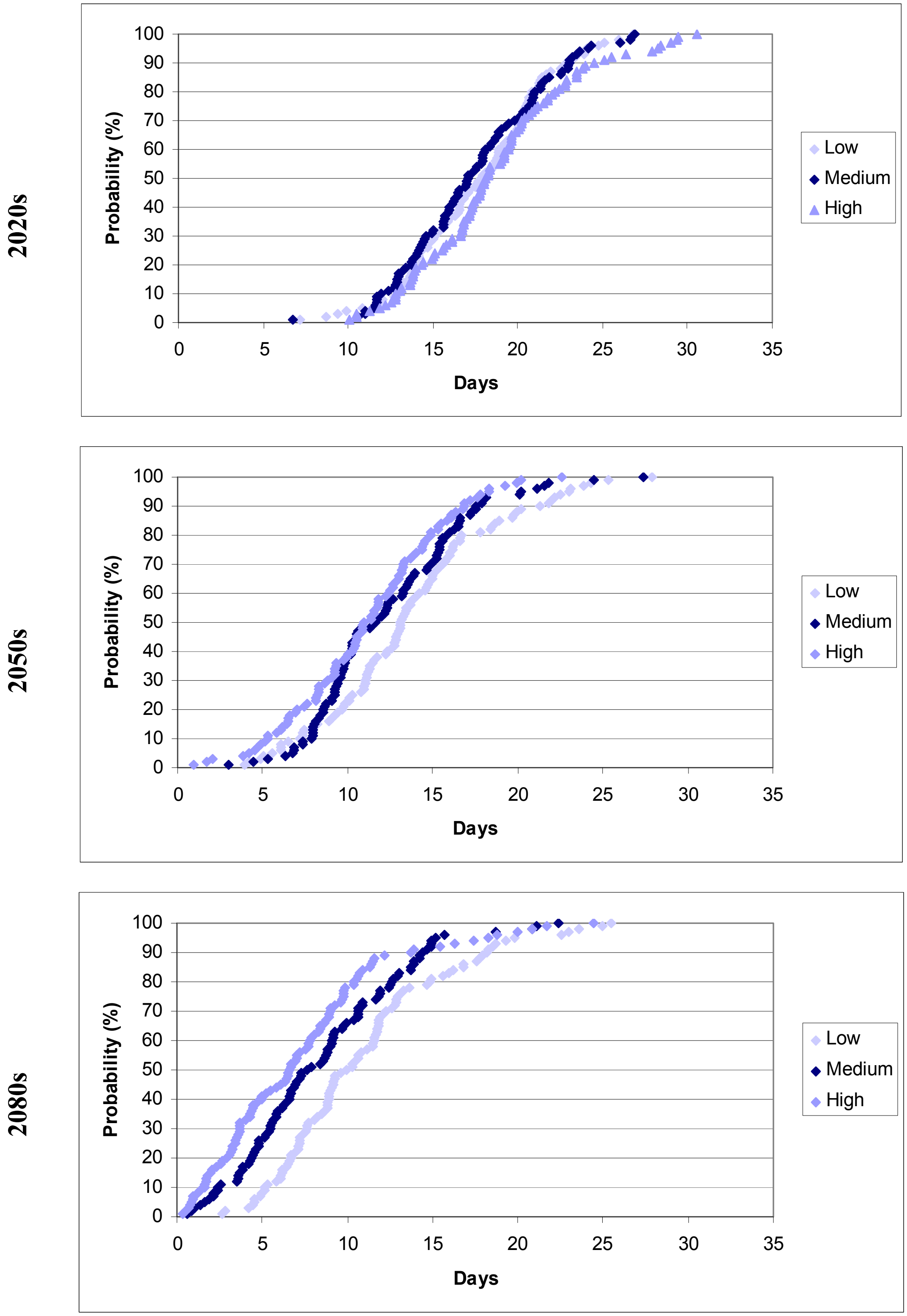


Figure 8.3. CDFs of projected annual number of days with minimum temperature of 0ºC or lower for <u>Heathrow</u> under low, medium and high emissions for the 2020s, 2050s and 2080s

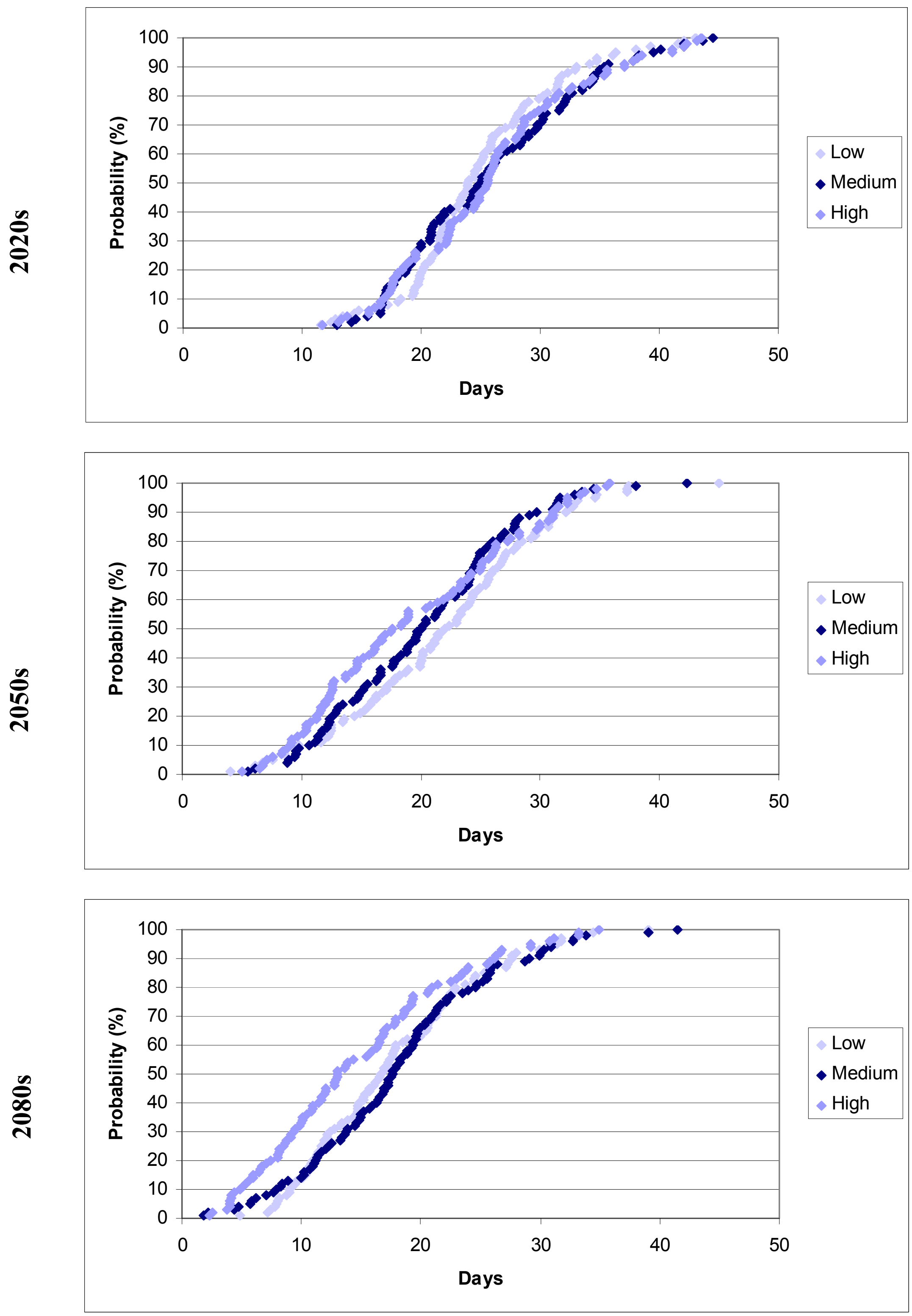


Figure 8.4. CDFs of projected annual number of days with minimum temperature of 0ºC or lower for <u>Leuchars</u> under low, medium and high emissions for the 2020s, 2050s and 2080s

2020s

2050s

2080s

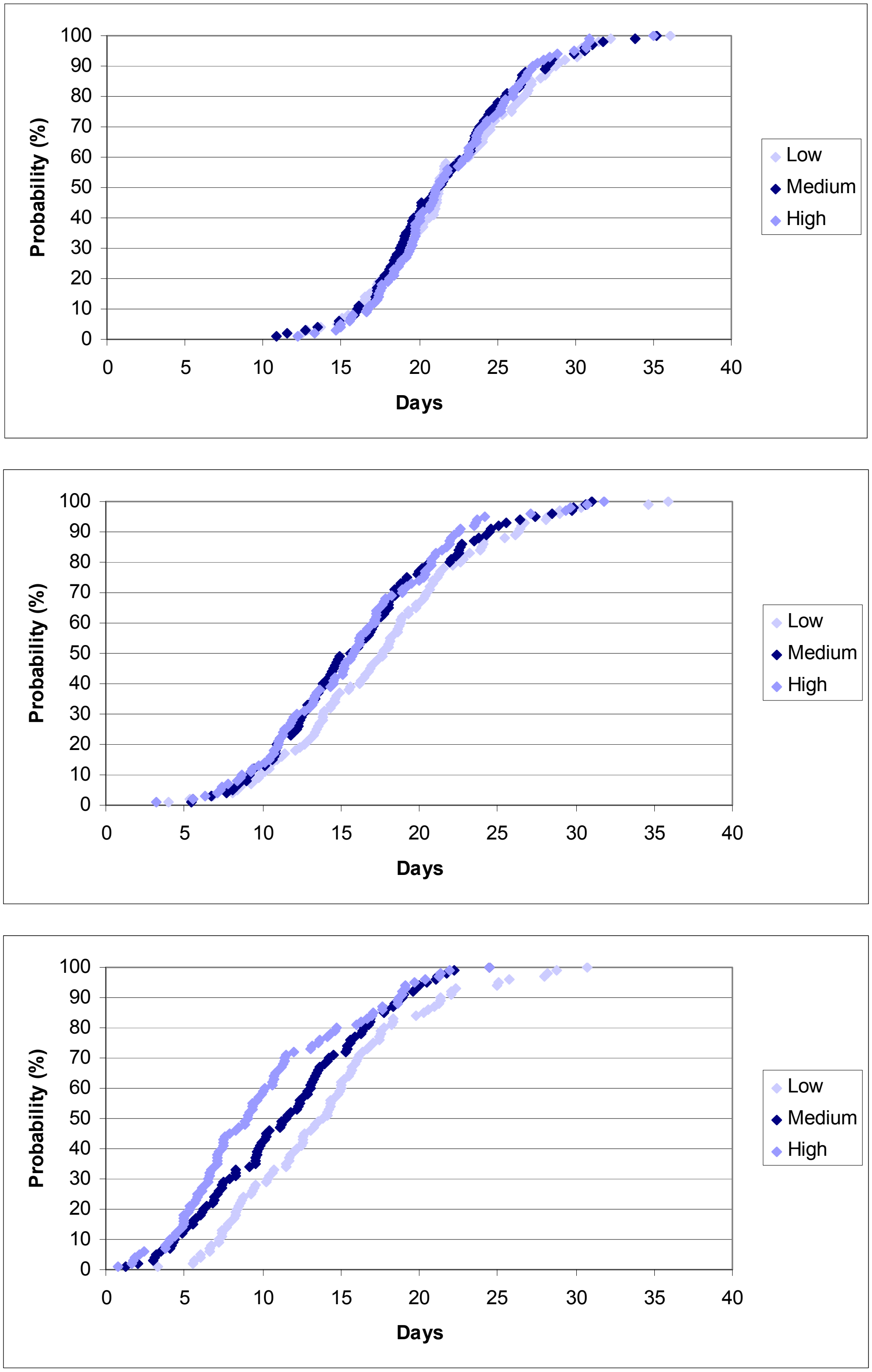
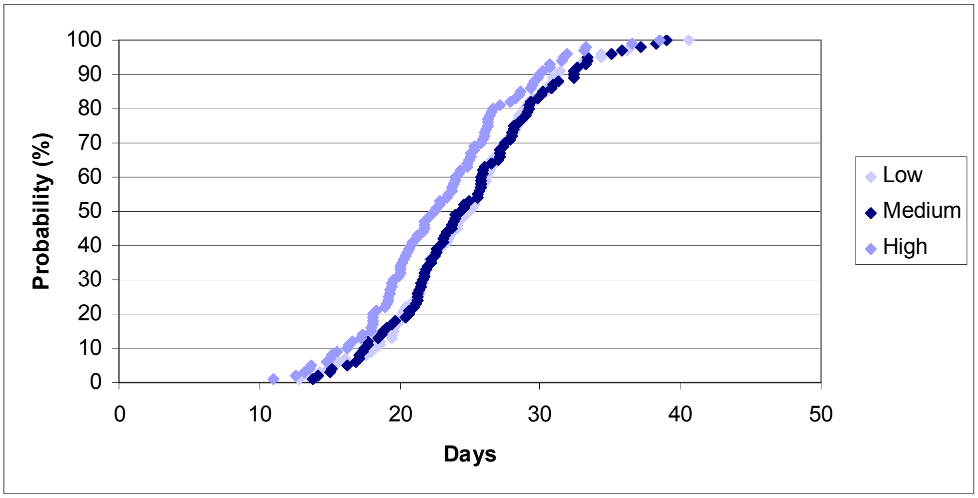
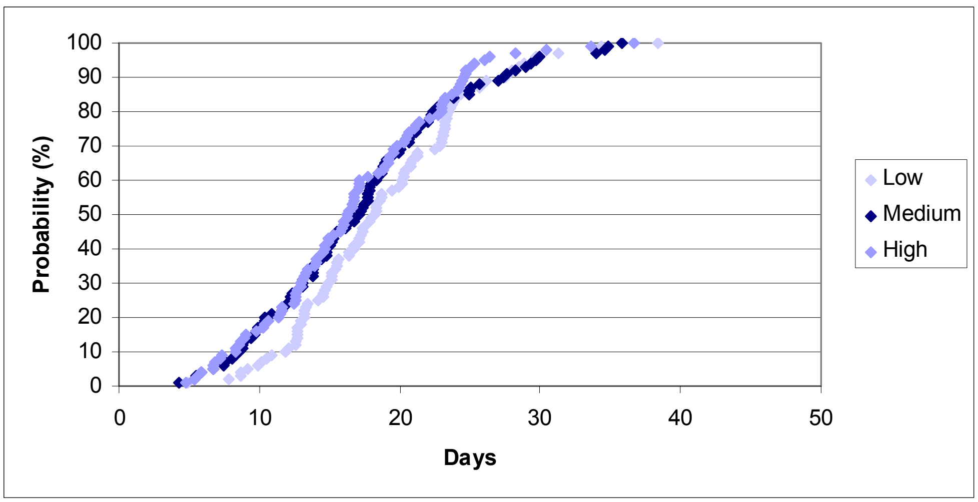


Figure 8.5. CDFs of projected annual number of days with minimum temperature of 0ºC or lower for Lyneham under low, medium and high emissions for the 2020s, 2050s and 2080s

2020s



2050s



2080s

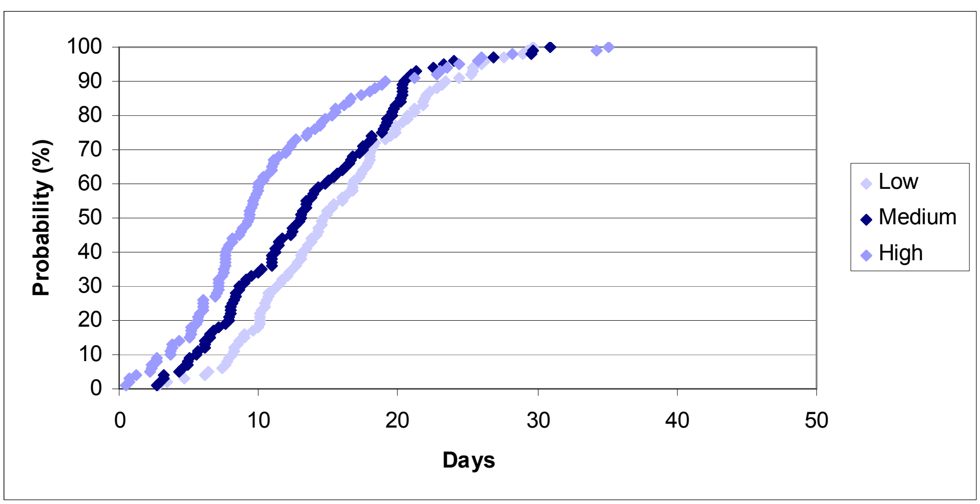
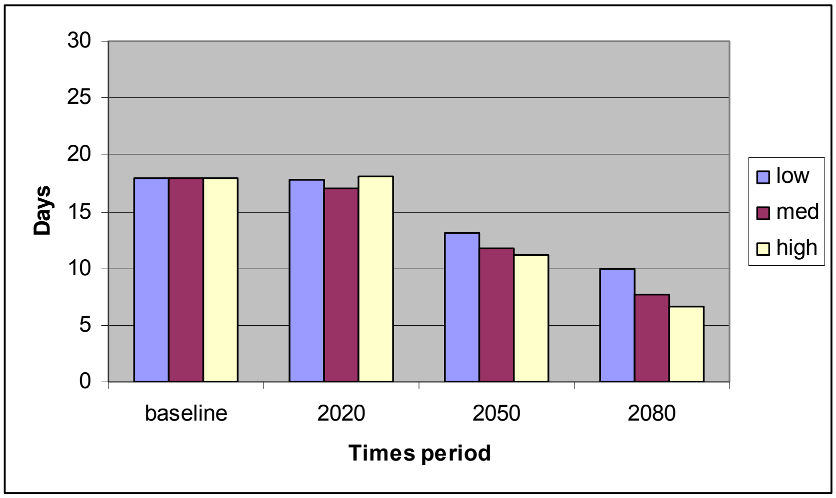


Figure 8.6. CDFs of projected annual number of days with minimum temperature of 0ºC or lower for Waddington, low, medium and high emissions for the 2020s, 2050s and 2080s

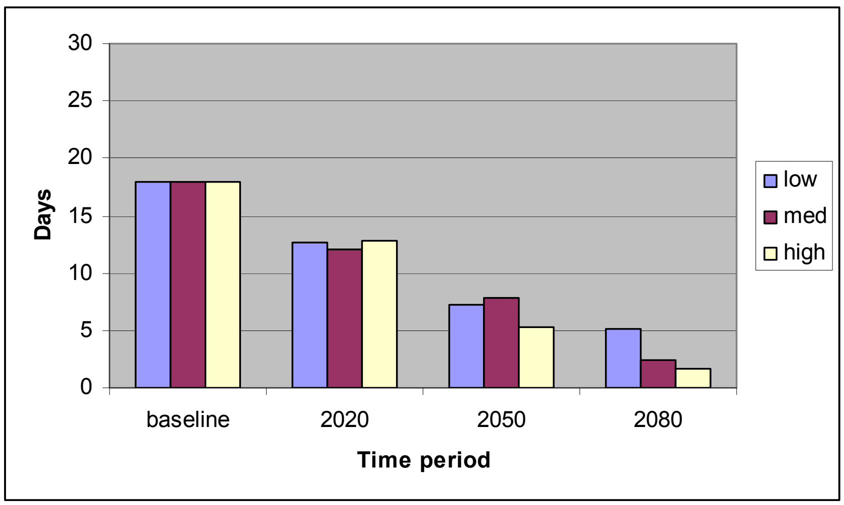
As the time period and emissions increase, the curve of the CDF moves towards the left, indicating a broad tendency towards lower numbers of frost days. Another broad trend is the divergence of the CDFs under different emission scenarios. The curves for the 2020s are relatively similar, with model noise likely accounting for minor differences. However, the curves become increasingly divergent at the 2050s and 2080s, owing to the differences in CO_2 build-up over the 50-year period. The increased model uncertainty at these time periods also accounts for the elongation of the distribution curves, with a wider range of potential outcomes, especially at the extreme probabilities.

Although the general patterns are similar at all four sites, several irregularities are also apparent. Although initially confusing, the greater warming signal for medium emissions at Heathrow compared with low and high emissions is probably another measure of the uncertainty of the model, being a relatively small difference, with the expected results being seen in the plots for the 2050s and 2080s. This pattern is mirrored in the relative closeness between the low and medium emission plots for Waddington for the 2020s. The 2080s distribution plot for this site is distinct, due to the concentrated distribution of relatively low frost day counts under high emissions up to the 70% probability level. However, it is unclear whether this is due to unique topographic characteristics of this area used to construct the model. Additionally, Leuchars shows a low relatively low warming pattern under medium emissions. The ice-day counts at 50% (central estimate), 10% and 90% probability levels are shown in Figures 8.7-8.10, in comparison with the baseline over the study period of 1998-2007.

