Guidebook for Enhancing Resilience of European Road Transport in Extreme Weather Events
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List of Abbreviations

DfT: Department for Transport (UK)
DOT: Department of Transport (U.S.)
EC: European Commission
EEA: European Environment Agency
ERA-NET: European Research Area Network
ESP: Electronic Stability Programme
EWENT: Extreme Weather impacts on European Networks of Transport
FHWA: Federal Highway Administration (U.S.)
FMI: Finnish Meteorological Institute
LPI: Logistics Performance Index
MDSS: Maintenance Decision Support System
METRo: Model of the Environment and Temperature of Roads
NWP: Numerical Weather Prediction
PIARC: Permanent International Association of Road Congress (= World Road Association)
RDS: Radio Data System
RIMAROCC: Risk Management for Roads in a Changing Climate
RTD: Research and Technical Development
RWIS: Road Weather Information System
RWM: Road Weather Forecast Model
RWS: Road weather station
SME: Small and medium sized enterprise
SMS: Short message standard
TMC: Traffic Message Channel
TRB: Transportation Research Board
U.S.: United States (of America)
UK: United Kingdom
VMS: Variable message sign

WEATHER: Weather Extremes: Assessment of Impacts on Transport and Hazards for European Regions
The MOWE-IT project: The goal of the MOWE-IT project is to identify existing best practices and to develop methodologies to assist transport operators, authorities and transport system users to mitigate the impact of natural disasters and extreme weather phenomena on transport system performance. The project is funded by the European Commission’s 7th RTD framework programme between October 2012 and September 2014. MOWE-IT is co-ordinated by the Technical Research Centre Finland (VTT) and involves 12 European research institutes and companies. For more details please consult our website www.mowe-it.eu.

This guidebook pulls together recent knowledge and good practice cases on the risk of severe weather events in the current and future climate impose on the road transport sector and how they can be tacked best with short and long-run strategies. Despite concentrating on European cases, events and solutions worldwide have been analysed to enrich the knowledge basis as far as possible.

This guidebook in first place is written for the use by policy-makers, public authorities and transport professionals. Namely it addresses weather data services, road operators, local bus and coach undertakings as well as haulage companies and their customers. Private road users are addressed, but rather to inform road operators on their behavioural patterns than to provide advice to private users directly.

This guidebook intents to highlight a number of interesting issues to be considered when planning services and strategies in the sort and long run, rather than providing a full overview of all aspects of risk management and mitigation strategies. To go deeper into detail, the reference section of this document contains several sources, including meteorological data, procedural guidelines and norms and standards for further reading.

1. Threats – the Meteorological Science Basis

1.1 The general picture on weather extremes

Prevailing weather conditions may have large impacts on societies in many parts of Europe. For instance, during wintertime, cold spells with snowfall can cause slippery conditions, resulting in problems affecting the transport sector, as was the case during the winters of 2009/10 and 2010/11 in Northern Europe. Dense snowfall can cause simultaneous decrease of visibility and road surface friction, which can trigger severe pile-ups on highways. Intensive winter storms, which are typically formed over the North Atlantic Ocean and move over Western, Central or Northern Europe, can also cause heavy precipitation (snowfall as well as rainfall) and violent wind gusts resulting in substantial damages. In addition, heavy rain and melting snow can lead to flooding, especially when ground water reserves are at high level. Furthermore, extreme heat and wind have a significant impact on road management through damages like deterioration of pavement and wind gusts.

Due to a changing climate it has to be expected that the patterns of severe weather events change to some degree. Various severe weather events occurring over the European continent have a potential to impact the European road transportation networks. Due to locally varying conditions, these events are more frequent in some regions than in others. However, their potential to have a significant impact on road transport depends also on the awareness of the road stakeholders and authorities.

With this guidebook, we intend to provide a short overview of the most important weather phenomena and their characteristics. The characteristics of the selected events were analyzed
within the framework of the EWENT project. The most important weather events for road transportation are listed in Table 2.1, including information on their geographical and seasonal relevance; the expected changes until the 2050s (and 2020s, if significantly different); typical duration and warning times and their impact on road transportation networks. It has to be noted that regional climate models cannot reproduce all weather events with the same accuracy and results partially disagree between the models. Purely temperature related phenomena (heat and cold waves) can be reproduced fairly well, while dynamic phenomena (winds and precipitation) are more challenging. Small-scale phenomena such as thunderstorms, blizzards and fog cannot be fully resolved by current models, thus changes in these phenomena have to be retrieved using indirect methods, implying additional uncertainties. The listed impacts represent the direct, weather-induced consequences, which in turn have the potential to cause delays, increased accident rates and temporary road closures.

Table 1: The most important severe weather events by geographical and seasonal relevance, changes until the 2050s (2041–2070), duration and warning time and main impacts.

<table>
<thead>
<tr>
<th>Extreme weather event</th>
<th>Geographical and seasonal relevance</th>
<th>Likely changes until the 2050s</th>
<th>Duration and warning time</th>
<th>Impact on road transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat waves</td>
<td>Most frequent and extreme in southern Europe, especially Iberian Peninsula, Greece Turkey; Common in central and eastern Europe; Summer phenomenon</td>
<td>Significant increase in the probability of hot days across Europe, especially in currently hot regions</td>
<td>Depending on the region – from days to several weeks; Several days of warning time</td>
<td>Damage of pavement; Vehicle failure (Tyres); Forest fires; Fatigue among the drivers</td>
</tr>
<tr>
<td>Cold waves</td>
<td>Most frequent and extreme in Scandinavia and alpine regions; Decrease toward south; Winter phenomenon</td>
<td>General decrease all over Europe, especially in currently most affected areas</td>
<td>Depending on the region – from days to several weeks; Several days of warning time</td>
<td>Reduced surface friction; Road maintenance; Technical failure of vehicles and infrastructure; Deterioration of pavement</td>
</tr>
<tr>
<td>Heavy precipitation (large-scale systems)</td>
<td>Most frequent in southwestern Norway, Alps, Gulf of Genoa and British Isles; All year phenomenon with strongest events mostly during winter</td>
<td>Slight mean increase for most regions; Slight decrease in some Mediterranean areas; Climate models disagree to some extent</td>
<td>Duration of several hours to days; Warning time of days</td>
<td>Reduced visibility and surface friction; Floods and landslides</td>
</tr>
<tr>
<td>Snowfall</td>
<td>Most frequent in northern Europe, alpine regions, eastern Europe; Relevant also for southern Europe; Winter phenomenon</td>
<td>Overall decrease in snowfall events over Europe strongest in northern Europe; More frequent strong events over the Scandes and parts of eastern Europe</td>
<td>Duration between hours and several days; Warning time of days</td>
<td>Reduced visibility and surface friction; Obstacles on roads due to snowdrift and broken branches</td