Central estimate



10% probability (very unlikely to be less than)



90% probability (very unlikely to be more than)

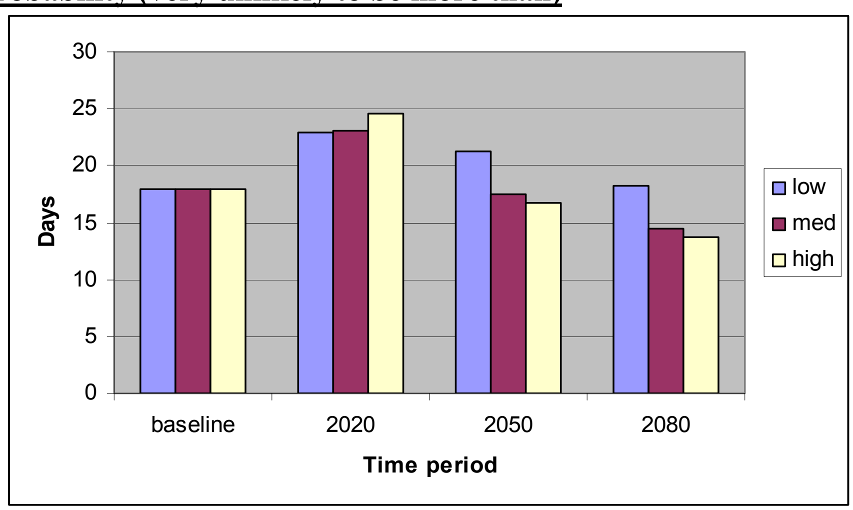
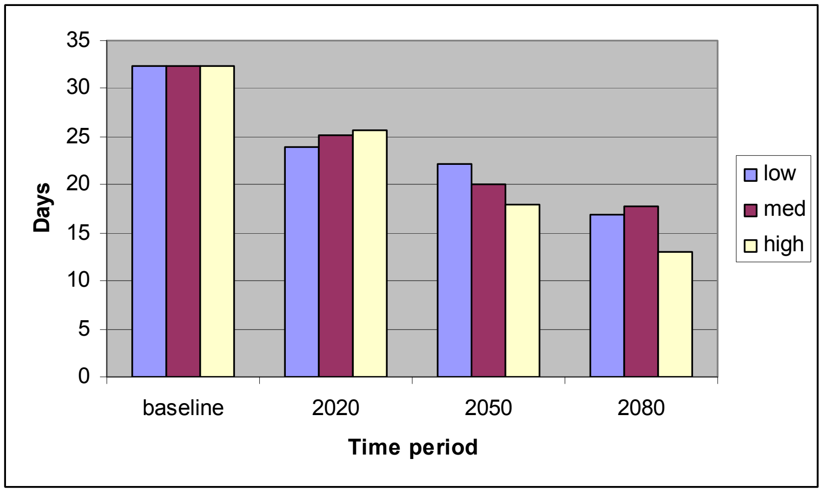
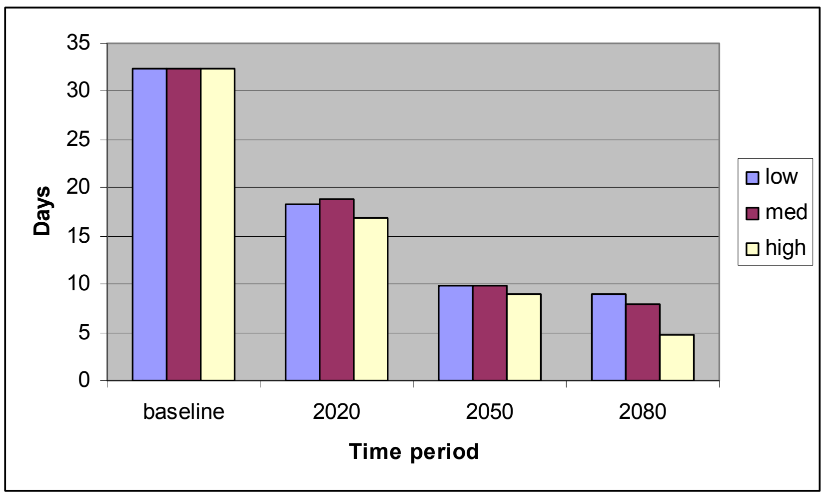


Figure 8.7. Projected number of annual frost days for Heathrow under low, medium and high emissions for the baseline, 2020s, 2050s and 2080s

Central estimate



10% probability (very unlikely to be less than)



90% probability (very unlikely to be more than)

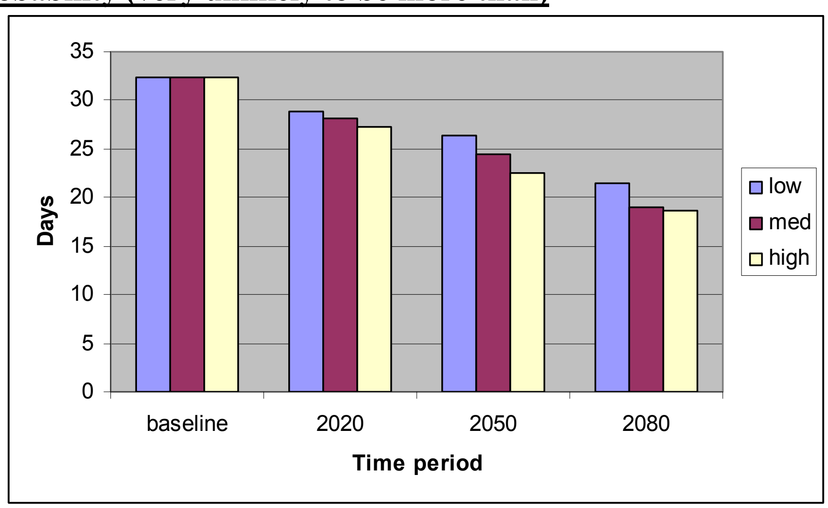
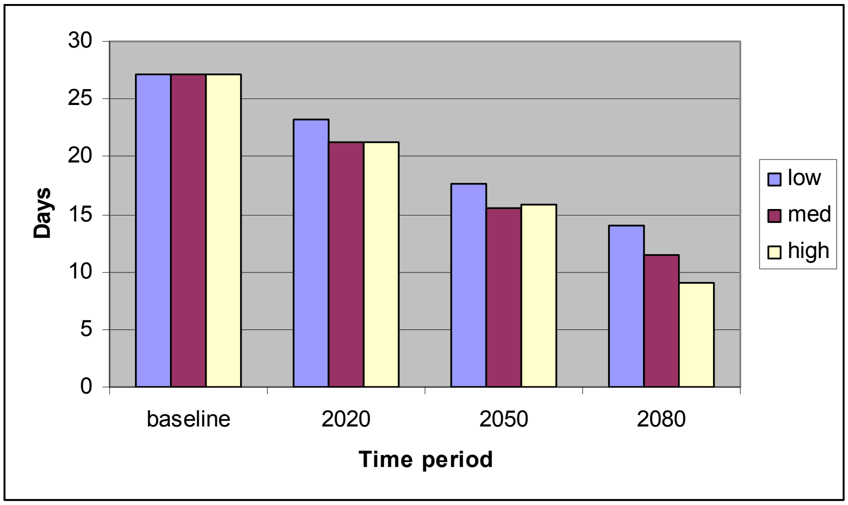
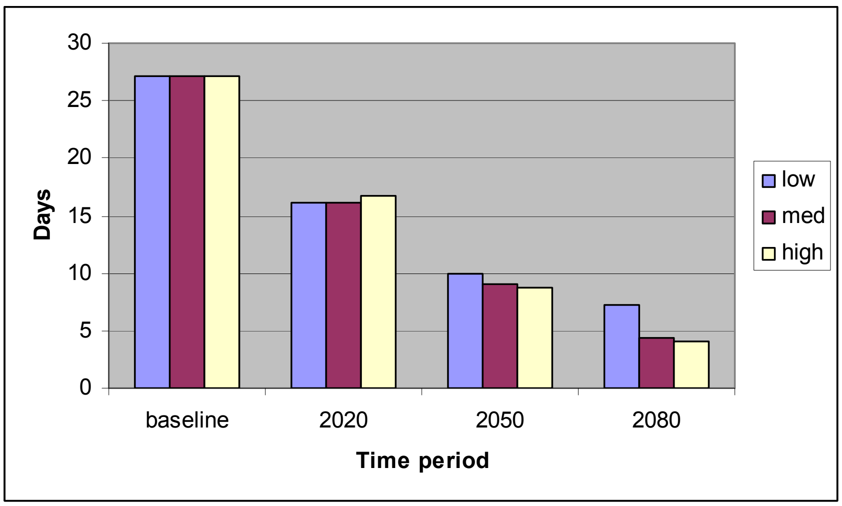


Figure 8.8. Projected number of annual frost days for Leuchars under low, medium and high emissions for the baseline, 2020s, 2050s and 2080s

Central estimate



10% probability (very unlikely to be less than)



90% probability (very unlikely to be more than)

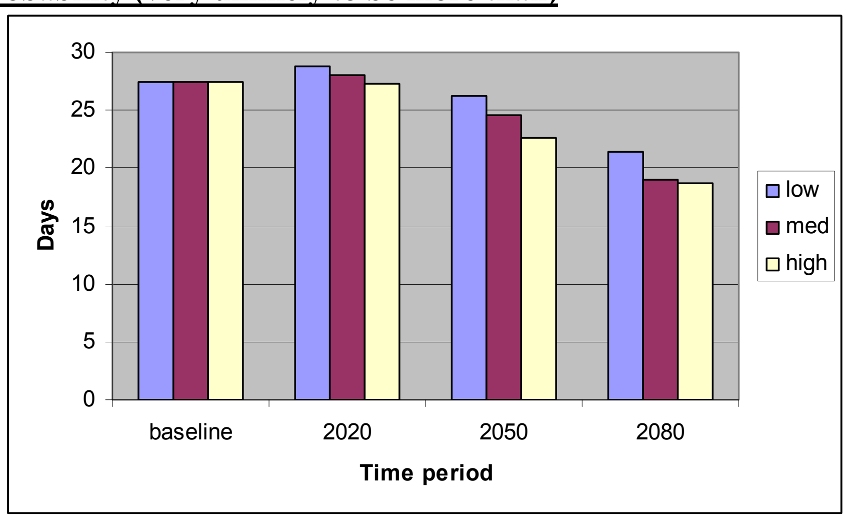
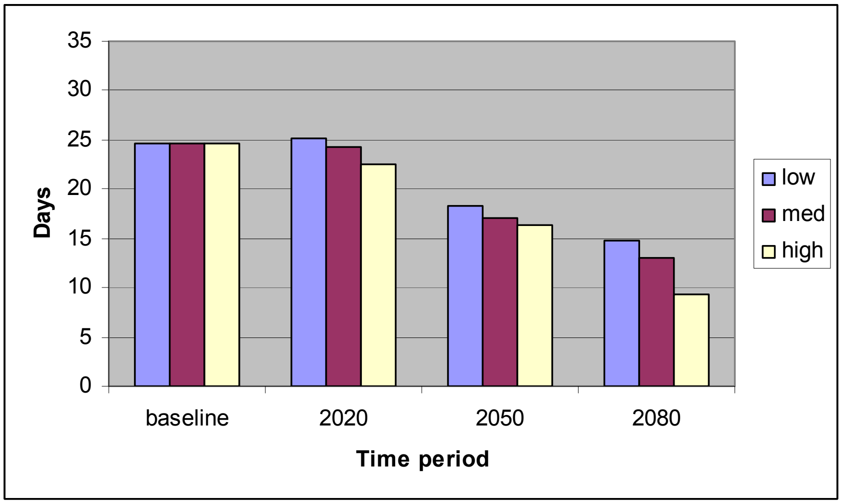
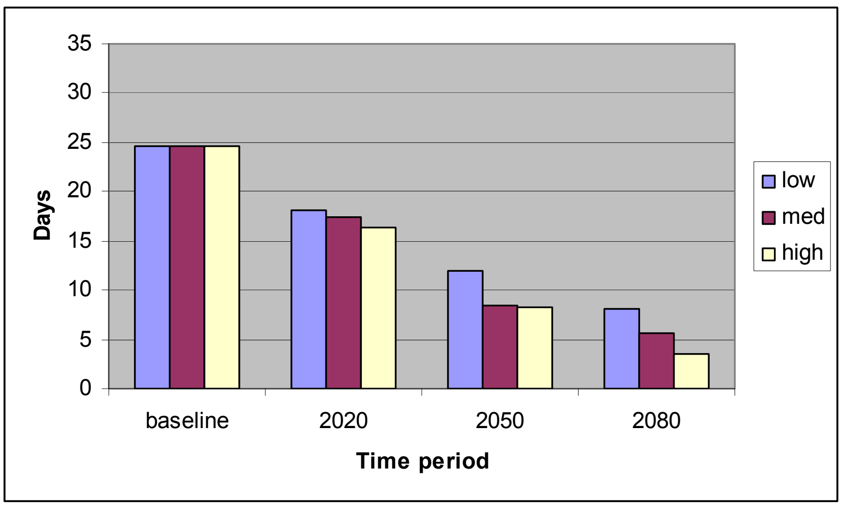


Figure 8.9. Projected number of annual frost days for Lyneham under low, medium and high emissions for the baseline, 2020s, 2050s and 2080s

Central estimate



10% probability (very unlikely to be less than)



90% probability (very unlikely to be more than)

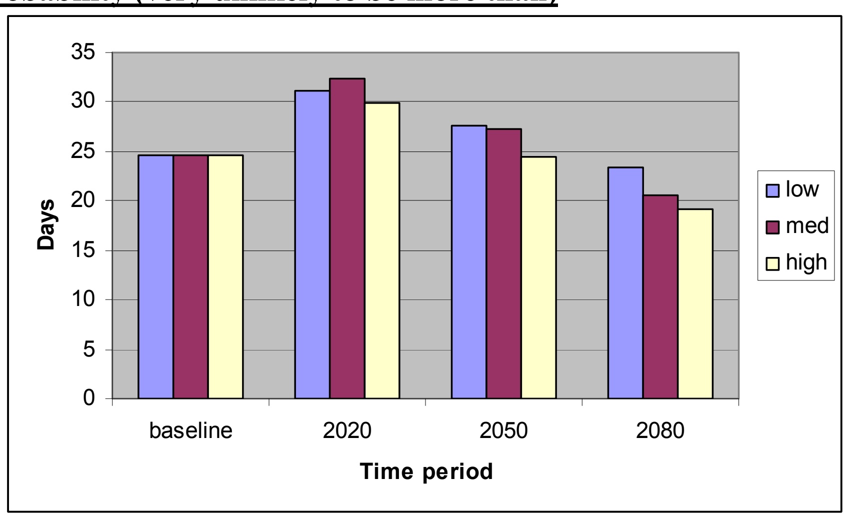


Figure 8.10. Projected number of annual frost days for Waddington under low, medium and high emissions for the baseline, 2020s, 2050s and 2080s

Over the study period (1998-2007) Heathrow, which represents the South East region, recorded an annual average of 18 frost-days, the lowest of all four sites. For the central estimate this remains relatively unchanged at 2020s under all emission scenarios, with the slight variations potentially indicating model error. This decreases to 11.7 (-35%) and 11.1 (-38%) days per year under medium and high emissions by the 2050s and to 7.7 (-57%) and 6.6 days (-63%) per year under medium and high emissions by the 2080s. Under the most likely emission scenarios (medium emissions) the model suggests that there is a 90% probability of the number of annual frost-days being less than 18.2 (+1%), a central estimate of 7.7 (-57%), with a 10% probability of an annual frost-day count of less than 2.4 (-87%). The central estimate under medium emissions therefore predicts an average annual reduction of 10.3 frost-days by 2080, a reduction of 57%. At the greatest extremes under low emissions there is a 10% probability of the number of frost-days being more than 18.2 (+1%), with a 10% probability of less than 1.6 frost-days (-91%) under high emissions by the 2080s, again showing the range of potential scenarios projected through the UKCP09 model.

Waddington, representing the central region of Great Britain, had a slightly higher annual average frost-days of 24.6 over the study period. A similar pattern of decreasing frost-days is seen at this site, with very little change from the baseline by the 2020s under the central estimate, with steady reductions thereafter. For example, under the central estimate the model predicts a winter average of 17.1 (-28%) and 16.3 (-34%) frost-days under medium and high emissions by the 2050s, and an average of 14.8 (-40%) and 13 (-47%). Under medium emissions there is a projected 90% probability of an average annual frost-day count under 20.5 (-17%) by 2080, a central estimate of 13 (-47%), with a 10% probability of there being less than 8.5 annual frost-days a year (-65%). The extremes under this scenario are similar to those for Heathrow, although with a slightly narrower range and without any projected increase, with a 10% probability of there being less than 3.6 frost-days annually by the 2080s under high emissions (-85%) and a 10% chance of reduction to 23.1 days (-6%) by the 2080s under high emissions.

Leuchars and Lyneham show a significant difference to Heathrow and Waddington, in that the number of frost-days reduces from the baseline by the 2020s. For instance, at Lyneham the number of frost days declines from its study-period average of 27.2 days per winter to 21.3 (-22%) and 21.2 (-22%) under medium and high emissions by the 2020s. However, the reductions by the 2080s are to 19 (-30%) and 18.7 (-31%) under medium and high emissions, significantly less of a reduction in percentage terms than for Heathrow and Waddington. At the extremes this site is projected to have a 10% probability of having 4.1 (-85%) annual frost-days by the 2080s under high emissions, with a 10% probability of there being over 21.4 (-21%) annual frost days by 2080s under low emissions.

The reduction of frost-days by the 2020s is predicted to give 24 (-26%) and 25.1 (-23%) annual frost-days under medium and high emissions at Leuchars from a baseline of 32.4. This drops to 16.8 (-48%) and 17.7 (-45%) under medium and high emissions by the 2080s under the central estimate. Under medium emissions there is a 90% probability of there being less than 19 frost-days (-41%), a central estimate of 16.8 (-48%), and a 10% probability of there being less than 7.9 frost-days per winter by the 2080s (-76%). The extremes show a 10% probability of there being less than 4.8 frost-days per winter by the 2080s under high emissions (-85%), with a 10%

probability of there being over 21.4 frost-days per season by the 2080s under low emissions (-34%).

These projections suggest that significant reductions in frost-days could be present by the 2020s, although this may also be due to the model not representing the present day climate of these areas. However, the results show that even though there is an initial fall in frost-days by the 2020s at Lyneham and Leuchars is not seen at the other two locations, the rate of reduction then slows to give reductions by the 2080s of a similar magnitude to those at Heathrow and Waddington.

8.4. Future accident projections

The following maps (Figures 8.11 - 8.16) present projections of regional weather-related road freight accidents, based on the extrapolation of quantified relationships (Chapter 7) onto the previously outlined climate scenarios. The central estimate is presented in the middle column, with the upper and lower probability bands given either side. These projections are given at low, medium and high emissions for the 2050s and 2080s.

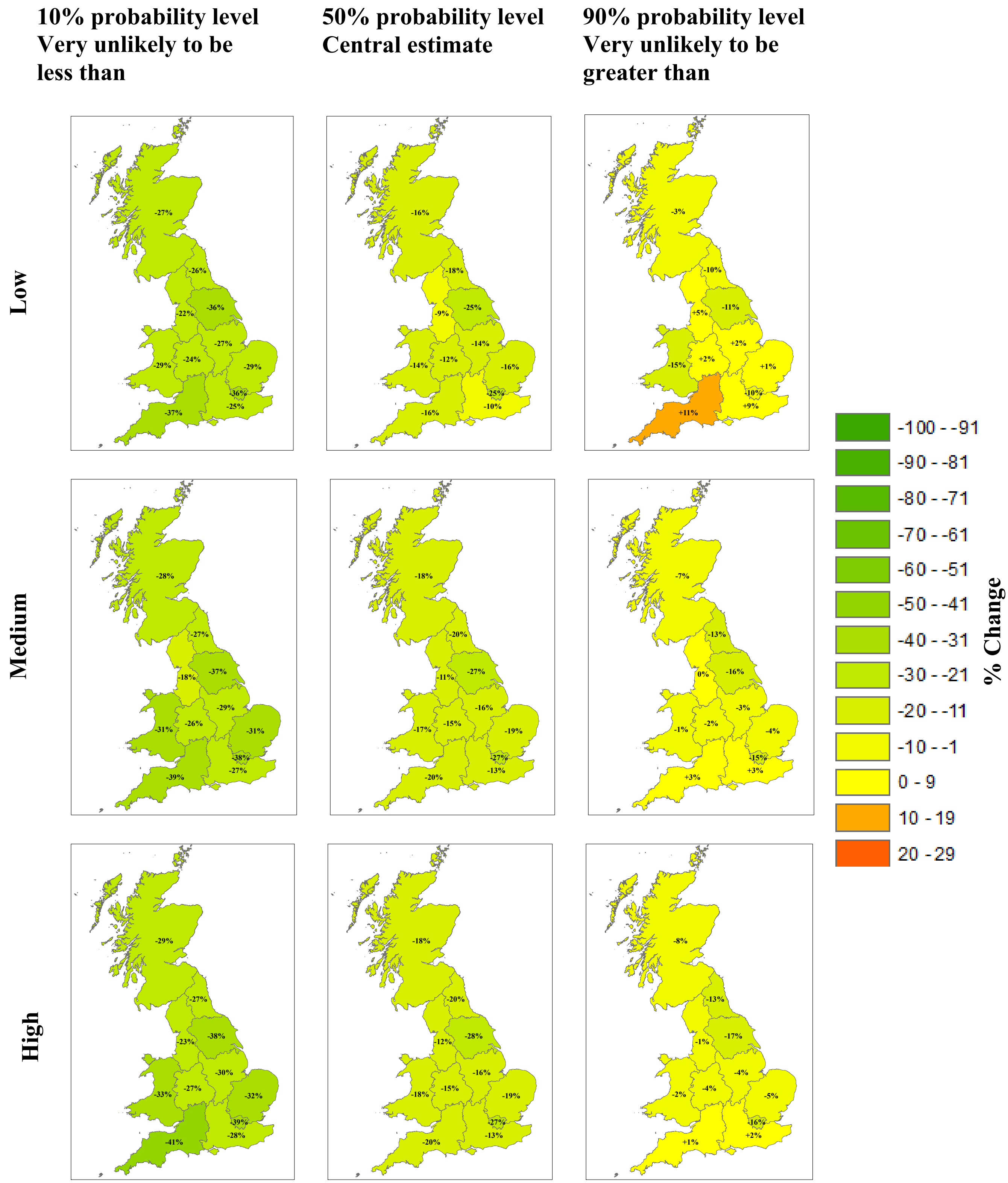


Figure 8.11. Projected regional change in summer precipitation-related accidents for the 2050s under low, medium and high emissions at various levels of probability

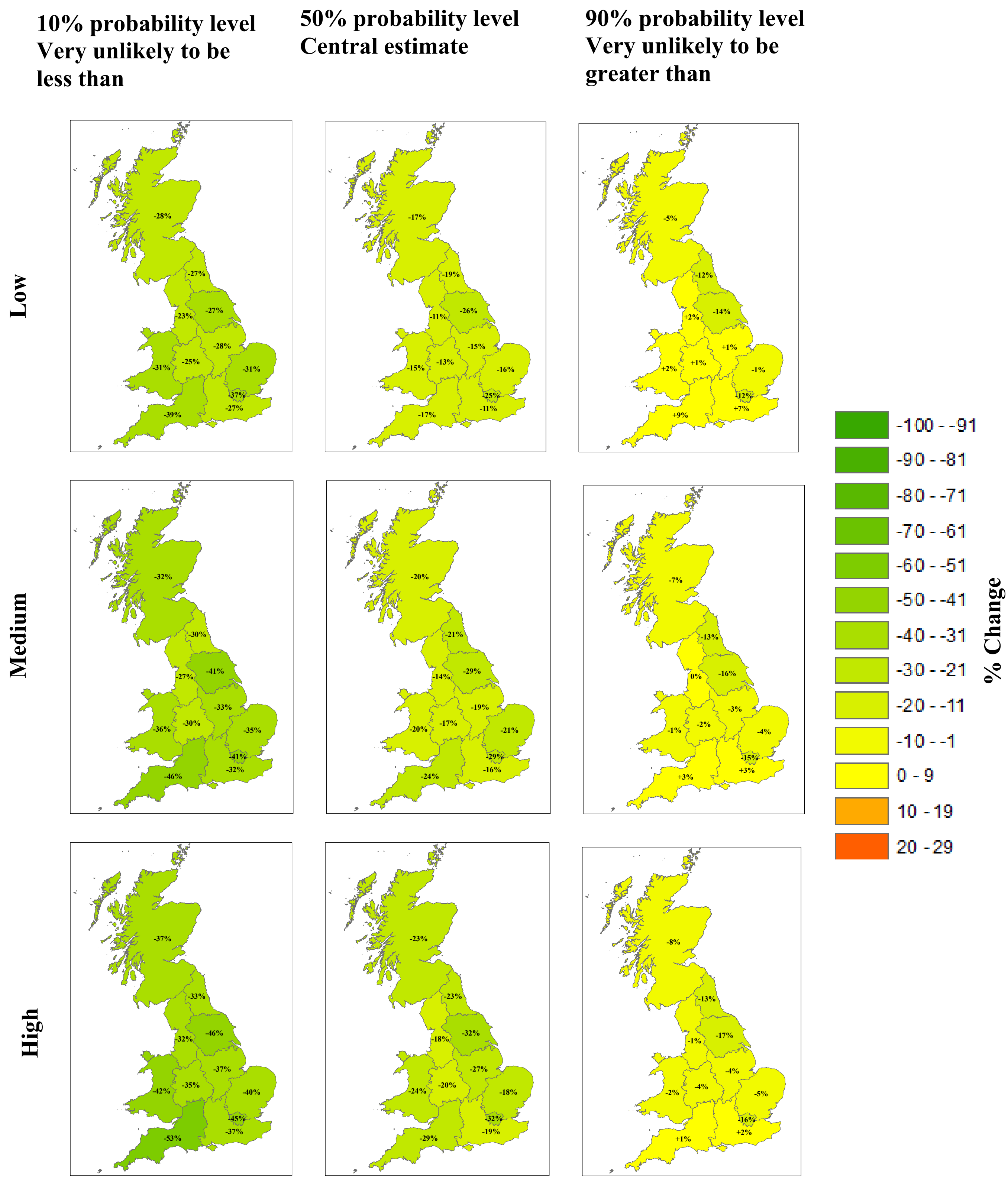


Figure 8.12 Projected regional change in summer precipitation-related accidents for the 2080s under low, medium and high emissions at various levels of probability

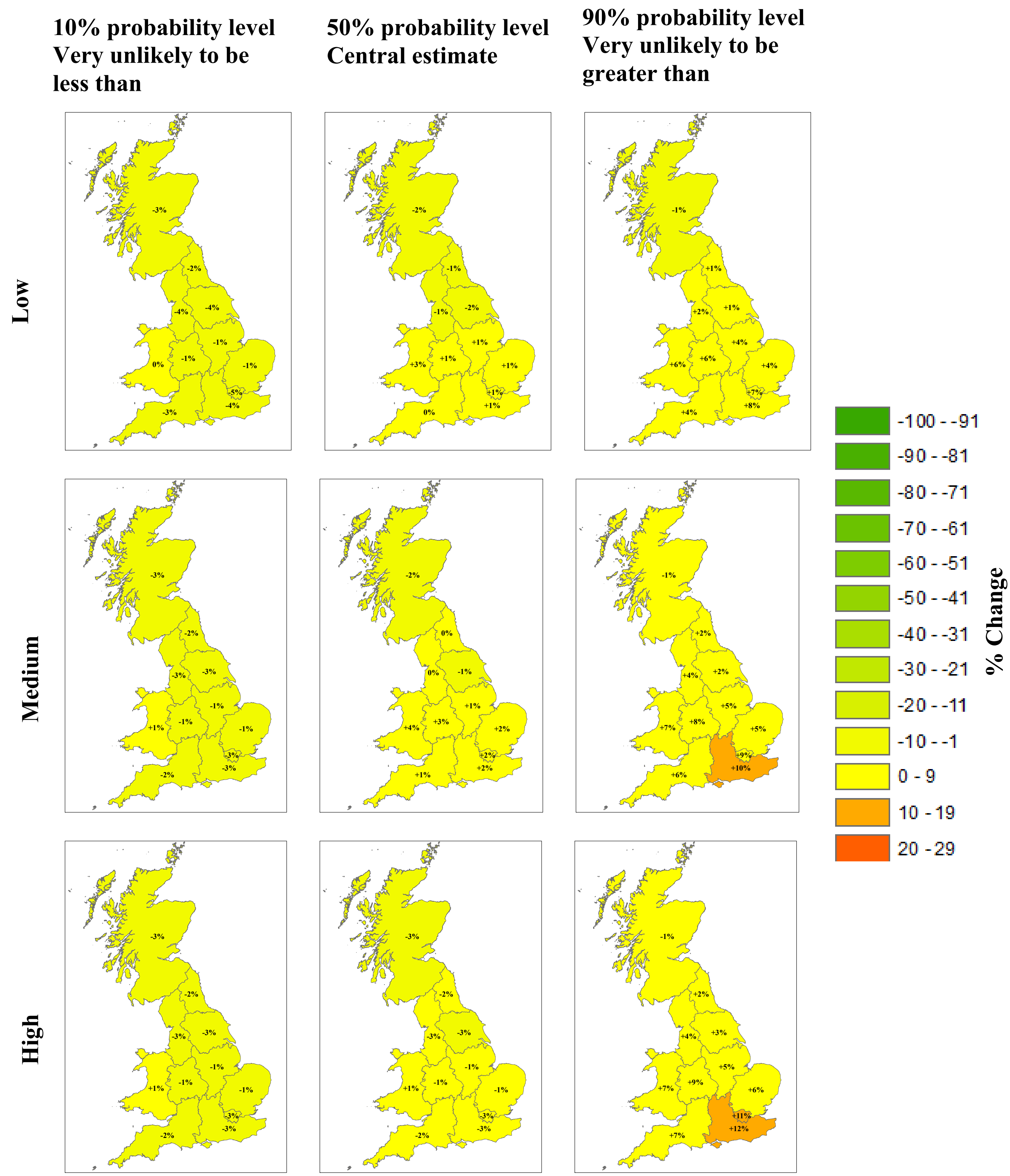


Figure 8.13. Projected regional change in winter precipitation-related accidents for the 2050s under low, medium and high emissions at various levels of probability

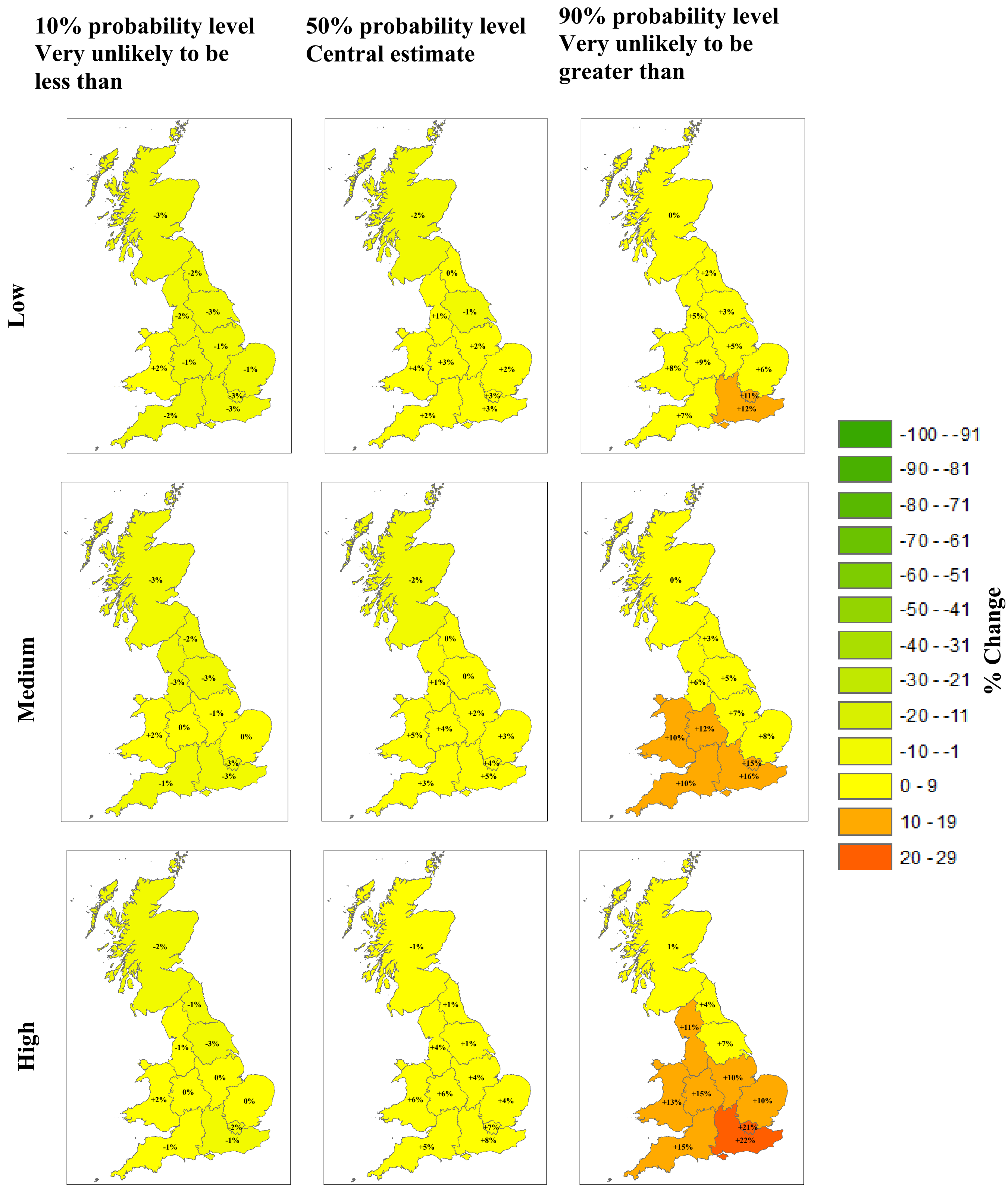


Figure 8.14. Projected regional change in winter precipitation-related accidents for the 2080s under low, medium and high emissions at various levels of probability

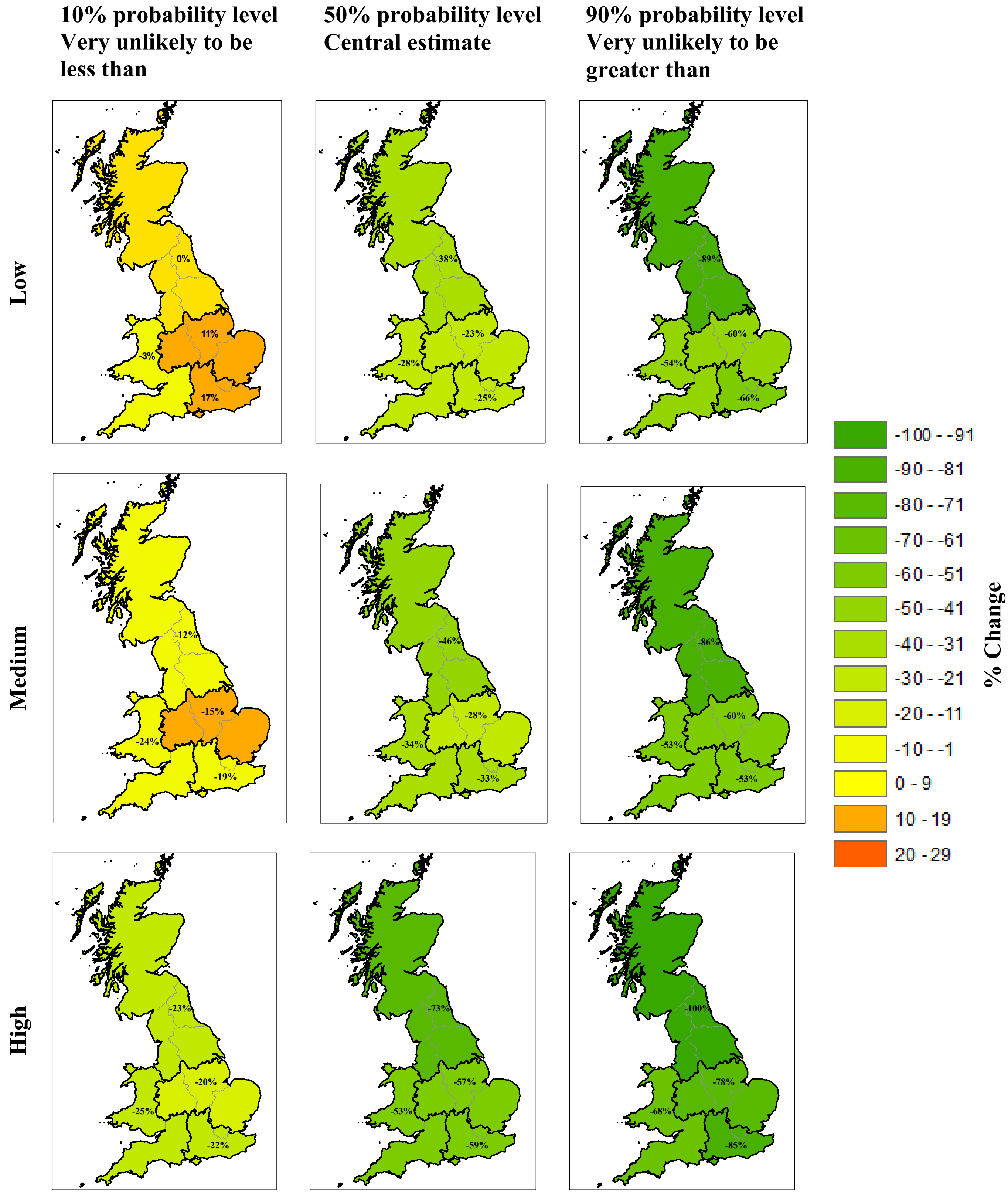


Figure 8.15. Projected regional change in winter ice-related accidents for the 2050s under low, medium and high emissions at various levels of probability

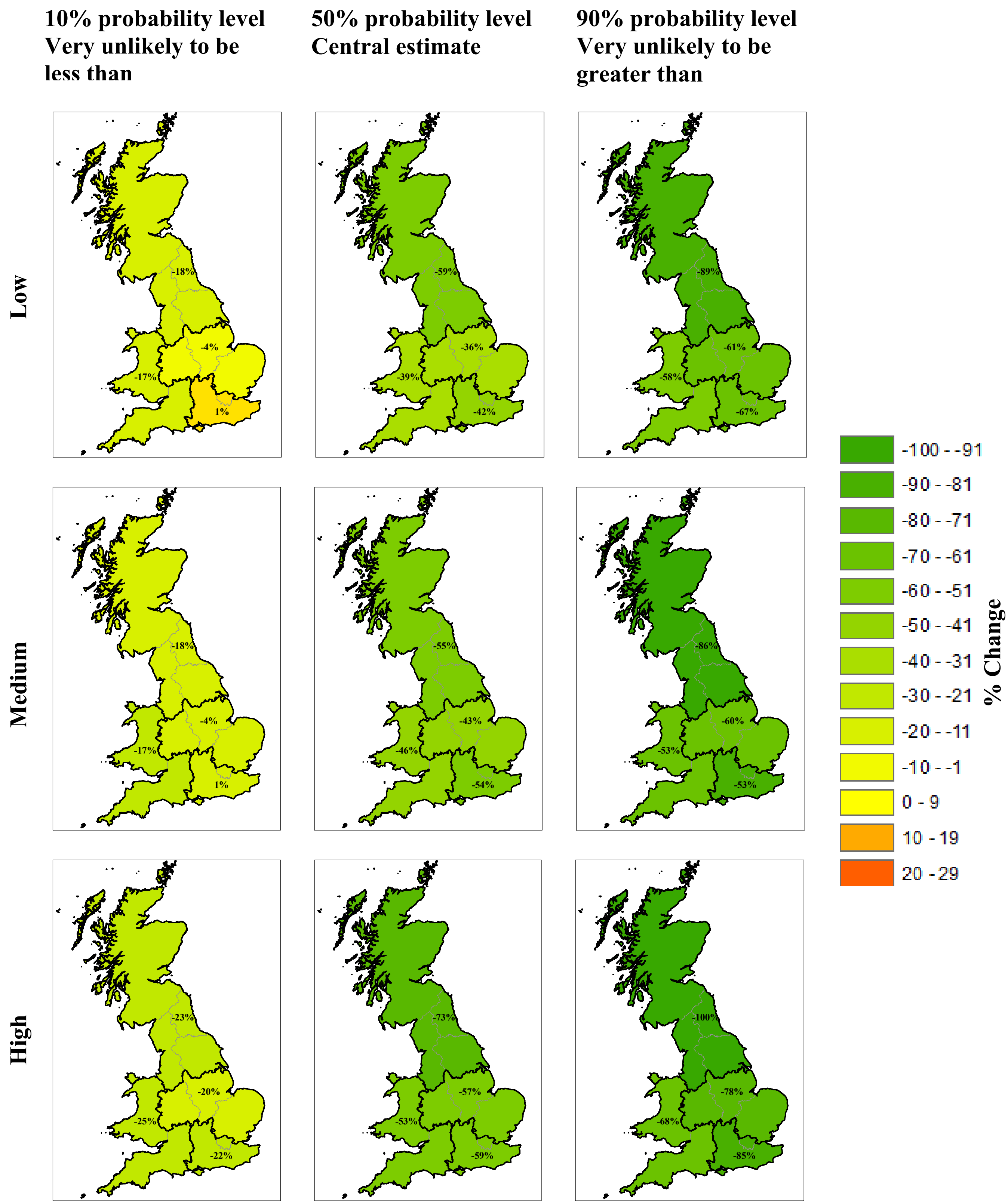


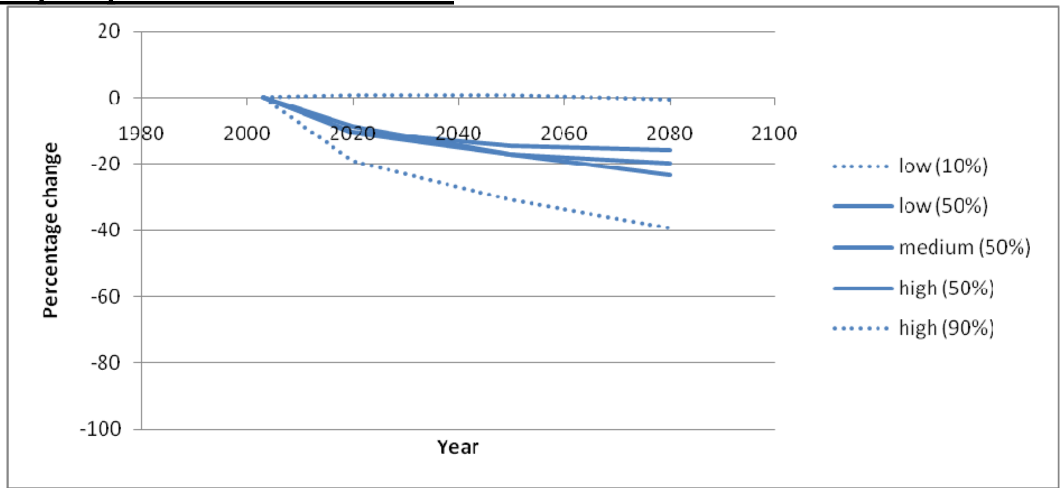
Figure 8.16. Projected regional change in winter ice-related accidents for the 2050s under low, medium and high emissions at various levels of probability

The summer (Figures 8.11 and 8.12) and winter (Figures 8.13 and 8.14) precipitation-related accident projections show divergent trends of differing magnitudes. 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 and across all regions by the 2080s. Under medium emissions at the central estimate London and Yorkshire show the greatest decrease by the 2050s (-27%) whilst the North West shows the smallest (-11%). At the 2050s the greatest regional change can be seen in the South West, where there is a 10% probability of a 41% decrease in accidents. By the 2080s that figure reaches 53%. This can be contrasted with a 10% probability of increases in excess of 11% by the 2050s under low emissions for the same region, falling to 9% by the 2080s.

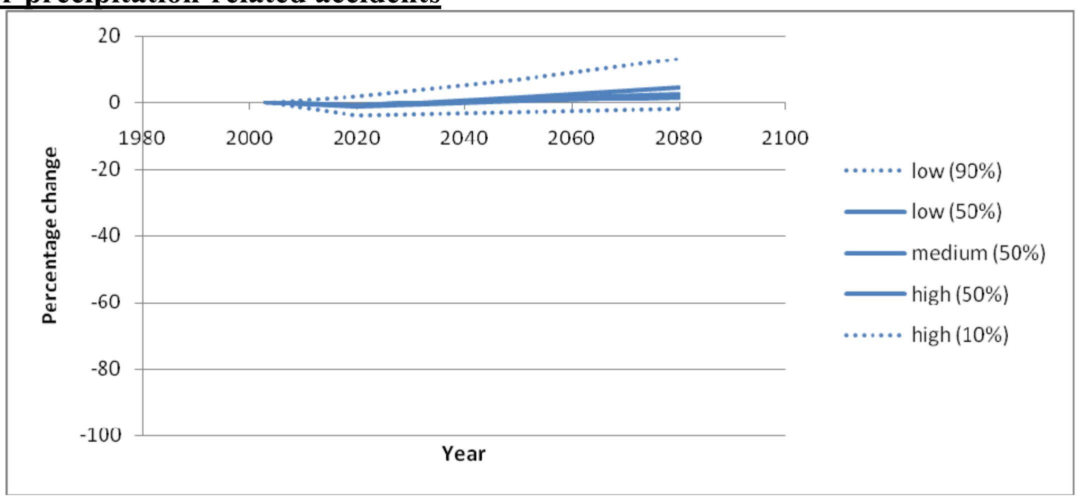
The winter-precipitation shows an increasing accident trend, but of a lesser magnitude compared to summer-precipitation. Slight regional trends at the 2050s become more apparent by the 2080s, showing to a tendency for increased accidents in the South East, decreasing in magnitude to the West and North, with very little change in Scotland. For example, the central estimate under medium emissions shows a 2% increase in the South East and London and a 2% decrease in Scotland by the 2050%. This increases to 7% in London and 8% in the South East by the 2080s, whilst Scotland moves only slightly to -1%. However, under high emissions the changes become more pronounced, with 10% probability of increases greater than 21% in London and 22% in the South East. Again Scotland shows little change, with a 1% projected increase.

Winter ice-related accident projections (Figures 8.15 and 8.16) show the greatest percentage change and greatest range of potential outcomes of the parameters studied in this CIA. For instance Scotland shows a potential decrease of 55% for the central estimate under medium emissions by the 2080s, greater than any regional change in precipitation-related accidents under even the highest emission scenarios or the most outlying probability band. Under low emissions there is a 10% probability that the decrease in accidents will be less than 18%. In the South East this figure falls to just 1%, suggesting a potential for very little change from the current accident patterns. However under high emissions there is a projected 10% probability of a 100% reduction in average ice-related accidents in Scotland. This is based on the reduction in average frost days in the climate projections for this region. As annual variations around this average will still occur, the 100% reduction is an overestimation. Still, reductions of this magnitude, as well as those in the West (-68%), the Central region (-78%) and the South East (-85%), present a fundamental change to the relationship between weather and road freight accidents in Great Britain. The changes in accidents are large even at the central estimate under medium emissions, with the remainder of the regions showing reductions around 50%.

Summer precipitation-related accidents



Winter precipitation-related accidents



Winter ice-related accidents

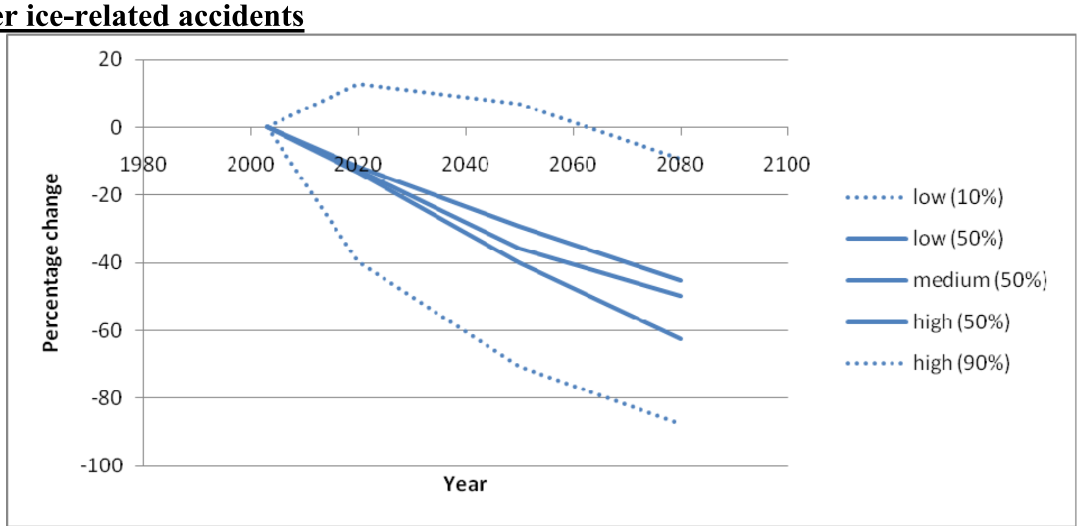


Figure 8.17. Future freight accident rates as a percentage change from 1998-2007 average

It is possible to represent the GB-wide accident projections in several ways (Figures 8.17-8.19), with each reprentation giving a markedly different interpretation of the data, that if taken alone could be misleading (especially when viewing Figure 8.19 in isolation), highlighting the importance of presenting a multitude of viewpoints. The graphs shown in Figure 8.17 display the percentage change in average seasonal accidents for summer precipitation, winter precipitation, and winter ice. This representation shows a marked difference between the relatively small percentage increase (in some cases a slight decrease) in winter precipitation-related accidents even at the extremes of emission scenarios and probabilities (between -3% and +7% by the 2050s and -2% and +13% by the 2080s), compared with the large magnitude and range of potential changes for winter ice-related accidents (between +7% and -71% by the 2050s and -9% and -87% by the 2080s). Projections for summer precipitation-related accidents sit between these two weather types (ranging between +1% and -31% by the 2050s and 0% and -39% by the 2080s). These figures suggest that the impact of climate change on winter precipitation-related accidents will be relatively small compared to the large-scale decrease in accidents caused by winter ice.

However, when viewed in real-terms the impact on accident numbers is far higher for winter and summer precipitation-related accidents compared to winter-ice related accidents. Although precipitation-related accidents show a percentage change almost an order of magenitude lower than ice-related accidents, the higher number of current preciptiation accidents means that the smaller percetage change has a far greater impact in real terms. By the 2050s the baseline of 3280 rises to 3323 under medium emissions for central estimate (3367 by the 2080s), with a potential fall to 3186 under low emissions (3217 by the 2080s) and rise to 3503 under high emissions (3716 by the 2080s). Summer precipitation-related accidents, which sit between the two other weather types in terms of baseline accident rates and percentage change shows a similar (albeit negative) absolute change. Accidents are projected to fall from the baseline of 1550 to 1282 under medium emissions by the 2050s at the central estimate (1243 by the 2080s), with a potential fall to 1074 under low emissions (943 by the 2080s) and rise to 1564 under high emissions (with a slight fall to 1542 by the 2080s).

In real terms the large percentage reductions in ice-related accidents become comparitvely small. For instance, by the 2050s there is predicted to be a fall from the baseline of 230 to 147 under medium emissions at the central estimate (116 by the 2080s). At low emissions there is a rise to 245 accidents by the 2050s, followed by a fall to 208 by the 2080s. Under high emissions a considerable fall is projected, with 68 accidents by the 2050s and 29 accidents by the 2080s.

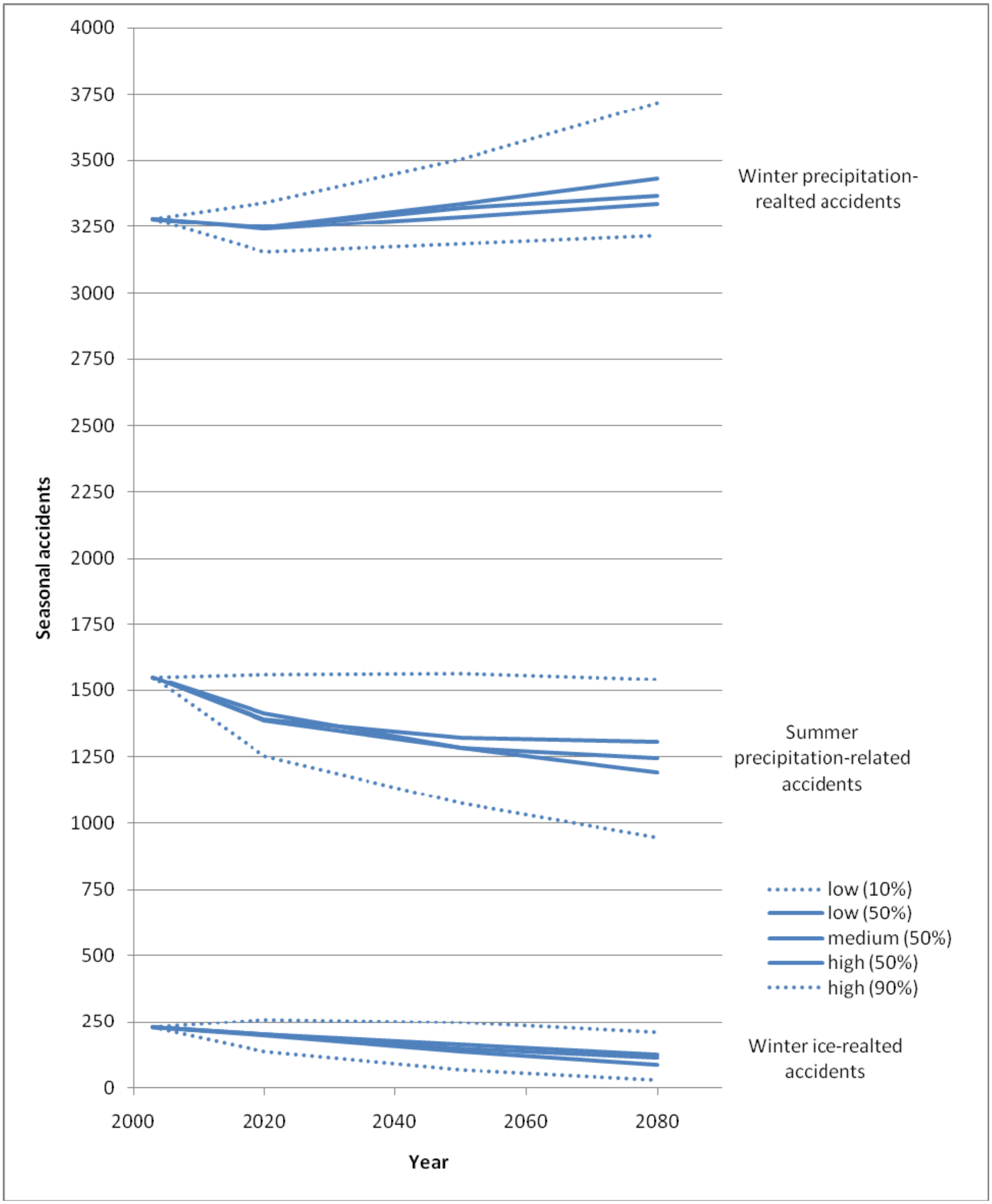


Figure 8.18. Future road freight accident rates for summer precipitation-related, winter precipitation-related and winter ice-related accidents

The importance of this detailed examination of the various representations of impacts is exemplified in Figure 8.19 which shows the net impact of climate change to summer precipitation-related accidents, winter precipitation-related accidents and winter ice-related accidents in percentage terms. This graph shows that reduction in sumer precipitation and ice-related accidents is largely cancelled out by the increase in winter precipitation-related accidents, despite the relatively small increase in winter rainfall. This limits the reduction of accidents to 6% under medium emissions at the central estimate by the 2050s and 7% by the 2080s. High emissions see a maximum reduction of 8% by the 2050s and 7% by the 2080s, whilst projections under low emissions show a 1% fall by the 2050s and a 2% fall by the 2080s. Importantly, no emission scenario at any probability level shows a net increase in weather-related accidents over the forecast period, despite the projected increases in winter precipitation-related accidents.

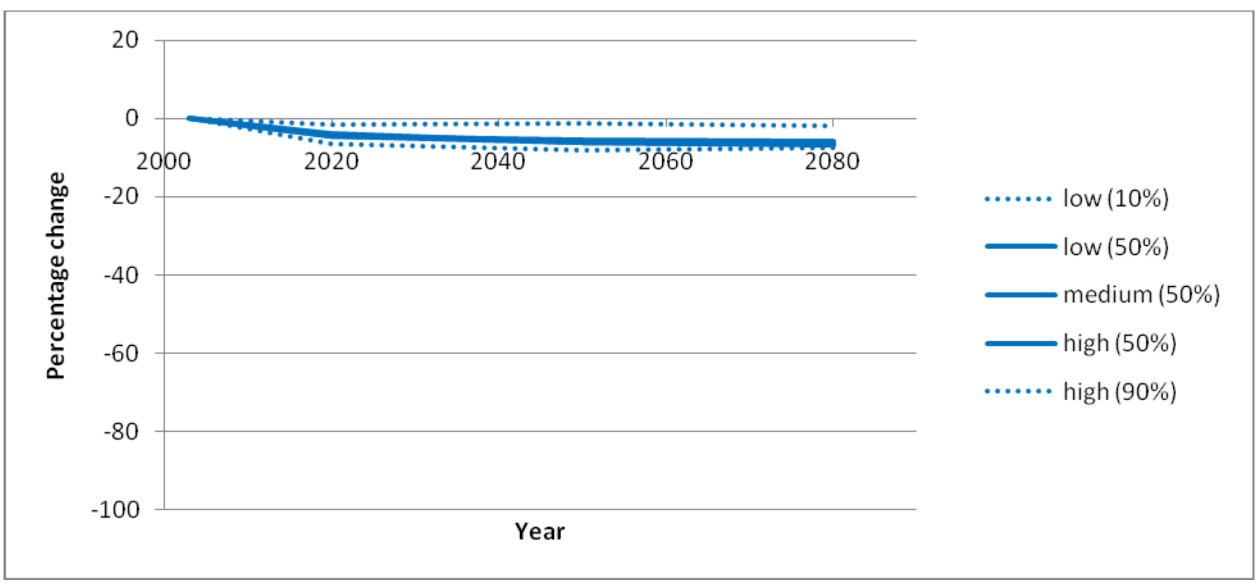


Figure 8.19. Future accidents rates as a percentage change from the 1998-2007 average

8.5. Discussion

The results above show the projections of a first generation CIA, hence all of the caveats discussed in Chapter 2 apply at this stage. For example, it is impossible to know the impact of concurrent economic and societal change, and whether this would promote more freight transport and hence greater exposure, or improved vehicle safety leading to reduced sensitivity. However, it is important to discuss the raw potential impacts of the projections given. This step relates to the top right hand box of Tol's (1998) schematic shown in Figure 2.1, or "future climate, current society".

Unfortunately there are several logical reasons to suggest that not all of the projected improvement in accident rates will be seen in reality. Firstly, a reduction in frost-days may prompt a reduction in the provision for winter road maintenance (e.g. Andersson and Chapman, 2010). As the frequency of events drops road authorities may scale back expenditure on road salt, gritting equipment and staff. This would increase the chances of ice forming on unsalted roads when an ice event occurs. This may be more apparent during times of fiscal retrenchment where a run of years with few frost-days and projections for future reductions (perhaps outlying scenarios such as the ones presented in this project) could be used as justification to legitimise reduced maintenance.

Secondly, the overall warming of average temperatures may mean that where large sections of road would have formed ice under the current climate, the future may see more nights where only small sections of roads freeze. Chapman et al (2001) show the importance of local topographic factors that may lead to black spots which are harder to forecast. This may have the effect of increasing the accident rate on these nights, due to the 'law of rare events' mentioned by Elvik (2006). This is exemplified by Matthews and Barnes (1988) in Figure 8.20 which shows the accident rates for hazards or stimuli, in this case curves in the road against the length of the straight before the hazard. Reducing the amount of road that freezes would have the effect of lengthening the stretch of roads between the hazardous road surface conditions.

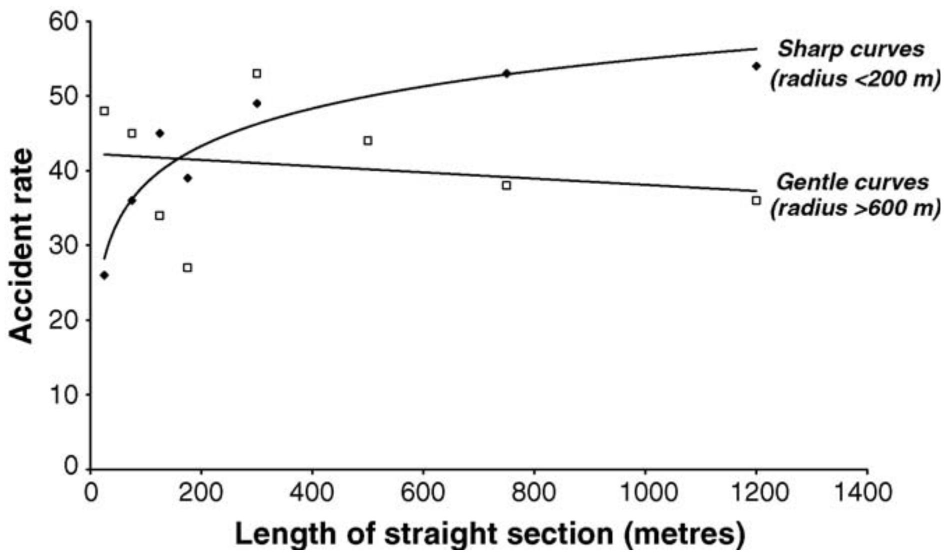


Figure 8.20. Road accident rates in New Zealand as a function of the length of straight section preceding a curve, and curve radius (Matthews and Barnes, 1988. In Elvik, 2006)

Finally, the reduction in frequency of events may have strong psychological and behavioural impacts similar to those outlined in Elvik's (2006) laws of accident causation. The likely effect can be hypothesised with the use of the earlier mentioned learning curve from Brüde and Larsson (1980) in Figure 8.21. Although this is for Norway, and hence does not represent the impact in the Great Britain, the potential effect is stark. If we take the frequency of exposure as the proportion of current frost-days in Great Britain (18% of the winter) and then reduce this exposure to the central estimate under medium emissions for 2050 (7%) this makes each event much more severe. The curve estimates that the risk factor would increase to 10 from 5 and therefore cancel out much of the expected benefit of warmer winters.

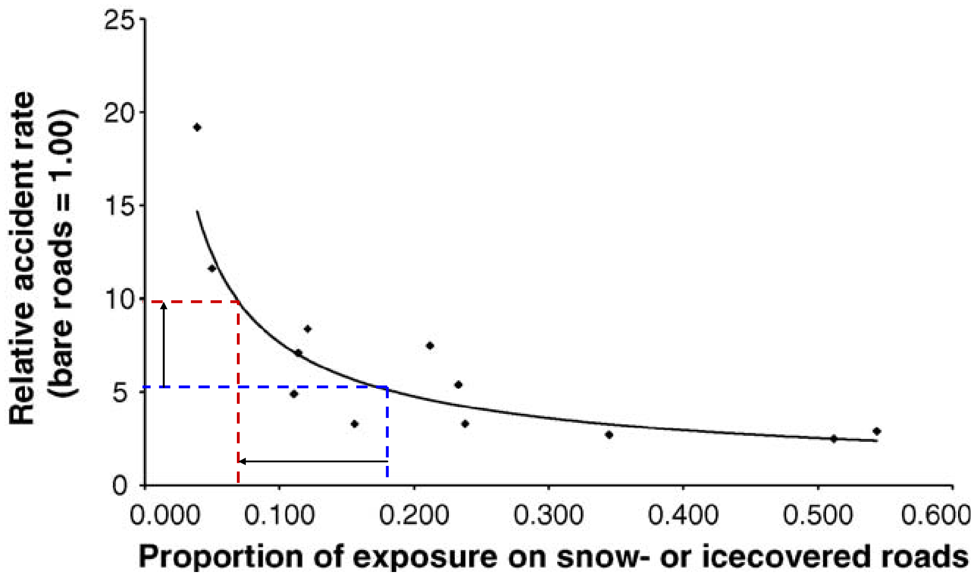


Figure 8.21. Adapted learning curve from Brüde and Larsson (1980; reproduced in Elvik, 2006) showing illustrative theoretical impact in relative accident rate from projected reductions in frost-days in the South East by 2080 under medium emissions

The behavioural impacts of the precipitation changes are more complex. The overall amount of precipitation is likely to stay the same on an annual basis (Murphy et al, 2009). As can be seen in figure 8.21, as the proportion of exposure increases, the rate of change of the curve decreases along with the gradient. As Great Britain experiences a high proportion of precipitation conditions, any increase or decrease is unlikely to produce as much of a change in relative accident rates. Another difference is that ice is a seasonal hazard, with a long time between exposure, potentially increasing to years under certain climate scenarios. This would not happen to anywhere near that extent with precipitation, reducing the potential risk of drivers becoming less able to cope in these conditions, hence large-scale changes in relative accident rates would not be expected.

8.6. Conclusion

Regional climate projections show increases in winter precipitation, decreases in summer precipitation and a reduction in winter ice-days. Precipitation increases most in the South during the winter, with the South also seeing the greatest decrease in precipitation during the summer. All regions show a large-scale reduction in the number of frost-days, reducing to single figures under the highest emission scenarios under outlying probability levels by the 2080s. By using probabilistic climate projections several potential scenarios are found which allow impacts to be placed within a variety of bands of likelihood. In real terms the net effect of changes to winter and summer precipitation and winter temperatures suggest a modest decrease in accidents. However, this headline figure masks the significant shift in seasonality of accidents, with summer precipitation-related and winter ice-related accidents decreasing, whilst winter precipitation-related accidents see a projected increase. It must also be remembered that these projections are averages. If the distribution of annual figures around these averages is of a similar nature to that seen today, it would mean some regions experiencing no frost-days in some years.

However, even before taking into consideration future changes in the network, reasons exist to suggest why the projected results, especially ice-related accidents, combined with several institutional and behavioural changes could lead to higher relative accident rates during future events. This adds further risk of complacency to the winter road maintenance industry discussed by Andersson and Chapman (2010). This chapter constitutes a first generation climate change impact assessment, and provides a base which will be altered in the following chapter which adds the considerations of changes in the future network to arrive at a more realistic projection of future impacts.

Chapter 9: Scenarios for Future Freight Resilience

9.1. Introduction

The nature of the projections for weather-related road freight accidents arrived at in the previous chapter highlight the importance of considering concurrent socio-economic change in CIA. Although reductions in summer precipitation and winter ice-related accidents are likely, it has been shown that these benefits may be offset by the projected increase in winter precipitation-related accidents, creating a situation where overall accident numbers reduce only slightly compared with the present day. This overall negligible reduction means that the future volumes of freight transport vehicles on the road, as well as their sensitivity to meteorological hazards, will have a large bearing on the magnitude and potentially the sign of the impact of climate change on weather-related accident numbers.

Chapter 9 presents a set of scenarios for potential future trends in traffic volume and safety. This is achieved through several methods, including interviews leading to an expert Delphi, and examination of the UKCIP socio-economic scenarios in Chapter 10. Although the Delphi study produces primarily quantitative output, the interviews add a layer of qualitative interpretation and amplification which is valuable in potentially explaining some of the reasons for responses. This is especially important when examining perceptions of risk from meteorological hazards, where past experiences of accidents allow a greater level of individual insight. The results discussed in this chapter relate to Component 3 of the CIA, completing the requirements of a 2nd generation vulnerability assessment framework according to Füssel and Klein's typology (2006)

9.2. The Delphi study

This section discusses the results of the expert Delphi carried out between November 2008 and March 2009, as well as a set of preliminary interviews during the summer of 2008. Discussion is split into views on meteorological risk, climate change, past and future safety, and the future growth of the freight sector. The results are based on the first round of the Delphi, which was primarily concerned with changes in the freight sector up to the year 2020.

9.2.1. Meteorological risk

It was deemed important to gauge the levels of risk associated with different weather types as a means of evaluating the potential institutional treatment of meteorological hazards within the industry. This is especially important considering the likely changes in the frequency and intensity of these hazards discussed in Chapters 3 and 8. The Delphi responses provide a set of relative scores for the potential accident risk of snow, ice, wind, rain fog and melting tarmac are (Figure 9.1), with the risk of disruption given in Figure 9.2.

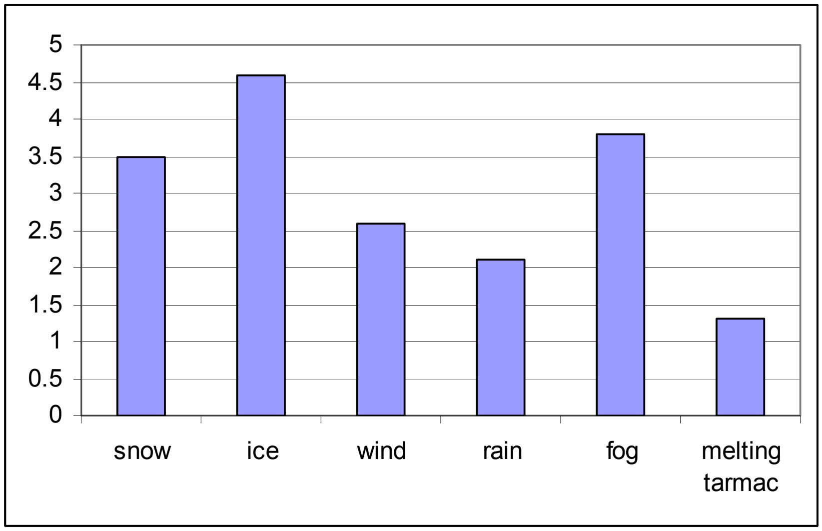


Figure 9.1 Assessment of potential accident risk of weather types

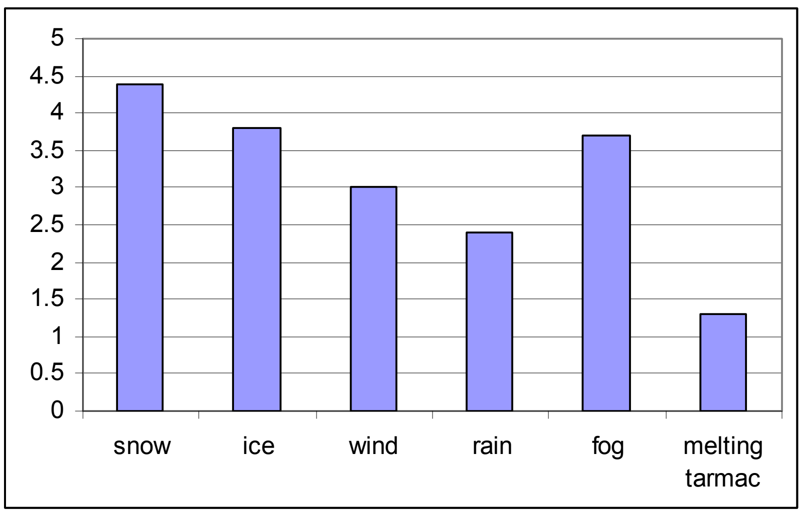


Figure 9.2. Assessment of potential disruption risk of weather types

Snow and ice rank highly for both measures of risk, with ice being judged the greatest accident risk and snow the most disruptive. This can be compared with rain, which has a relatively low risk score, even though previous research (e.g. Edwards, 1999) and the analysis of STATS19 data in Chapter 7 show it to cause the greatest number of accidents overall. The high level of risk attributed to snow and ice was also apparent during the initial interviews. Most participants attributed this to the potential loss of control while driving in these conditions. For example one participant described the experience of driving an HGV in snow and ice:

> If you lose control in snow it doesn't matter how fast or slow you're going, if you haven't got traction that's the most dangerous position to be in, if you slam the brakes on then you are going to slide, with 18 tonnes moving there's only one way you're going to stop – when you come into contact with something, same with ice. (Stephen, TPL A)

This fits in with much of the aforementioned research, which indicates that snow (especially in the UK) has a much higher associated increase in accident rates when present compared with precipitation (Qiu and Nixon, 2006). Sheppard (1975) identified a correlation between increased frequency of experiencing certain climatic hazards and the reduction in drivers' perceived concern, with the most feared hazard being the one they least often experience. This is linked with Elvik's (2006) laws of accident causation, which suggest that a hazard which is encountered less frequently allows fewer opportunities to learn and retain the driving skills needed under these conditions. However, although throughout the interviews the physical hazard of ice and snow was acknowledged, the actual impact of these hazards to the participants' companies was often downplayed:

> In ten years we haven't had anything slip off the road (Stephen, TPL A)

> This year I can't think of more than one day with ice on the road, it doesn't really come into our thinking, all the trucks have thermometers on the dash boards, it lets the drivers know when it's going to be below freezing and there might be ice on the roads….. and usually it's pretty well

> gritted, I mean, unless you were coming off onto B-roads and country roads then I suppose you really need to exercise some caution (Brian, TPL B)

This observation of the relatively low impact of snow compared with its perceived risk fits in with the accident data in Chapter 7, with ice and snow accounting for 1% and 0.4% of all accidents between 1998 and 2007. Rain ranked at a relatively low position of fifth, below snow, ice, wind and fog. Again this may be due to the psychological effects of encountering a hazard frequently described by Sheppard (1995). However, it must be noted that several informal conversations with freight drivers while visiting the companies in this study saw rain placed as the greatest concern. Although in no way a full survey, it could indicate a disconnect between the drivers and managers, and one which has implications for driver safety. Interestingly, one respondent in the initial interview stage did place rain as the greatest accident risk, going on to say that snow carries the greatest risk of disruption:

> I'd say rain because of the increase in stopping distance, the possibility of skidding and the reduction of visibility. I'd say it is probably the most dangerous and also the most frequent….. In terms of disruption though I'd say snow, the last time we had 3 or 4 inches of snow in Northampton it brought the whole town to an absolute stand still (Paul, TPL D)

Paul's response also demonstrates the geographical detail often given during the interviews. As examined in Chapter 7 and by Edwards (1998), the relative risk of accidents varies across Great Britain, so an identification of hazardous areas is important. Table 9.1 lists the stretches of road which were highlighted by the Delphi participants as areas that present a particular risk of weather-related accidents and disruption. As mentioned in Chapter 6, the geographical distribution of respondents was not even, so it must be assumed that there will be a bias towards the areas around which their companies are based. However, many of these companies operate across the whole of Great Britain, so will experience conditions throughout the road network. All of these roads can be considered critical infrastructure in Great Britain.

Table 9.1. Roads particularly associated with weather-related accidents and disruption

Road	**Type of hazard**	**Type of problem caused**
M6	Snow, Wind	Accidents
M6 Junctions 15-13 southbound	Poor visibility in adverse weather conditions	Delay due to slow moving traffic and more accidents
Spaghetti Junction	Snow, Rain	Slow moving traffic, more accidents likely
M62 Saddleworth	Fog, Snow	Accidents
M25	Not mentioned	Not mentioned
A14	Not mentioned	Not mentioned
M6 (8-10)	Weather slowing traffic	Not mentioned
M1	Wind	Accidents
A66	Snow	Delays
A1	Snow	Delays

During the interviews Stephen identified the Severn and Dartford crossings as particularly hazardous routes for wind. The Severn Crossing in particular is an infrastructure which is extremely vulnerable to weather. The two bridges carry both the M4 and M48 over the River Severn Estuary. The motorway suspension bridge offers the shortest route between the South West of England and Wales and often subject to high crosswinds (Macdonald et al 2003) and is known to close under high winds. As well as the safety implications of high winds on exposed bridges (e.g. Chen and Cai, 2004), an increase in the number of extreme storms in the future could easily raise the number of times the road has to close. This would potentially impact on the Welsh economy due to a reduced number of deliveries being made. Other expressed concerns include the potential financial risk of taking long-distance hauls to Scotland during times of severe weather. For instance, Stephen additionally reported:

> If I send up a driver to Scotland and it snows or there's a flood then he might be stuck there for two nights….we wouldn't send a vehicle to Scotland (During severe weather), we would try to persuade a customer to use another company (Stephen, TPL A)

The last statement highlights another important determinant of the impact of weather on road freight transportation: the operational reaction of companies. During the course of the investigation it was noticed that several large companies would bring their vehicles off the road during severe weather events. It was useful to know whether any procedures exist for the smaller companies. The interviews revealed a potential conflict between ensuring the safety of the drivers and meeting agreed delivery schedules. For example Stephen describes a scenario where he would intervene to prevent travel, yet also explains how financial considerations are always present;

> If we felt it was going to be really bad then we would bring them off the road, if we knew there was going to be gale force winds and depending on the size of the vehicle, because some of them act like a kite (Stephen, TPL A)

> We are ultimately driven by the customer, if they say we don't care, we want it sent then we have to, unless we think we are putting the driver at risk (Stephen, TPL A)

The monetary impact of taking vehicles off the roads during severe weather was mentioned throughout the interviews:

> It costs a lot more to take a vehicle off the road now than it did, especially with supermarkets who are trying to control the distribution networks, they tend to have charges and don't allow for bad weather, they seem to think that you can get through anything, which obviously you can't (James, Eco A)

> If you have bad weather today and you pull out, then all of that work gets delayed – and although the customers can understand you've got bad weather today they aren't going to understand when it knocks on tomorrow (Brian, TPL B)

> We don't stop, we can't afford to stop! (Henry, TPL C)

It was also clear that almost no attention was being paid to the severe weather warnings implemented by the Highways Agency after the events of Windy Thursday 2007. However, the integration of weather forecasts and telematics can play a role in reducing accidents:

> (On the Highways Agency's severe weather warnings) It's just another glorified weather forecast, which no one ever gets 100% right (Brian, TPL B)

> From our point of view the internet is important. We can access it almost instantly regarding motorway blockages and severe weather, now we can make decisions based on information we

wouldn't have had before, plus we have satellite tracking on all our vehicles, so if there is a problem we can see where we might have to divert around (Paul, TPL D)

9.2.2. Climate change

Figure 9.3 displays the Delphi participant's views on the likely effect of climate change on the frequency on meteorological hazards. When looked at as a broad overview, the distribution of responses shows two clear characteristics. Firstly, there is a view that most meteorological hazards are more likely to increase than decrease in frequency. Secondly, and most strikingly, is a sizeable minority view that there will be no change in frequency.

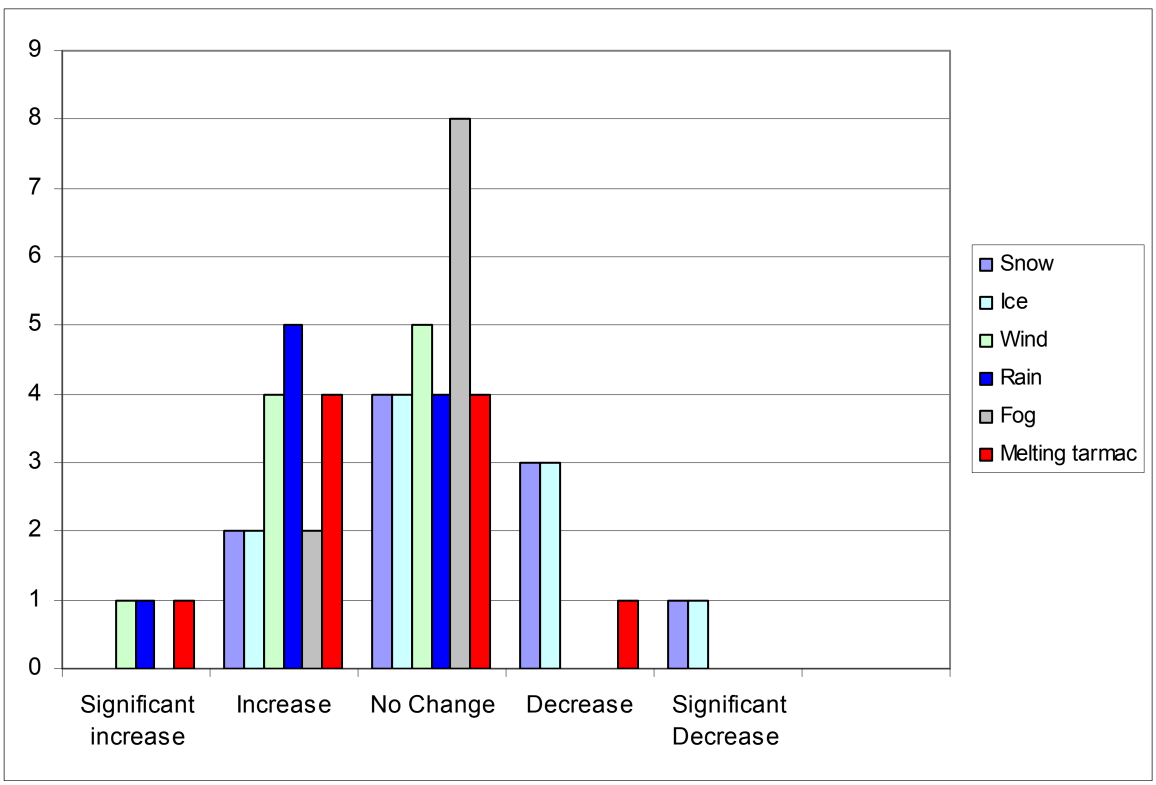


Figure 9.3 Numbers of participants reporting on views likely changes in meteorological parameters due to climate change

This view was also apparent in the interviews, where many participants seemed unconvinced by the evidence for climate change, e.g:

> If you believe everything you read in the paper then we're going to be wetter and windier with more storms, well that's what they say – who knows! (Henry, TPL C)

> We can all get data and read what we want into it (Brian, TPL B)

Although the majority held the view that the climate is likely to change, one suggested that there is no use in changing behaviour:

> I've got different views on climate change, I think the damage has already been done and it's irreversible – you can't change it, it's there to stay, all we can do is make sure we don't do any harm in the future (Frank, TPL E)

This is also seen in the clear split in the views of when climate change will impact upon the freight industry. Two Delphi respondents said that climate change would never impact their business. One also reported that there would be no change in any of the meteorological parameters, which would suggest that their assertion that climate change would not impact on the business is because they believe that climate change is not going to happen. Five respondents thought that climate change would affect their business by 2040 or earlier, with two of these indicating it would affect their business by 2020. However, three had a longer perspective, suggesting climate change would only affect their businesses by 2080.

9.2.3. Safety

As discussed in Chapter 7, it was important to investigate the reasons for the reduction in weather-related accidents over the past two decades. The Delphi responses are given in Figure 9.4. As expected, it is suggested that a combination of factors have contributed to the reduction, with improvements in driver training, new vehicle maintenance and safety regulations, and improvements in vehicle technology being the three highest scoring factors.

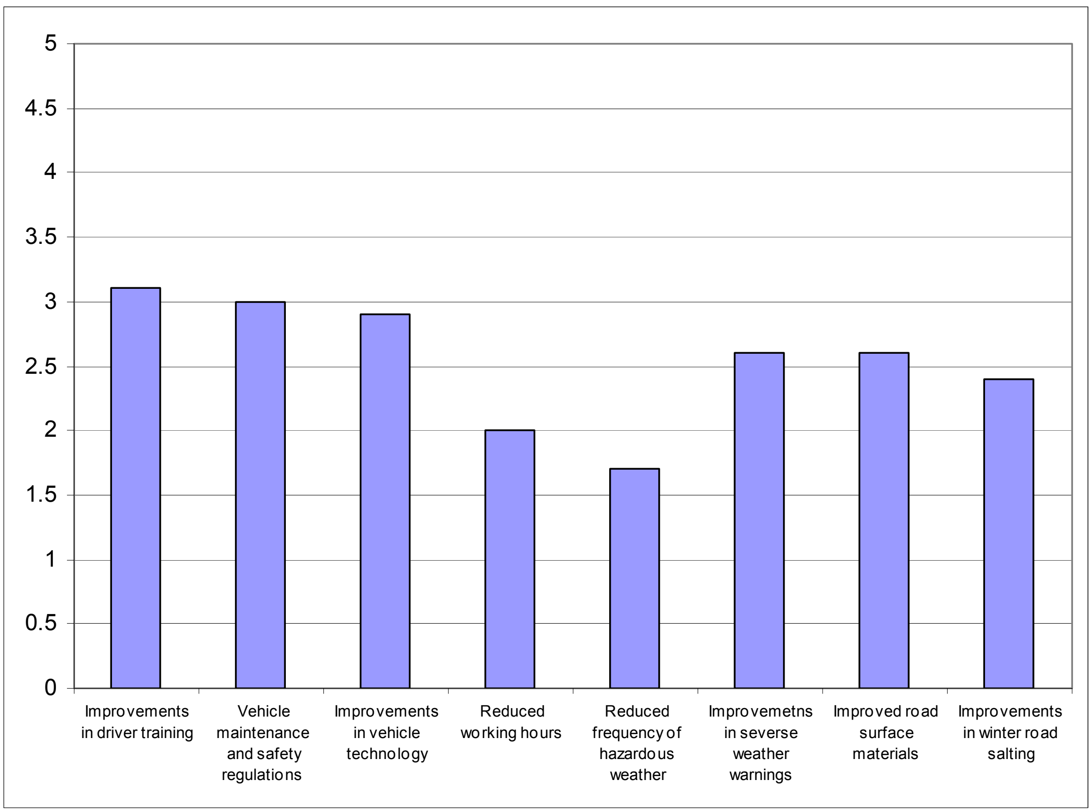


Figure 9.4. Relative scores for factors influencing the reduction of road accidents caused by meteorology between 1986 and 2006

The lowest scoring factor was 'reduced frequency of hazardous weather'. This low ranking potentially indicates that the reduction of accidents seen in the past two decades are as a result of reductions in the sensitivity of the freight sector through an improvement in a multitude of technological and institutional factors. Improvement in driver training was highly ranked among these, and was often mentioned during the interviews:

> It's a more professional job than it ever has been. The drivers that go out now know their responsibility that they've got for the vehicle for the goods for themselves and for the general public. As a whole it is good, but is on the verge of getting too much, with too much red tape (Brian, TPL E)

Vehicle technology also featured throughout, especially improvements in braking and tyre technology, which confirms Broughton and Baughan's (2003) findings in relation to the importance of these developments in reducing accidents in Great Britain:

> The vehicles are a lot safer, stronger, and they regulate them a lot more now, you have more checks now than you used to. From when I started driving they are 200% safer (Henry, TPL C)

> Modern trailers are better with ABS and disc locking systems, which gives you extra traction (James, Eco A)

> I think it's a combination of better warnings and better vehicles. Tyres also make a massive difference as that is the only contact you've got with the ground – and also I think driver training is much better (Stephen, TPL A)

Moving to question which factors identified from the literature and the initial interviews would be important for future improvements to vehicle safety, again no single factor stood out (Figure 9.5). Interestingly, vehicle body design seems to be one of the least important factors. This links back to the interviews, which often emphasised driver training and regulations. Table 9.2 presents the components Delphi participants considered to be of most and least importance to future improvements in safety.

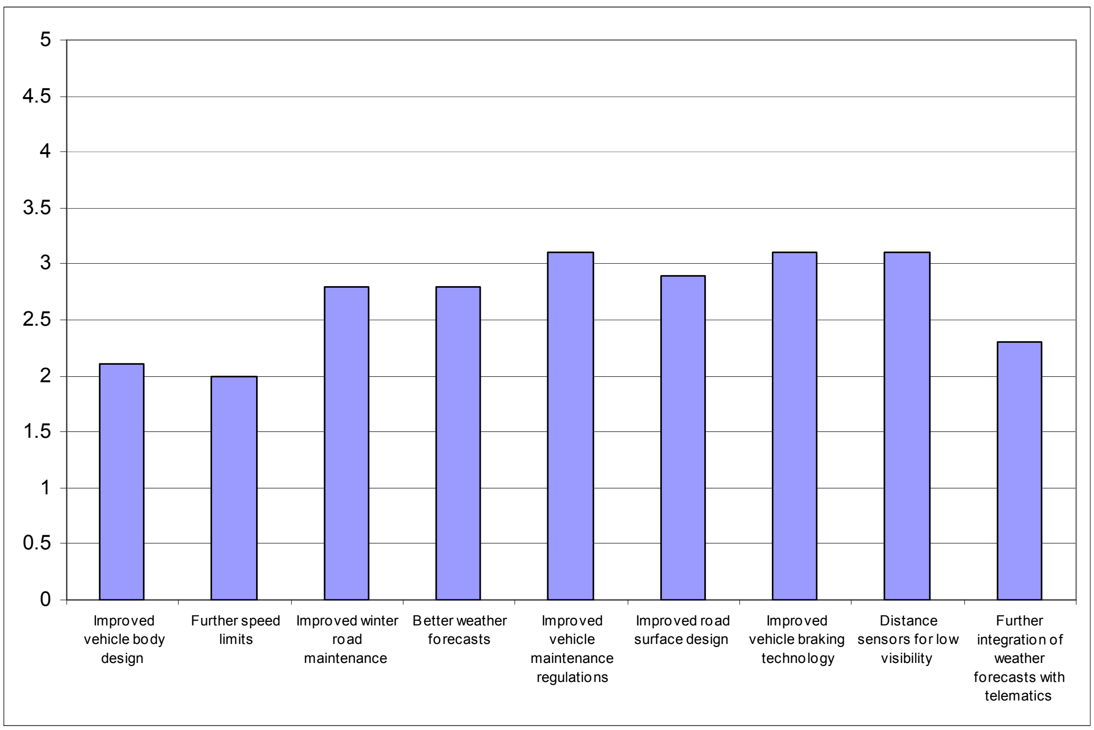


Figure 9.5. Importance of factors contributing to future increases in vehicle safety

Table 9.2. Number of participants indicating the likelihood significant improvements to the following aspects of transport

Component of Safety	Highly likely	Likely	Unlikely	Highly unlikely
Improved vehcile body design	3	6	1	
Further speed limits	1	6	3	
Improved winter road maintenance		4	6	
better forecasts		6	4	
Improved vehicle maintenance regulations		6	4	
Impoved road surface design		6	4	
Improved vehcicle braking technology	2	8		
Distance sensors for low visibility		6	4	
Improved electronic road side information signs		7	3	
Further integration of weather forecasts with telematics		3	7	

While the majority of the potential developments were considered likely, very few 'highly likely' responses were given and no 'highly unlikely' responses were offered, suggesting that the list of developments presented were plausible but not certain. When asked if there were any other important factors that would lead to a reduction in accidents Robert of ECO B mentioned the number of vehicles on the road, with rising fuel prices leading to fewer vehicles on the road exposed to meteorological hazards.

Almost all participants predicted a reduction in accidents, with seven suggesting a 10% reduction and two a 20% reduction. During the interviews several participants suggested that there is a limit to improvements in safety, and that although training has improved, driver error cannot be eliminated. The following response is typical, yet also hints at the impact of the emerging integration of software and vehicle technology, as mentioned in the Foresight vehicle technology roadmap (2002):

> There's only so much safety you can achieve, you can never eliminate driver error – unless you had some technology which stops drivers hitting each other, which I suppose could come (Brian, TPL B)

9.2.4. Trends in the freight and logistics by 2020

To inform the question design of the Delphi, the initial interviewees were asked at what time-horizon it would become increasingly difficult for them to predict changes in the freight industry. Most respondents were happy to look at least 10 years in the future. The views given were often informed by the current trends in the industry:

> To see which way you're going you have to look back 10 years; see how you have grown and magnify that forward, and that gives you an idea of where you're going (Brian, TPL B)

Table 9.3. Number of participants agreeing with statements on future freight and logistics trends

	Strongly agree	Agree	Disagree	Strongly disagree
Freight transport will move towards larger vehicles such as double-decker trucks		7	3	
Pallet systems will become more widespread within the industry		7	3	
The average journey leg length across the industry will decrease		6	4	
Cleaner fuel technologies will be adopted	2	8		
More long distance freight will be taken by train	1	4	5	
Fuel price will be the key determining factor in the growth of the industry	2	4	4	
There will be a decrease in the number of small hauliers		6	4	
Climate change will have no impact on the industry by 2020		7	3	
Government schemes will be introduced to improve infrastructure		2	8	
The growth of just-in-time delivery will continue	1	7	2	
Tighter margins and customer demands will increase the costs associated with delays	2	8		
New technology and computer systems will allow freight operations to become more efficient	2	8		
There will be a trend towards more centralized logistical distribution centres		7	3	

A combination of current as well more radical future trends was presented to the Delphi participants (Table 9.3). These statements on the future growth of the freight and logistics sector were chosen based on the strong views that came out of the interviews and present areas of disagreement amongst the group which required further investigation.

The viewpoints that produced the strongest agreement in the first round of the Delphi were that cleaner fuel technologies will be introduced, 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.

The view that costs associated with delays will increase is important to this study. With margins already being tight, any increase in disruptive weather will reduce the profits of freight companies. Also interesting is the fact that all participants agreed that cleaner fuel technologies will be introduced, even though not all participants thought that climate change would happen. A point of contention is that the participants expressed the view that new technology would be introduced to increase the efficiency of freight activity, whereas there was a consensus view that further integration of telematics and weather forecasts was not likely.

There were several areas that created a clear split in response. One of the most significant is whether the average leg length distance will decrease in the future. While a majority thought there would be further centralisation of logistics structures, which has the potential to increase leg length (McKinnon, 2007), there were dissenting voices. If the leg length does increase, associated factors that contribute to freight accidents such as tiredness may also increase (Corfitsen, 1993). Interestingly, the view of interviewees that fuel price would be the key determining factor in the future growth of the freight and logistics sector was not supported so strongly by the Delphi. In fact this was a major area of contention.

Of real importance in Great Britain is the potential movement of freight to the rail network. This again showed a clear split in views as to whether this would happen. The rail networks' resilience to meteorological impacts is significantly different to that of the road (e.g. Dobney et al, 2010). It could be argued that the move to rail would be more favoured under the 'Global Sustainability' scenario and perhaps the 'World Markets' scenario. However, the interview respondents were less than enthusiastic about rail freight:

> I notice you've got down a shift from road to rail, but without some serious investment in rail infrastructure that's not going to be possible in the near future (Stephen, TPL A)

> I think rail freight transport is a fad, I don't think it could ever be cost effective, not unless you had rail running to every business and household in the world. You've still got to get it to the depots and from the depots. If someone wants something in Scotland then you've got to get it to the depot, it's got to go up on the train, it's just a lot slower (Brian, TPL B)

Another important split in view which has a direct relation to the future sensitivity of freight operations is the potential move of freight to larger vehicles such as road trains. This has a bearing on the accident rate; a lower number of vehicles carrying the same (or increased) amount of freight exposes less vehicles to the effects of meteorology, although vehicle size does determine susceptibility to wind-related accidents (Baker, 1993).

Finally, the participants were asked to predict the percentage change in road freight traffic volume on the road by 2020. Two companies reported a reduction, with ECO A predicting a reduction of 10%, whilst the Large TPL A predicted a 4% reduction. ECO B predicted a rise, although earlier mentioned the possibility of traffic volumes falling if fuel prices continued to rise. All other companies reported an increase, with five opting for 10%, two for 15% a one for 20%, indicating that exposure is likely to rise in the coming decade.

9.2.5. Longer term trends

The final section of the Delphi sought to introduce the socio-economic scenarios and gauge views on long term-change. Specifically, participants were asked whether the UKCIP World Markets scenario would promote growth in freight traffic volumes. Eight said traffic volumes would increase, two that they would decrease. No respondents indicated that traffic volumes would increase or decrease significantly. David at TPL F predicted a decrease due to the smaller manufacturing base and therefore less freight to be moved, with increased imports moved on either larger vehicles or by rail. Darren at TPL I said there would be an increase because of high economic growth rates, increased population and the overall increase in transport demand. This fits in with the previous theories on freight activity being coupled with economic growth. Martin of Large TPL A disagreed, noting that population growth would lead to an increase in transport demand for FMCG (fast moving consumer goods) and other consumer items. James of ECO A said that it would promote increased freight, with high economic growth, freer trade and innovative infrastructure being the important factors, again associating freight sector growth with economic growth. James also commented on the World Markets scenario in related to the Global Sustainability scenario:

> (On Global Sustainability) This 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)

Participants were asked whether this scenario would promote increased safety. Although six respondents indicated that safety would increase and one that it would increase significantly (James from ECO A), three indicated a decrease by 2050. This is despite the unanimous view that accidents would stay the same or decrease by 2020. However, this may be a product of the wording of the question, and the switch from talking of a decrease in accidents to an increase in safety. This is discussed further in Chapter 10.

During the interviews it was possible to explore some radical visions of future freight transport, which are helpful to consider when moving onto the scenario analysis. For example, both Stephen and Brian explain how a possible move towards city-based distribution centres would work:

> Monster trucks but not going into cities – I think you are going to have city bases, so that small vehicles will go into the cities, they will be 7.5 tonners maximum. Superhubs – whether they come down by train depends on investment, otherwise it's supertrailers, but our roads can't take anything more than 38 tonnes (Brian, TPL B)

> I think what we will see, and we can already see this coming, is that most cities will have an approved logistics operation that will have the contract to deliver into town centres and what we'll be doing is delivering into that local distribution centre and they will then deliver into the centre, much in the same way they do at terminal 5 at Heathrow. Say ten haulage companies deliver to this one guy at Heathrow, then he takes our one pallet each then the one vehicle, rather than us all sending in a vehicle separately, so I think we will see a reduction in the number of vehicles on the road (Stephen, TPL A)

The effect of this vision on weather-related road freight accidents is unclear. Although exposure will be reduced due to fewer vehicles on the often exposed trunk road network (Perry, 1990), the sensitivity of larger vehicles to crosswinds may counteract some of the benefit. This vision is contrasted with Paul of TPL D, who suggests that freight will become more regionalised:

> Shorter average leg length – even to the point where our vehicles are only working on a local basis, within a 50 mile radius (Paul, TPL D)

This would resolve some of the issues mentioned earlier by Stephen where long distance hauls are vulnerable to lengthy disruption by snow. Frank of TPL E revisits the potential shift to rail freight mentioned earlier:

> It's almost full circle back to the days of BRS where the majority of freight was moved on rail, but then we had much more comprehensive rail network and every town had a station – everything moved on rail and then distributed on the small little three wheeler trucks (Frank, TPL E)

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:

> 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)

9.4. Discussion

The results of the first round of the Delphi gave a generally conservative prediction of growth by 2020. However, several disagreements were uncovered. These were present in the discussion of the likelihood of specific developments by 2020, and then exacerbated in some of visions for the freight and logistics sector in 2050. For instance, the split in opinion of the likely trend for average leg length evolved into diverging visions of on one hand regional distribution of the like described by Böge (1995), and on the other a trend towards hub and spoke systems operating outside cities.

It is possible to hypothesise on the modifying effect changes in exposure and sensitivity outlined above would have on the impact of climate change. For instance the 10-20% increase in vehicles would increase exposure and therefore increase accidents. This would be balanced by the 10-20% reduction in accidents through improvements in regulations, training and braking technology. However, this projection is for 2020, which does not allow for significant divergences in climatic or socio-economic environments.

The second round of the Delphi had a low response rate and failed to produce trends for the freight sector in 2050. Possible reasons for this are discussed in Chapter 10. In order to imagine the potential future of freight transport in Great Britain, it was decided to use the UKCIP and BESEECH scenarios with reference to the interviews in this chapter and the literature in Chapter 4. This final integrated assessment is reached in Chapter 10.

9.5. Conclusion

This chapter presented the results of a set of interviews and an expert Delphi, with the aim of producing forecasts for key components of freight exposure and sensitivity. Supplementary questions revealed ice and snow to be the main concerns in terms of weather-related accidents and disruption. Recent reductions in weather-related accidents were related to improvements in regulations, driver training and improved vehicle technology. Growth in traffic volume was hypothesised at 10-20% by 2020, with a reduction of accidents of 10-20%. The following chapter integrates the accident projections in Chapter 8 with the exposure and sensitivity forecasts arrived from the Delphi, with further predictions provided by elaboration of the UKCIP / BESSECH scenarios.

Chapter 10 - Integrated Scenarios, Reflections and Recommendations

10.1. Introduction

This chapter integrates the projections of future weather-related road freight accidents arrived at in Chapter 8 with scenarios for the future exposure and sensitivity of freight transport based on the interviews and Delphi in Chapter 9, with further elaboration provided by the UKCIP socio-economic scenarios. Accident projections are matched with the relevant socio-economic scenario, based on the associated emissions level. The scenarios are then assessed for their likely influence of future exposure and sensitivity, determining whether this will moderate or exacerbate the accident projections.

This chapter concludes with reflections on the approach taken in this project and recommendations for future research. The concepts of adaptation and adaptive capacity are introduced, with suggestions as to how they might be integrated into the assessment framework in order to achieve an adaptation policy assessment (Füssel and Klein, 2006). Alternative scenarios are explored as a possible means of greater quantification. The implementation of the Delphi is discussed, with an exploration of the possible influence of the recent economic situation. The relationship and climate methodologies are critiqued, with potential improvements suggested. A discussion on future research dissemination is also made.

10.2. Integration

As previously discussed, the nature of each UKCIP socio-economic scenario promotes an associated level of GHG emissions. Futures centred around setting and meeting environmental goals therefore have relatively low emissions, with those favouring more traditional industrialisation having accordingly higher emission levels (UKCIP, 2001). To reduce complexity, CIA often assumes that these trends are global. This avoids a situation where the country in question reduces emissions unilaterally, although it has to be remembered that such scenarios are also plausible.

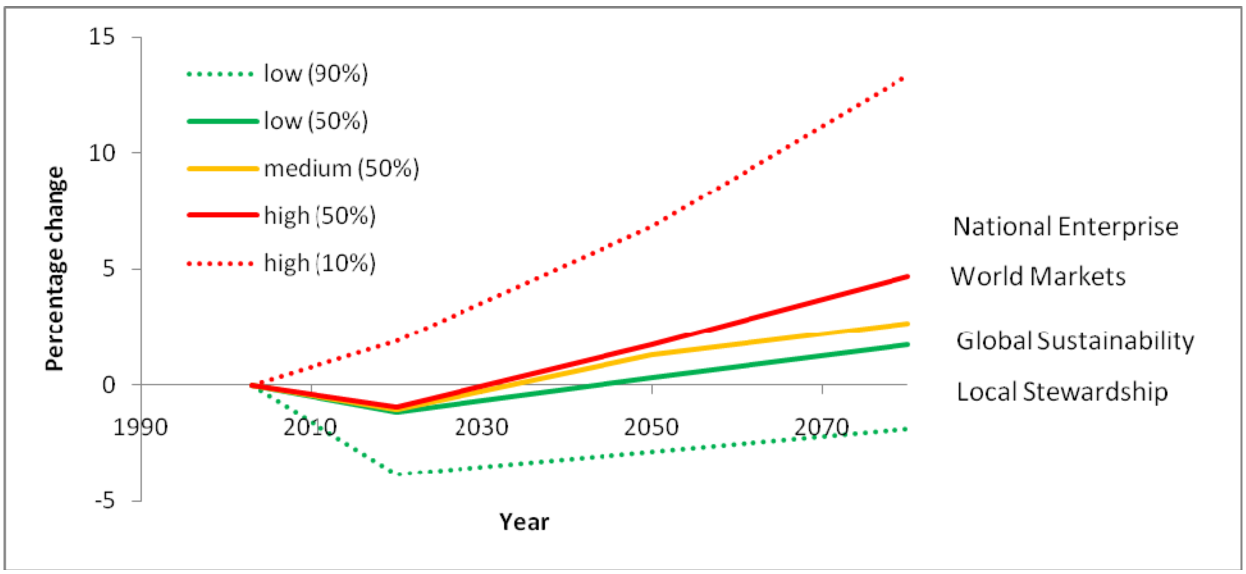


Figure 10.1. Winter precipitation-related accident projections with indication of likely socio-economic scenarios

Figure 10.1 displays a figurative example of how the UKCIP socio-economic scenarios can be linked with their associated emission and impact levels based on the reference table in Chapter 6 (Table 6.3: UKCIP, 2001). The National Enterprise and World Markets scenarios are associated with high emissions, and correspondingly large increases in accidents are projected for this weather type. The ‘green scenarios’, Global Sustainability and Local Stewardship, have lower associated emissions, so benefit from a smaller increase in winter precipitation related accidents. World Markets and Global sustainability can be considered the two ‘conservative’ visions of future society, which is reflected in their emission scenarios and resultant accident projections. National Enterprise and Local Stewardship are described as more extreme in their divergence away from current emission trends, so sit as outliers on the accident projection plot. As discussed in Chapter 8, this relationship is reversed for summer-precipitation and winter ice-related accidents, with higher emissions causing greater reductions (Figure, 10.2).

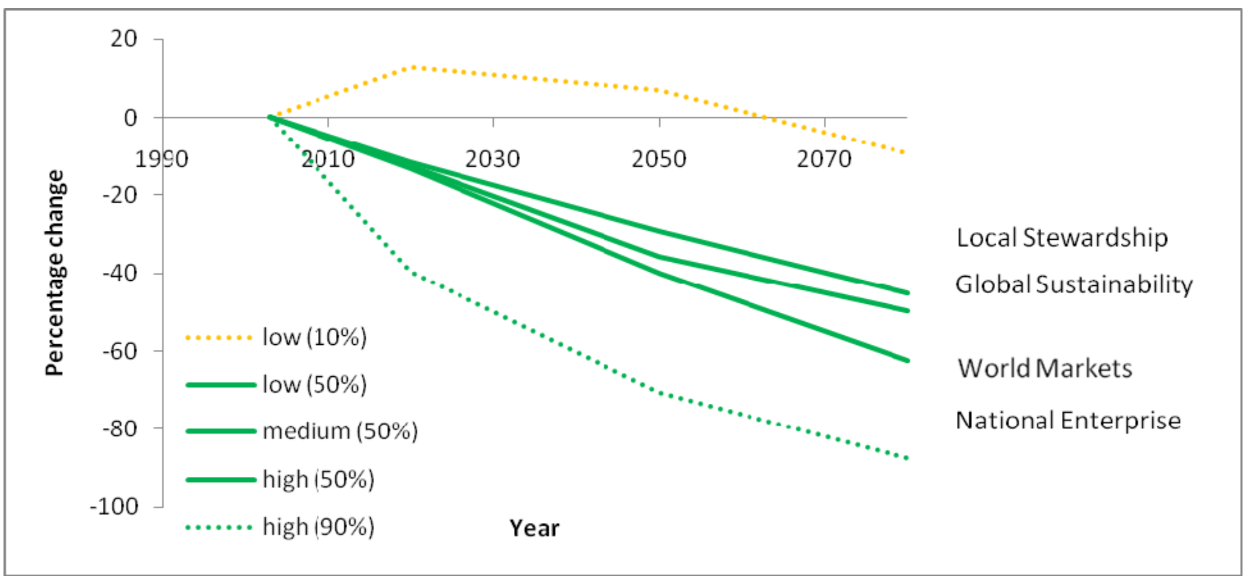


Figure 10.2. Winter ice-related accident projections with indication of likely socio-economic scenarios

The Delphi suggested that growth in the freight sector and improvements in regulations, training and technology would cause exposure to increase and safety to improve at similar rates by 2020.

Hence the negative effects of greater exposure are likely to be cancelled out by reduced sensitivity. As climate change in this time-frame is negligible under the central estimate (Chapter 8: Murphy et al, 2009) accident numbers would be expected to remain static. However, any scenario which promotes an increase in exposure without a corresponding increase in safety will lead to a more vulnerable freight sector. This combined with greater levels of climate change by the 2050s would likely result in increased accident numbers.

The finer details of the scenarios are important, as although several have similar emission levels, the exposure and sensitivity of the freight sector can be significantly different. Several of the areas of disagreement in the Delphi also differ between scenarios. For example, although Global Sustainability and Local Stewardship would both promote a low emissions scenario, average leg length would be predicted to decrease at a greater rate under Local Stewardship due to the emphasis on regional production and distribution, hence lowering exposure. The greater emphasis on commerce in Global Sustainability the global sustainability scenario may see the centralisation described by McKinnon (2006) continue, maintaining or increasing leg length and hence exposure. However, it could be assumed that the priority of environmental protection would allow rail to be incorporated into this system to a greater extent than at present. Figure 10.3 displays an interpretation of the expected relative trends in emissions, exposure and sensitivity for each of the UKCIP socio-economic scenarios. Further specifics used in this interpretation are presented in Chapter 6 (Table 6.1, pages 141-143).

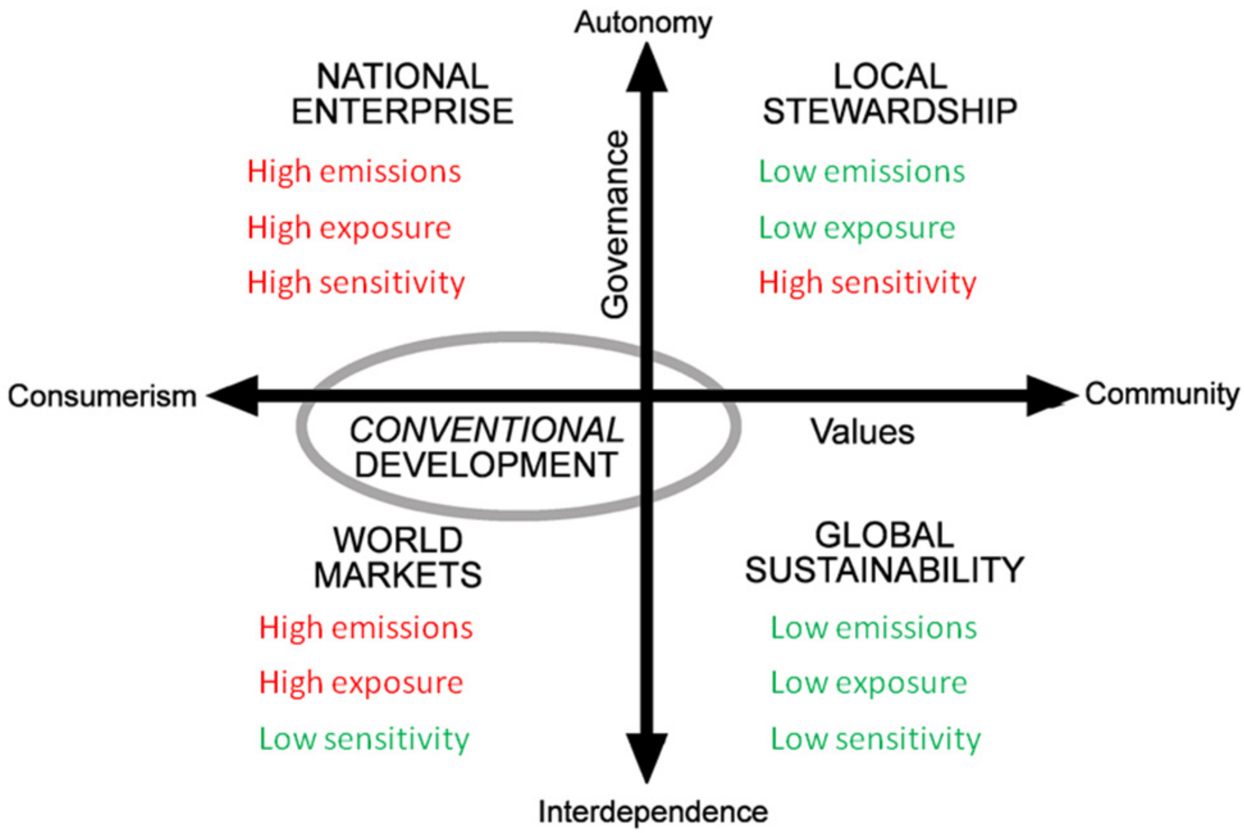


Figure 10.3. Modified UKCIP scenarios (2001) showing relative emission levels, road freight exposure and sensitivity

According to UKCIP (2001), National Enterprise sees a reliance on manufacturing, with bulkier goods potentially decreasing the efficiency of freight and increasing exposure (McKinnon, 2007). The relatively low proportion of public transport carried by rail (7%: UKCIP, 2001) would suggest a similar reluctance of the government to promote the movement of freight by rail, again increasing exposure relative to the other scenarios, especially Local Stewardship and Global sustainability. Economic growth is concentrated around London and the South East in this scenario, which would potentially expose greater traffic volumes to areas identified as among the highest risk of future winter precipitation-related accidents (By up to 22%; Figures

8.13-8.14, pages 204-205). Sensitivity can be assumed to be relatively high under this scenario, with little investment in infrastructure. It is also suggested that investment in innovation is low, again reducing the implementation of vehicle technology.

The low population and GDP growth under Local Stewardship, along a shift towards rail and a move to more regionalised economies makes this the scenario with the lowest level road freight transportation and hence lowest exposure. This scenario is the most likely to see the type of supply chain restructuring mentioned by (Böge, 1995). The move to regional production of goods and the narrowing of the geographical sourcing of supplies may mean that less long-distance travel is involved in the production and distribution of goods. In this way it also agrees with Waller's (2006) vision of a move away from increasingly lean production cost abroad and towards local production, based on environmental and social concerns. The fact that the even spread of economic growth is promoted may also mean that the exposure of freight vehicles is also more evenly distributed across the country. The low investment in infrastructure may cause an increase in sensitivity, although this scenario may still promote safety through the predicted high rates of investment in innovation. This scenario will benefit from a much lower increase in winter-precipitation accidents than National Enterprise, although it will see a smaller reduction in summer-precipitation and winter ice accidents. This scenario would be the most likely to produce the move towards radically reduced average leg lengths explored by Paul of TPL D during the interviews.

World Markets and Global Sustainability differ from the previous two scenarios by taking a more globalised economic standpoint. However, they differ on social and political values, especially regarding the environment. Hence World Markets sees a similar reliance of road transportation as the National Enterprise scenario. Global sustainability has higher economic groeth than Local Stewardship and hence has a greater demand for transport. However, there is a trend towards eco-efficiency, with low emission vehicles and a move towards rail. There is also increased miniaturisation, which would again act to reduce exposure by allowing the same number of products to be carried by fewer vehicles. Sensitivity under Global Sustainability and World Markets is likely to fall due to high investment in infrastructure and technology. Both seem likely to promote centralisation of distribution centres, although the precise nature of this is likely to differ. For example, World markets may see the introduction of road trains as described by Brian of TPL B, whilst the environmental values of the Global Sustainability scenario would be more likely to promote the integrated use of rail to link distribution centres as described by Frank of TPL E. World Markets will see increases in winter precipitation-related accidents, but also significant reductions in winter ice and summer precipitation-related accidents. Global Sustainability shows a smaller increase in winter precipitation-related accidents, but also a smaller decrease in winter ice-related accidents.

10.3. Reflections and recommendations

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 vary significantly. Additionally, despite the indication that several socio-economic scenarios may promote similar emission scenarios, the discussion shows how exposure and sensitivity may vary significantly. It must also be remembered that only winter ice and summer and winter precipitation were considered in this study. The behavioural theories of Elvik (2006) suggest that much of the benefits from a reduction in winter ice events will be offset by a reduced ability to cope in this condition. Fridstrom et al (1995) suggests that reduced daylight hours can significantly increase the risk of accidents, indicating that the effect of winter precipitation has been underestimated in this study. It is plausible that when other weather types are added to the analysis high emissions may promote more accidents than low emissions.

It should be remembered that road freight transport is a small but significant contributor of GHG gases (McKinnon, 2007), so plays an active role in the future level of climate risk. In this sense the convergence of 'gold' and 'green' aspirations that come about through more efficient freight (Goodwin, 1993; In McKinnon, 1996) may have the additional benefit of making freight safer. However, the type of accidents projected in this thesis may not be seen in reality, due to adaptation. The remainder of this chapter discusses the limitations of the approach taken in this thesis, and suggest ways in which it can be improved to provide more realistic impact scenarios.

10.3.1. Adaptation

In recent years adaptive capacity has emerged as a key concept describing the ability of a nation, region or sector to cope with the impacts of climate change. The IPCC defines adaptation as "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities" IPCC (2007b). Furthermore adaptive capacity is defined as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" IPCC (2007b).

The UKCIP and BESEECH scenarios used in this project are 'non-climate', in that they describe futures in the absence of adaptation to climate change. This is an important point, as it means that the scenarios for future accidents arrived at in the previous section are unrealistic. In reality a scenario under which a large increase in accidents is predicted, for instance National Enterprise would likely take action to adapt to the new climatic environment in order to prevent these accidents. Although the initial UKCIP scenario predicts that infrastructure will be poor under the National Enterprise scenario, the fact that increased winter precipitation is causing more accidents may prompt the future government to build better infrastructure. This action may not be necessary under a World Markets Scenario where provision of quality infrastructure is already predicted, or under Global Sustainability, where the values and governance of the scenario promote a move towards rail regardless of the hazard presented by a changed climate. This is the reasoning behind creating the type of scenarios presented in this thesis: they allow a measure of both impact of climate change and the level of adaptation (or indeed mitigation) needed to counteract this.

The ability of future societies to implement the required level of adaptation, a concept known as 'adaptive capacity', will also be determined by the socio-economic scenario. For instance, Tol (1998) makes the observation that more prosperous societies will have more to lose to climate change (in financial terms), but will also have more to spend to protect themselves. Determinants of adaptive capacity include critical institutions, governance, human capital, economic resources and structure and equity and are largely determined by socio-economic development (Dahlström and Salmons, 2005).

Attempts have been made to include cultural theory, a concept associated with risk literature, to determine the potential adaptive capacity of future socio-economic environments. The research conducted by UKCIP in preparing the BESEECH scenarios (Dahlström and Salmons, 2005) included grid group theory in combination with the usual drivers of values and governance. It is theorised that each cultural type will have a different response to climate change and hence a different adaptive capacity. The possibility space of future socio-economic scenarios is divided into four cultural types; fatalism, hierarchy, individualism and egalitarianism (Figure 10.4). It argues that the way in which societies view nature can have a large bearing on their ability to adapt to it.

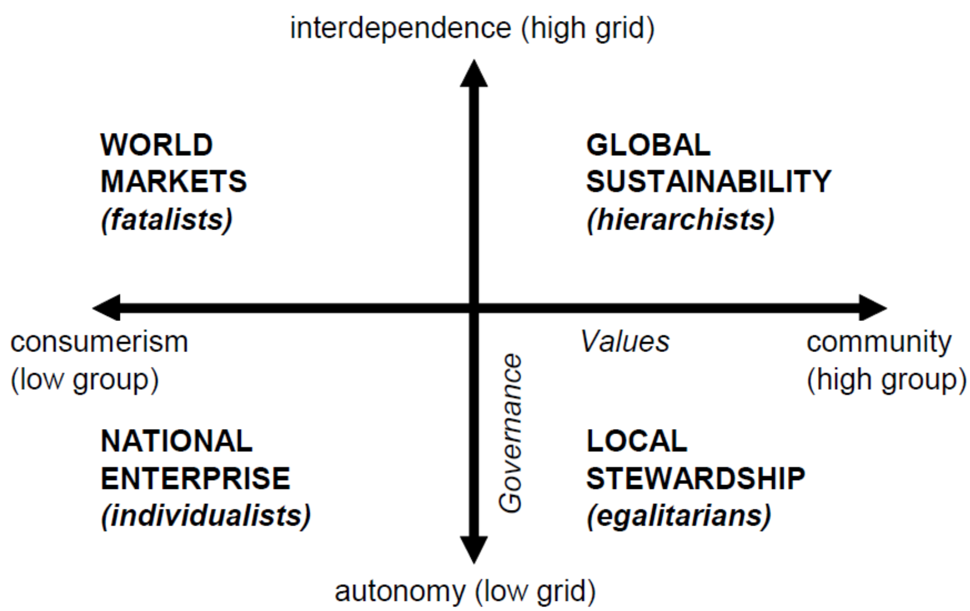


Figure 10.4. Combined socio-economic scenarios and cultural types (Dahlström and Salmons, 2005)

However, adaptive capacity is very much an emerging field, and its application to climate assessments has not been without criticism. In her critique, Vincent (2007) focuses on problems with scale specificity and the uncertainty that this produces in many assessments. Although this centres on the differences between national and household adaptive capacities and the requirements therein, it can be assumed that adaptive capacities will vary significantly even for different companies operating within the same sector. Generic determinants of adaptive capacity must be found at various scales in order to produce an authoritative assessment. Projects that extensively consider these issues can be placed within the most advanced category of adaptation policy assessments (Figure 4.7).

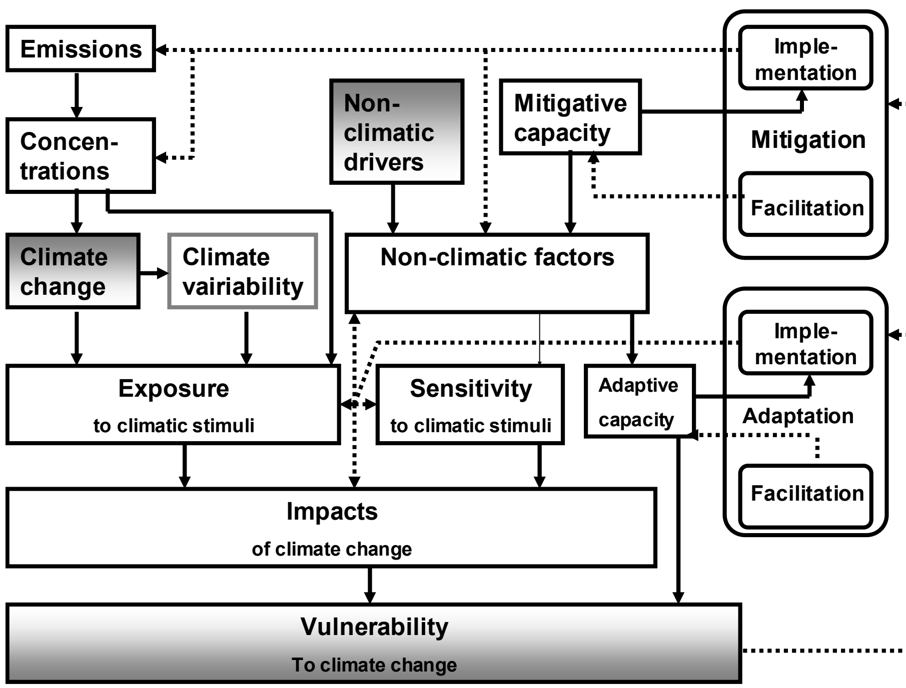


Figure 10.5. Conceptual framework for an adaptation policy assessment (Füssel and Klein, 2006)

It would be useful to incorporate these theories into future assessments to indentify the likely adaptive measures necessary to ensure future transport resilience under different scenarios. It would also be useful to gauge the current and future adaptive capacity of Britain, in order to determine whether these measures are possible. This could be achieved through a research dissemination event, as discussed at the end of this section.

10.3.2. Scenarios

This thesis attempted to elaborate upon existing generic socio-economic scenarios in order to produce sector-specific visions for freight exposure and sensitivity. However, in a critical review of the UKCIP tools, Hughes et al (2009) observed that a major barrier to the uptake of socio-economic scenarios is the perceived resource intensiveness in tailoring them for specific use within a sector, leading to a desire for 'off the shelf' tools to fit directly into the ongoing empirical impact modelling. For instance, although concerned with one facet of the future trends in transportation (the use of information and communication technology), Foresight's Intelligent Infrastructure scenarios (2006) could be used to add detail to generic UKCIP socio-economic scenarios, providing sensible choices in matching scenarios from two sources can be made.

The mitigation literature also provides examples of such scenarios. The MARKAL (MARKet ALlocation) modelling conducted for the UK Energy Research Centre (UKERC) determined the likely futures for transportation technology, based on the way a least-costs model reacted to future energy demands driven by policy, retirement of existing energy capital changing energy resource supply curves among other factors (Strachan and Kannan, 2008). This provides useful information on the potential nature of future transport, and assuming that the trends in mitigation policies used in the model are assumed to be followed multilaterally, could also have feedback into the climate forcing models used in CIA. This backcasting approach was used by the Tyndall Centre (Mander et al, 2008; Anderson et al, 2008) in the creation of the decarbonisation scenarios for the UK.

As transportation is a significant contributor to GHG emissions, several mitigation scenarios have already been created to provide potential pathways for reductions. McKinnon (2008) estimates that domestic freight transport account for around 313 million tonnes of CO_2 annually in the UK. This amounts to around 21% of transport emissions and 6% of emissions from all sectors. McKinnon and Piecyk (2009) investigated the feasibility of meeting the UK government's targets of an 80% reduction in CO_2 emissions from 1990 levels by 2050. This was achieved by forecasting changes in tonne kilometres, modal shift, empty running, payload weight, fuel efficiency and carbon intensity of the energy source. Although this was partially based on linear extrapolation of earlier 2020 and 2030 Delphis, the study is useful as it is one of the first to produce scenarios for 2050. The inclusion of quantified parameters is also importance, as tonne kilometres and modal shift could be used as indicators for exposure, with empty running and payload useful for sensitivity.

The results of future decarbonisation of freight and logistics operations in the UK will likely influence exposure and sensitivity. A report by Ricardo (2009) for the Department for Transport reviews several technologies which may be used in this effort. For example, aerodynamic trailers act to reduce drag, with the benefits being lower fuel consumption and reduced risk of veering and overturning. This effect can also be achieved by the addition of aftermarket fairings. Automatic tyre pressure adjustment monitors can reduce fuel consumption, while the even distribution of weight over the drive axles reduces tyre wear. Use of GPS routing and telematics produces more efficient routes, lowering exposure and emissions.

It can be argued that the use of any scenarios apart from those created by or elaborated from major impact organisations should be supplementary in nature, as the integrated assessment of climate change impacts across all sectors on a national level requires a commonality in approach and compatibility in data (Cohen and Tol, 1998). For instance, the ability to link to emission levels, as performed earlier in this chapter, may be lost if scenarios become too atomistic and disconnected from the broader socio-economic environments.

It is also possible to elaborate on developments that are not directly related to transport. For instance, a more environmentally orientated society may such as those described under the Global Sustainability and Local Stewardship scenarios may alter the time zone of the UK to reduce emission in the winter, in effect implementing British Summertime throughout the year and reducing the time that heating and lighting are used. This would make winter nights lighter for longer, potentially reducing a known risk factor for vehicle accidents (Fridstrom, et al 1995). In a 1998 study by Broughton and Stone it was estimated that such a move could reduce the number of deaths caused by road accidents by up to 138 per year.

Finally, a more fundamental critique can be made of the existing socio-economic tools, including the ones used in this thesis: they treat transport as an output domain of the socio-economic environment, and not as a driver. For instance McKinnon (2006) suggests that changes in logistical structures may affect the way society develops, while Sessa et al (2009) discusses this dilemma, demonstrating that it can act in both ways. This is a difficult concept to incorporate into CIA, although co-evolutionary methods of the type described by Lorenzoni et al (2000) could be used to arrive at a suitable 'storyline' of feedbacks between transport and socio-economic development.

10.3.3. Delphi

Although the Delphi was successful in indicating views on trends in the freight and logistics up to 2020, the second round failed to extend this to 2050. Although a degree of iteration and overlap of views was made between the interview stage and the first round of the questionnaire, the intended two-stage Delphi described in the methodology was not fully achieved. Without a successful second round, the results presented in this thesis do not strictly conform to the requirements of the Delphi methodology. The low response rate may indicate that the presentation of the scenarios in the questionnaire was not engaging enough to achieve this. Tonn et al (2006) suggest that participants are comfortable with thinking up to two decades ahead, so the extension to 2050 was a task which required careful implementation. During the interview stage James of ECO A was the only participant to fully engage with the possibilities of the contrasting scenarios, potentially due to his company's alternative approach within the industry.

One of the most challenging aspects of this research is the fact that it was conducting during the transition between the most sustained run of economic growth in the UK's history and the onset of the deepest recession since the 1930s. During the final two quarters of 2008 the UK economy shrank by 0.8% GDP (ONS, 2009). The number of heavy goods vehicles on the road dropped by 7% in the fourth quarter of 2008 and by 12% in the first quarter of 2009 (DfT, 2009). This may have had an impact on the response to the second round of the Delphi, as it became increasingly difficult to recruit and retain participants.

As an aside, it must be noted that several informal conversations with freight drivers during the interview period indicated rain as the main concern for accidents. This could be more formally incorporated into future studies. Finally, the timing of the many of the first round responses to the Delphi coincided with a period of particularly wintry weather (Eden 2010) which may have had an impact on the relative perception of ice and snow as hazards.

10.3.4. Meteorological relationships and climate projections

Several improvements can be made to the relationships produced in Chapter 7. As discussed in Chapter 8, much of the projected decrease in winter ice-related accidents may be offset by a reduction in the ability of the driver to cope in those conditions, as a result of encountering that hazard less frequently. Unfortunately, Elvik's laws (2006) cannot be modelled as part of the relationships, only implied afterwards. However, future research could be conducted to produce quantitative relationships between exposure and relative risk from weather-related hazards in the UK, similar to those by Brüde and Larsson (1980) in Sweden.

The costing of monetary impacts of climate change on the freight industry has not been attempted in this thesis, although the UKCIP (2004) does provide guidance on how this would be performed. However, the current operations of the freight sector would need to modelled if the results were to be fully quantified. For instance, the shift in seasonality of impacts predicted in this thesis may have a disproportionate effect on the industry, as it is noted that disruptive and congested events are worse when production centres are running close to capacity (McKinnon, 1998c). This may be the case in the run up to Christmas, a period which would suffer from increased precipitation. The importance of costing the impact of delays from weather-related disruption in future assessments is clear. McKinnon et al (2009) estimates that £313 million of freight inventory is on the road at any given time. As each journey is delayed by an average of 7.6 minutes, the cost of financing this extra in-transit inventory is £4.2 million. The contribution of meteorology to this figure could potentially be elicited and extrapolated onto future climates.

The physical characteristics of vehicles have a large impact on their sensitivity to meteorology (e.g. Baker, 1993; Summerfield and Kosior, 2001). However, no distinction was made between different types of goods vehicles in this thesis. A more accurate approach may be to form separate relationships, as different socio-economic scenarios may promote the usage of certain vehicle types over others. For instance, e-commerce and home-delivery has seen a trend towards more freight being delivered by van (Figure 10.6), which will have a different relationship to weather than traditional heavy goods vehicles. Different socio-economic scenarios may act to increase or reduce this trend.

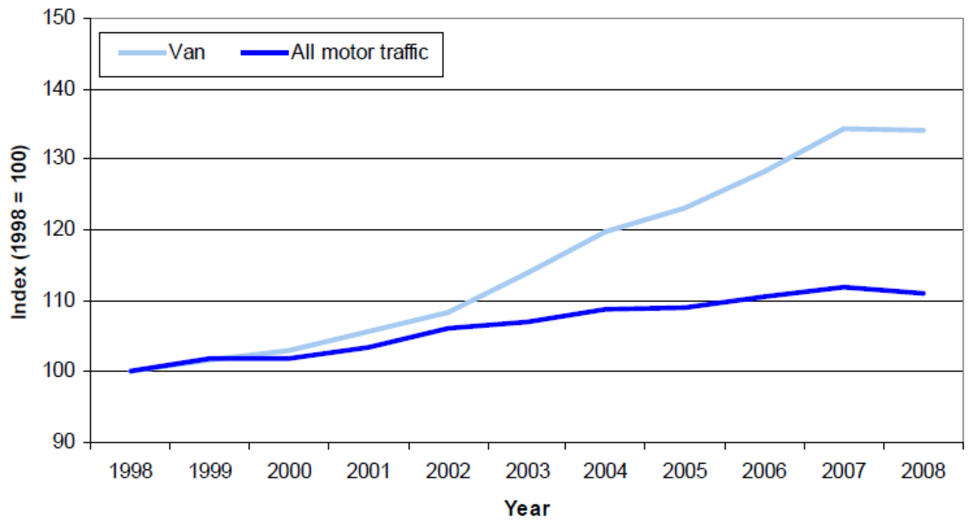


Figure 10.6. Van and all motor vehicle traffic between 1998 and 2008 (DfT, 2009)

10.3.5. Research dissemination

The dissemination of research within the industry is a key step in identifying adaptive strategies to cope with the predicted impacts of climate change. However, several barriers exist to the comprehension of the data produced in thesis. One of the greatest issues arising from the CIA literature concerns the increasingly large number of projections produced by ensemble models. For example, ice-related accident projections show a large potential range -9% to -87% by the 2080s (Figure 10.2). This gets more complicated still as socio-economic change is added as a dimension, increasing the number of potential scenarios geometrically. A potentially bewildering array of scenarios is conceivable, which may act as a barrier to stakeholder dissemination.

It has been demonstrated that the institutional environment of the sector concerned may play a role in the level of comprehension, with sectors that are used to probabilistic forecasts such as water resources able to assimilate a large range of scenarios (Groves et al, 2008). Reilly et al (2001) suggest that emphasis should be placed on a limited number of key results most important for policy making. The plume plots in this chapter and Chapter 8 display five possible pathways for impacts, which could be reduced to three (low, medium and high emissions) to assist with the dissemination.

As well as members of the freight industry, any dissemination would need to include members of the Highways Agency and Department for Transport, as this may be the institutional and governance level at which adaptation is carried out. The likely form of this would be a workshop event, allowing collaboration between the institutions and companies. However, the success of climate impacts dissemination is debatable, especially for individuals and companies. Douglas et al (1998) suggests that although information provision plays an important role in raising awareness of issues and knowledge gaining, its influence on attitudes and behaviours is less clear, and often limited.

10.4. Conclusion

This chapter integrated accident projections with scenarios for exposure and sensitivity. It was shown how the impact projections arrived at in Chapter 8 may be modified to a large extent by the overlying socio-economic environment. Trends which caused disagreement in the Delphi, such as leg length and modal shift, vary significantly between scenarios, and hence alter sensitivity and exposure. It was found that the National Enterprise scenario may result in the greatest number of future accidents, with Global sustainability potentially resulting in the fewest. As a result of discussion on the approach taken in this thesis, the following recommendations for future research can be made:

- Incorporate adaptation and adaptive capacity
- Include quantified forecasts from the energy literature
- Investigate monetary impacts of changes in accidents
- Link potential changes in day length to socio-economic scenarios
- Model remaining weather types (especially wind)
- Produce separate relationships for different vehicle types
- Implement a research dissemination event

Chapter 11: Conclusion

The impact of climate change of road freight transport safety was identified as an important area for investigation, due to the potential risk increases in meteorological hazards may present to freight drivers. There was also the opportunity to use the latest climate impact assessment tools to account for change in the socio-economic environment as well as the climatic. As a result the methodological requirements of this thesis necessitated a multidisciplinary approach, the findings of which are outlined below with reference to the objectives:

1. To develop a methodological framework in which both climatic and socio-economic change can be integrated to determine a range of impact-scenarios for the road freight sector.

A multi-component framework including techniques from transport meteorology, climatology, social sciences and futurology was formulated, with reference to the classifications of Füssel and Klein (2006). Existing methodologies from the accident analysis literature were adapted for the requirements of a CIA. This involved aggregating road freight accidents over a wider geographical area and coarser temporal resolution than previous studies by Andrey et al (2003). Relationships were formed for the administrative regions of the UK and then used to extrapolate accident numbers onto future climates, provided by the UKCP09 climate scenarios. For this, a mixture of area averaged ensemble projections and representative weather generator time series were created for summer and winter precipitation and winter frost-days.

Concurrent changes in the socio-economic environment of Great Britain were investigated using the Delphi methodology. A set of initial interviews were conducted with freight experts, informing the first round of the Delphi. The Delphi contained both quantitative and qualitative aspects to provide the latitude for radical views of freight development. UKCIP and BESSECH scenarios were also used to complete the assessment to 2050. The two dimensions of change were then integrated using the likely emission scenarios under each socio-economic environment.

2. To determine a set of empirical relationships between observed meteorology and road freight accidents.

The patterns of weather-related road freight accidents during the 1998-2007 period were compared with those from earlier studies by Edwards (1994, 1996, 1998, 1999). Broad similarities were apparent, including the predominance of precipitation as a cause of accidents and the tendency for more weather related accidents from November through to March. Accident patterns during extreme storm events were investigated, with the 'Great Storm' of 1987, the 'Burn's Day' Storm of 1990 and 'Windy Thursday' in 2007 showing pronounced spikes in accident numbers during the event, against relatively low baselines.

Relationships were created between winter and summer precipitation and precipitation-related accident numbers, and winter frost-days and ice-related accidents across the GB EU regions. Summer precipitation relationships were found to be stronger than winter precipitation relationships, potentially due to the increased number of confounding factors in the winter including reduced daylight hours. Winter ice accident relationships were stronger than those for winter precipitation, although they were based on more aggregated observations.

3. To extrapolate the current relationships between meteorology and accidents onto a number of future climates.

Plume plots were produced for future precipitation anomalies, using the UKCP09 climate tools. Winter precipitation showed a general increase, with summer precipitation declining. The weather generator projections for frost-days showed large scale reductions under most scenarios. This included projections for single-figure frost day counts by the 2080s in certain regions.

Winter ice-related accident rates saw a large scale reduction of up to 80% under the most extreme climate scenario. Summer precipitation related accidents also saw large reductions of up to 40%. Winter precipitation-related accidents were the only type to increase, with a maximum of 20% projected under the high emission scenario. However, the relatively large baseline number of winter precipitation-related accidents means that this increase acts to cancel out most of the benefits from the other two hazards. Reference is made to behavioural research, which suggests that the overall reduction in accidents may be lower still, due to drivers becoming less used to operating in certain hazards such as icy roads.

4. To create a set of expert-defined scenarios for the future of the freight sector.

The initial interviews and Delphi elicited views on meteorological risk and climate change. The greatest perceived threat came from ice and snow, with rain placing lower than the cumulative accident numbers would suggest. It was found that a narrow majority of freight experts believe that climate change will affect their business in the next 40 years.

Freight growth in terms of vehicles on the road was predicted to increase by 10 to 20% by 2020, with a similar percent fall being expected in accident rates. The improvements in vehicle safety during the past two decades were put down to a combination of better vehicle design, driver training and regulations, amongst a wide range of contributory factors. When asked how the World Markets Scenario would affect the industry, most believed it would promote improved safety. Views were more split on the effect on traffic volume, although a majority said that they would increase.

5. To integrate the future climatic and socio-economic scenarios into a holistic impact assessment.

Integration was performed on the two sets of projections. It was broadly found that scenarios that promoted high emission were also likely to have increased exposure to meteorological hazards as well as have poorer infrastructure and lower rates of innovation. National Enterprise and World Markets from the UKCIP and BESEECH socio-economic scenarios were the two examples of this confluence of meteorological risk and high vulnerability.

Limitations

Although the methodology used in this thesis was developed with reference to state of the art conceptual frameworks for CIA, three main limitations exist. Firstly, the analysis was limited to precipitation and temperature. As fog, snow and wind are not currently projected under the UKCP tools, these were handled qualitatively. This is unfortunate, especially for wind which is traditionally associated with high-side vehicle accidents. It also means that the net impact of climate change on weather-related accidents cannot be projected fully.

Secondly, the assessment does not explicitly include adaptation. Although the results presented satisfy the requirements of a CIA, an adaptation assessment would have additional value to stakeholders. However, the format of the results are easily amendable for a future considerations of adaptation. Finally, due to a low response rate the Delphi failed to elicit consensus in round two. This limited the projections for future socio-economic environments to the 2020s, reducing the quantitative overlap between socio-economic and climate projections. It also limits the stakeholder involvement in the construction of scenarios for exposure and sensitivity, something which would otherwise be useful for future adaptation assessments.

Recommendations for future research

Recommendations were made for future research. These included using a finer spatial and temporal resolution for constructing relationships, the incorporation of behavioural theory into these models, and the use of urbanisation figures from socio-economic scenarios as a surrogate from urban heat island development. The need for the consideration of adaptation in future assessments was also stressed. Improvements were suggested for the socio-economic component, including using workshops and focus groups. Research dissemination was also suggested, although this is dependent on an effective method of presenting probabilistic projections.

Appendix 1 Interview design

Preamble (2-3minutes)

- Thank participant for taking part
- Go over project again briefly (any questions)
- Go over structure of Delphi and how this interview fits in
- Outline confidentiality
- Explain tape recording of interview
- Get final agreement for participation

1. **How long have you been in the business**
2. **How many trucks have and what area do you operate in**

Section 1 - General freight trends (15 minutes)

A. Do you consider day to day weather a hazard to the operation of your business and in what way if any has the weather affected your business in the past.

B. Where do you pull out

C. Ice Rain fog snow wind melting tarmac

D. Do you think the costs involved with disruption has increased in the last 20 years

11. Do you think freight transport is safer than 20 years ago?

- yes/no

12. What developments have lead to this? [perhaps show the accident rate graph]

- collect information on developments

[Explain future studies are relevant to climate change]

1. What aspect of your business do you plan the furthest for and why?

- Record qualitative data

2. How do you rate your confidence in these forecasts

> 0 1 2 3 4 5 6 7 8 9 10

[Could change scale]

3. How do possible changes in the economy of the country come into your planning?

- Collect data and try to identify any indicators

4. Do you think that your planning horizon is average in the industry?

- yes/no

5. If you think about the rest of the industry in this period what factors do you think are important in determining it's development and growth? [List in order]

GDP Environmental taxation new technology

Changes in the cost of freight transportation E-commerce

Freight Modal shift change of composition of GDP

Dematerialisation Links in the supply chain

Globablisation changing logistical structures

Improvements in the efficiency of vehicle routing Rate of spatial concentration

Regional development Sourcing of supplies

6. Do you think there are any other factors missing?

- Collect other factors

7. Explain why these factors are important [top three]

- collect the qualitative data

9. What is the furthest ahead that you think other businesses plan and what do you think allows or necessitates them to do this?

- Year/Types of businesses

8. Going back to those factors, which ones become more important for longer range planning? [Again, add any missing factors]

GDP Environmental taxation new technology

Increase in the cost of freight transportation E-commerce

Freight Modal shift change of composition of GDP

Dematerialisation Links in the supply chain

Globalisation changing logistical structures

Improvements in the efficiency of vehicle routing Rate of spatial concentration

Regional development Sourcing of supplies

10. If you were to hazard a guess at how the industry might grow in terms of approximate numbers of vehicles when would this become increasingly difficult?

10 20 30 40 50 60 years

Section 2 – Safety (10 minutes)

13. What do you consider the key factors determining the future safety of freight transport [list in order of importance + add]

Telematics   Road information   Vehicle body design   Trailer loading

Traction control   Weather forecasting   Automation

Speed limits   Road design   Winter road maintenance

14. How long to you think it will take for the general safety of vehicles to reach x% of it's current rate?

- years

Section 3 - Introduce socio-economic scenarios (5-10 minutes)

[The participants will be shown the standard BESEECH matrix along with a page of brief descriptions of each scenario along with a few key indicators. A discussion will then commence on their understanding of this concept and the relevance it has to their predictions]

Questions will include:

- Are they familiar with these scenarios [which groups within the sector think in this way?]

- Broadly speaking, what kind of impact if any do you think these would have on the predictions you have made [is it possible to quantify these as a percentage]

- Could you give a description of how you think the industry would respond to the socio-economic environment presented?

Appendix 2 THE IMPACTS OF CLIMATE CHANGE ON THE FREIGHT SECTOR
EXPERT-DELPHI - QUESTIONNAIRE 1

SECTION 1 – ABOUT YOU AND YOUR BUSINESS

How long have you worked in the freight and logistics industry Years
How many years have you worked in your company? Years
Have you ever driven a HGV as part of a job? Yes☐/No☐
How many goods/freight vehicles does your company operate?
Do you subcontract freight delivery to other companies? Yes☐/No☐
Do you use pallet systems in your logistical operations? Yes☐/No☐
Are you personally involved with your company's long term planning? Yes☐/No☐
How many employees are there in your current company?

SECTION 2 DAY TO DAY METEOROLOGICAL HAZARDS

2.1. We have previously asked experts in the industry to list different types of hazards caused by meteorological events in the order of their potential to cause road freight accidents where 1 is the most hazardous and 6 is the least.

1. Snow
2. Ice
3. Wind
4. Rain
5. Fog
6. Melting tarmac

Do you agree with the ranking above? Yes☐/No☐

If you do not agree, please indicate your own ranking above next to the hazards.

2.2. Using a scale of <u>1 to 5</u> where <u>1 is low and 5 is high</u>, please score the hazards for their potential to cause accidents and their potential to cause disruption and delay (which may not relate to accidents).

Meteorology	**Accident Potential**	**Disruption Potential**
Snow		
Ice		
Wind		
Rain		
Fog		
Melting tarmac		

2.3. From what you know about climate change, do you think the frequency of the hazards will change in the future? Please tick the appropriate boxes.

Meteorology	Significant increase	Increase	No change	Decrease	Significant decrease
Snow	☐	☐	☐	☐	☐
Ice	☐	☐	☐	☐	☐
Wind	☐	☐	☐	☐	☐
Rain	☐	☐	☐	☐	☐
Fog	☐	☐	☐	☐	☐
Melting tarmac	☐	☐	☐	☐	☐

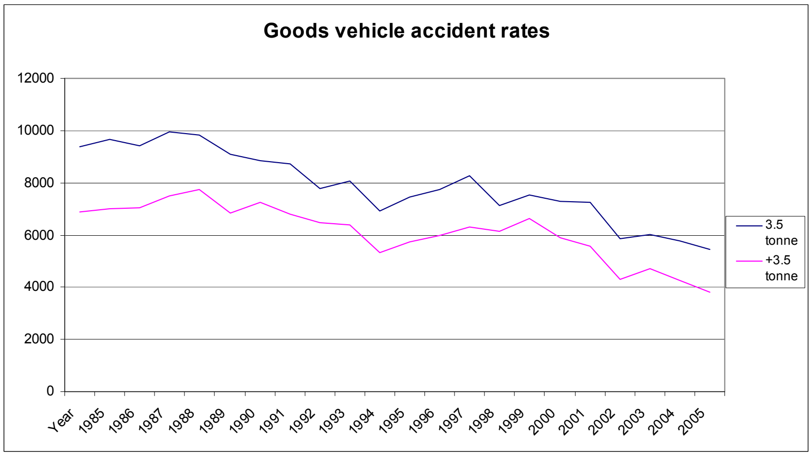
2.4. When do you believe climate change will begin to have a noticeable effect on the safety of the freight sector?

2020☐ 2030☐ 2040☐ 2050☐ 2060☐ 2070☐ 2080☐ Never☐

2.5. We are interested in identifying key infrastructure around the country which regularly presents a particular hazard during adverse meteorological conditions. Could you briefly list <u>up to four</u> stretches of the UK road network that your business regularly uses and describe the types of problems that occur.

Road stretch/route (e.g. M6 through lake district, A1 in North Yorkshire)	Type of hazard due to adverse meteorological conditions (e.g. snow; wind; fog etc.)	Type of problem caused (e.g. delay; road/bridge closure; increased risk of accident etc.)

2.6. There has been a decrease in accident rates caused by adverse weather conditions over the last 20 years, as shown in the diagram below. From previous interviews with experts we have ascertained various reasons why this has been the case.



Please rate each of the following reasons for the decrease in weather related accidents on a scale of <u>1-5</u> where, <u>5 is very important and 1 is not important</u>.

- Improvements in driver training
- Vehicle maintenance and safety regulations
- Improvements in vehicle technology
- Reduced working hours
- Reduced frequency of hazardous weather
- Improvements in severe weather warnings
- Improved road surface materials
- Improvements in winter road salting
- Other (Please state)

SECTION 3 FUTURE SAFETY TRENDS

3.1. Freight experts have expressed the view that the trend of reducing accidents caused by meteorological hazards will continue in the future. Do you agree with this view? (Assume that the frequency of hazards stays fixed and any changes come from changes in safety and behaviour)

Yes☐/No☐

If 'no' why not?

3.2. If you agree with a further reduction in weather related accidents by 2020, what level of further reduction is possible?

5%☐ 10%☐ 20%☐ 30%☐ 40%+☐

3.3. Please rate each of the following factors in terms of their importance in reducing accidents in the future, using a scale of 1-5, where 1 is not important and 5 is very important.

Factor	**Importance**
Improved vehicle body design	
Further speed limits	
Improved winter road maintenance	
Better forecasts	
Improved vehicle maintenance regulations	
Improved road surface design	
Improved vehicle braking technology	
Distance sensors for low visibility	
Further integration of weather forecasts with telematics	

Are there any other important factors that would lead to accident reduction? Please list these below and rate how important you consider them to be.

3.4. Please indicate how likely it is that significant improvements will be achieved in the following factors by 2020. Please tick the relevant boxes.

Factor	**Highly likely**	**Likely**	**Unlikely**	**Highly unlikely**
Improved vehicle body design	☐	☐	☐	☐
Further speed limits	☐	☐	☐	☐
Improved winter road maintenance	☐	☐	☐	☐
Better forecasts	☐	☐	☐	☐
Improved vehicle maintenance regulations	☐	☐	☐	☐
Improved road surface design	☐	☐	☐	☐
Improved vehicle braking technology	☐	☐	☐	☐
Distance sensors for low visibility	☐	☐	☐	☐
Improved electronic road side information signs	☐	☐	☐	☐
Integration of weather forecasts with telematics	☐	☐	☐	☐

If there you can identify any other factors please list these and identify the likelihood of these happening.

Factor	Highly likely	Likely	Unlikely	Highly unlikely
	☐	☐	☐	☐
	☐	☐	☐	☐
	☐	☐	☐	☐

SECTION 4 - FUTURE TRENDS IN THE FREIGHT AND LOGISTICS SECTOR

4.1. We asked experts about their views on trends within the industry between now and 2020. Please indicate the extent to which you agree with the following statements.

Freight transport will move towards larger vehicles such as double-decker trucks	**Strongly Agree** ☐	**Agree** ☐	**Disagree** ☐	**Strongly Disagree** ☐
Pallet systems will become more widespread within the industry	☐	☐	☐	☐
The average journey leg length across the industry will decrease	☐	☐	☐	☐
Cleaner fuel technologies will be adopted	☐	☐	☐	☐
More long distance freight will be taken by train	☐	☐	☐	☐
Fuel price will be the key determining factor in the growth of the industry	☐	☐	☐	☐
There will be a decrease in the number of small hauliers	☐	☐	☐	☐
Climate change will have no impact on the industry by 2020	☐	☐	☐	☐
Government schemes will be introduced to improve infrastructure	☐	☐	☐	☐
The growth of just-in-time delivery will continue	☐	☐	☐	☐
Tighter margins and customer demands will increase the costs associated with delays.	☐	☐	☐	☐
New technology and computer systems will allow freight operations to become more efficient	☐	☐	☐	☐
There will be a trend towards more centralised logistical distribution centres	☐	☐	☐	☐

4.2. Please identify the three most significant likely changes in the nature of UK freight and logistics operation in the UK between now and 2020.

4.3. Other experts have indicated that the number of freight vehicles on the road will increase by 2020, do you agree with this statement?

Yes☐/No☐

4.4. If you agree, please indicate the likely % increase in the number of freight vehicles on the road by 2020

%

4.5. If you disagree, please indicate the likely % decrease in the number of freight vehicles on the road by 2020

%

SECTION 5 LONGER TERM TRENDS

5.1. Finally, we have taken the year <u>2050</u> and asked other experts what they believe will be the important developments influencing growth in the sector between now and then. We have listed these factors below. Could you please indicate how important you believe each of these to be on a scale of <u>1-5</u>, <u>where 1 is not important and 5 is very important.</u>

Factor	**Score**
The growth of the economy	
Environmental taxation	
Automated vehicles	
Changing Logistical structures	
Reduction in size and weight of goods	
Climate change	
Regional development	
Improvements in vehicle routing	
Changing costs of transportation	
Globalisation	

5.2. Are there any other factors which will influence the freight industry in the long term (out to 2050)?

5.3. When we are considering changes over long time periods such as 2050, it is useful to think of different potential scenarios reflecting possible governance systems and values of the time. It is impossible to predict with any degree of certainty how the sector will develop in the next 40 years, but we can imagine what the country might look like in 2050 and the impacts on freight transport. Below we present one possible scenario for 2050.

World markets scenario

In this scenario globalisation is the dominant driving factor of change in the country. There will be a liberalisation of national and international markets along with a dismantling of trade barriers and a retreat of the state along with increased privatisation. This scenario will lead to a high rate of growth of 3.4%. Population will increase to 70 million.

This scenario sees rapid structural changes in the economy with the service sector, including financial services, healthcare and education, leisure, distribution and transportation dominating overall economic activity. Agriculture and mining decrease rapidly. Traditional forms of manufacturing decline substantially with an increase in high-tech manufacturing such as IT. Spatially, London dominates economic activity, with high regional disparities across the rest of the country.

There will be rapid innovation in technologies for the built environment. Under a World Markets regime, overall transport demand is greatly increased. This increased traffic is more efficiently managed using new control systems and would run on better quality infrastructure.

Summary of the world markets scenario

- Globalisation
- Freer trade
- High economic growth rates
- Increase in UK population to 70 million
- Structural change in economy
- Overall transport demand increases
- Innovative infrastructure

- Better traffic control system

5.2. Do you consider realisation of this scenario would promote growth in the freight and logistics sector?

Yes☐/No☐

5.3. If 'yes', which of the factors identified in the summary above would most promote this growth? (list no more than 3)

5.4. If you do not think this scenario will promote growth, why not ?

5.5. Do you believe realisation of a world markets scenario would lead to developments that would reduce accident rates?

Yes☐/No☐

5.6. If 'yes' what do you imagine these developments will be?

5.7. If you think this scenario does not promote increased safety, what are the reasons?

5.8. If you think back to your answer for question 3.2 regarding the potential accident rates in 2020, how do you think accident rates in 2050 will compare?

Decreаse significantly Decrease No change Increase Increase significantly

☐ ☐ ☐ ☐ ☐

5.9. Similarly, if you think back to your answer to question 4.4 regarding the potential change in the number of freight vehicles operating in the UK in 2020, how do you think this figure will change by 2050?

Decrease significantly	Decrease	No change	Increase	Increase significantly
☐	☐	☐	☐	☐

SECTION 6 OTHER COMMENTS

If you have any further comments that you would wish to make about the issues discussed in this questionnaire please make these below.

____

Although all responses will be treated in strict confidence it would be useful to have your contact details in case of any queries about your response.

Name:
Contact telephone number:
Email:
Address:

THANK YOU FOR YOUR TIME

Appendix 3

THE IMPACTS OF CLIMATE CHANGE ON THE FREIGHT SECTOR
EXPERT-DELPHI - QUESTIONNAIRE 2

Dear Sir/Madam

Thank you for your valuable help with the first stage of our expert Delphi questionnaire. This second questionnaire is based on the responses we received from the 10 participants. It seeks a consensus view from the group, and also tries to gain insight into disagreements that occurred. To save your time we have focused only on sections which raise points of interest. These include views on the growth in vehicle numbers by 2020, the reduction in weather related accidents by 2020 and further changes in the industry by 2050.

We hope that all the instructions are clear, but if you have any difficulties you are welcome to contact me with your query. When you have completed the questionnaire, please email it back to me by Monday the 23rd of March.

Yours Thankfully

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SECTION 1 – What the Freight Network will Look Like by 2020

1. We asked what would be the likely trends in the industry between now and 2020. The picture that emerged was one where the majority of experts agreed that we will see:

- Cleaner fuel technologies being adopted
- Freight transport moving towards larger vehicles
- Little new investment in infrastructure
- An increased number of freight vehicles on the road
- Further growth in just in time deliveries
- Increased costs associated with delays
- Technology making freight more efficient
- Increased adoption of pallet systems
- A further trend towards centralised logistical distribution centres

However, the following statements generated the most disagreement amongst respondents:

A) "The average journey leg length in the industry will decrease"
Please say why you Agree☐/Disagree☐ with this statement

B) "More long distance freight will be taken by train"
Please say why you Agree☐/Disagree☐ with this statement

C) "Fuel price will be the key determining factor in the growth of the industry"
Please say why you Agree☐/Disagree☐ with this statement

D) "There will be a decrease in the number of small hauliers"
Please say why you Agree☐/Disagree☐ with this statement

2. Furthermore, when asked about the growth or decline in the number of freight vehicles on the road by 2020, most experts stated that an increase of **10 to 20%** was likely, although one respondent argued that the number would reduce by 10% another by 4%. Do you agree or disagree with this view of a 10-20% increase and why? **Agree**☐/**Disagree**☐

3. The fellow experts also predicted a **10 to 20%** fall in weather related accidents by 2020. Related to this, results of the first round also showed that following safety developments were considered likely between now and 2020. Which **three** do you view as the most important in achieving this reduction in weather related accidents and why?

- Improved vehicle body design☐
- Further speed limits☐
- Improved winter road maintenance☐
- Better forecasts☐
- Improved vehicle maintenance regulations☐
- Improved road surface design☐
- Improved vehicle braking technology☐
- Distance sensors for low visibility☐
- Integration of weather forecasts with telematics☐

4. What are your reasons for limiting the reduction in weather related accidents to 10-20%?

5. The global financial and economic crisis has had large scale and rapidly increasing impacts on the UK economy during the course of the last 12 months. Do you believe this has made your assessment of the future of the industry by 2020 **more pessimistic** than it would have been 12 months ago?

A) Future growth in the industry: Not at all☐ slightly☐ Very much so☐

B) Future improvements in safety: Not at all☐ slightly☐ Very much so☐

SECTION 2 – What the Freight Network will Look Like by 2050

In the previous round we asked you to consider how the industry might change by 2050 if certain trends were to arise between now and then. We focussed on World Markets Scenario. As a recap we have produced a summary of this scenario below. Under a World Markets Scenario will look as follows:

- A strong and continued trend towards globalisation
- Freer international trade
- High economic growth rates of around 3.4% per annum
- A large increase in the population of the UK to 70 million
- Structural change in economy away moving further away from manufacturing and more towards services and high technology.
- An overall increase in the demand for transport
- Large scale investment in new innovative infrastructure
- Better traffic control system

6. When we asked whether this scenario would promote growth in the freight and logistics industry **all but one respondent argued that it would**. All but one also said that there would be an **increase in the number of freight vehicles** on the road compared to the figure they gave for 2020.

If you were to give an indication of how many more vehicles on there will be on the road under this scenarios by 2050 compared with today what percentage do you think the increase/decrease will be? Why do you think this scenario promotes an increase decrease?
Increase☐ / Decrease☐

A) 10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%☐90%☐100%

Why?

7. Likewise, **all respondents** believed that there would be a further decrease in the number of weather related road freight accidents from the figure they gave for 2020. What do you think this reduction will be compared to today and why does this scenario promote a decrease in road accidents?
10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%

Why?

8. For the remainder of this questionnaire we will briefly present three more possible scenarios for the development of the country by 2050. This will all have potentially different outcomes on the form of the freight network and its operations. The second scenario we can consider is **National Enterprise**. Under this scenario:

- The UK remains more autonomous, resisting the transfer of sovereignty to global and European institutions.
- Although markets are still favoured by the state, the government will intervene to protect national interests.
- Low priority on environmental measure; they are seen to impede economic development
- Protectionism causes low economic growth rates and reduces exports.
- There will be a decline in manufacturing
- Lack of investment in infrastructure means many roads operate at full capacity
- New vehicle technologies such as informatics are introduced only at the top end of the market.
- Little investment in the rail system, freight continues to be moved mainly by road.

Given this information, do you think that the number of vehicles on the road will grow by 2050 compared to today's figure, and considering your answer to the growth in 2020?
Increase☐ / Decrease☐ / Stay the same ☐

B) 10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%☐90%☐100%

Why?

9. Do you believe that this scenario would promote a further reduction in weather related accidents, or would there be an increase? Why do you think this is?
Reduction☐ / Increase☐ / Stay the same☐

10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%

Why?

10. The third scenario is Local Stewardship, a move towards environmental protection and a move away from international trade. Under this scenario:

- Economic growth is not an absolute political priority.
- The conservation of resources and the protection of the environment are strong political objectives.
- Decision making devolved to regional powers.
- Economic growth is relatively slow
- Small and medium-sized enterprises in the manufacturing sector prosper.
- Agriculture regains national importance
- Greater emphasis on regional development
- Urbanisation slows down
- There is a general migration away from larger cities and a corresponding growth of small and medium sized towns.
- Overall transport volume decreases.
- Transport sector affected by a major slowdown in the growth of trade and demand for mobility.
- Transport costs rise sharply due to high energy prices
- Vehicles based on low emission technology (fuel cells, electricity, hybrids) are commonly used

Given this information, do you think that the number of vehicles on the road will grow compared to today's figure?
Increase☐ / Decrease☐ / Stay the same ☐

C) 10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%☐90%☐100%

Why?

11. Do you believe that this scenario would promote a further reduction in weather related accidents, or would there be an increase? Why do you think this is?
Reduction☐ / Increase☐ / Stay the same☐
10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%

Why?

12. The final scenario is **Global Sustainability**. In terms of environmental protection, this scenario is an intermediary between World Markets and Local Stewardship, balancing economic growth with green issues. Under this scenarios:

- Loss of some power over monetary, defence, social and environmental policy at the UK level to the European Union.
- Working towards sustainable development is a political priority
- Average economic growth
- Evenly distributed regional development
- Greener industry with less manufacturing
- There is heavy investment in new infrastructure
- Modernisation and restructuring of freight and passenger transport is started.
- This should form an integrated system with an increased proportion of public road and rail transport.
- Eco-efficient vehicles are introduced.
- Investment in electronic communication technology as a substitute for travel.
- New roads, rail and airport infrastructures are built, with priority given to minimising their environmental impacts.
- The cost of transport rises substantially.

Given this information, do you think that the number of vehicles on the road will grow compared to today's figure?
Increase☐ / Decrease☐ / Stay the same ☐

D) 10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%☐90%☐100%

Why?

13. Do you believe that this scenario would promote a further reduction in weather related accidents, or would there be an increase? Why do you think this is?
Reduction☐ / Increase☐ / Stay the same☐

10%☐20%☐30%☐40%☐50%☐60%☐70%☐80%

Why?

14. How likely do you think each of these scenarios are on a scale of 0 to 10, with 0 being certain not to happen and 10 being definite of happening. Why

World markets scenario

0☐ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ 8☐ 9☐ 10☐

National Enterprise

0☐ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ 8☐ 9☐ 10☐

Global Responsibility

0☐ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ 8☐ 9☐ 10☐

Local Stewardship

0☐ 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ 8☐ 9☐ 10☐

13. What are the reasons for choosing your selections for least and most likely.

15. Finally, which scenario would you most like to see become reality and why?

World Markets☐National Enterprise☐Local Stewardship☐Global Sustainability☐

OTHER COMMENTS

If you have any further comments that you would wish to make about the issues discussed in this questionnaire please make these below.

Although all responses will be treated in strict confidence it would be useful to have your contact details in case of any queries about your response.

Name:

Contact telephone number:

Email:

Address:

Appendix 4 Relationship equations (summer precipitation)

P = precipitation anomaly

South East

Summer accidents = (1.77 x P + 102.9)

East Midlands

Summer accidents = (0.825 x P + 41.7)

West Midlands

Summer accidents = (0.876 x P + 57.9)

North West

Summer accidents = (1.443 x P + 86.7)

North East

Summer accidents = (0.231 x P + 21.3)

Eastern

Summer accidents = (0.942 x P + 46.8)

Yorkshire and the Humber

Summer accidents = (0.756 x P + 35.7)

London

Summer accidents = (0.51 x P + 53.7)

Scotland
Summer accidents = (0.909 x P + 21.9)

Wales
Summer accidents = (0.477 x P + 15.6)

South West
Summer accidents = (1.005 x P + 12.6)

Relationship equations (winter precipitation)

P = precipitation anomaly

South East
Winter accidents = (2.64 x P + 375)

East Midlands
Winter accidents = (0.618 x P + 237)

West Midlands
Winter accidents = (1.113 x P + 213)

North West
Winter accidents = (1.209 x P + 279)

North East
Winter accidents = (0.183 x P + 108)

Eastern
Winter accidents = (0.744 x P + 285)

Yorkshire and the Humber
Winter accidents = (0.747 x P + 213)

London

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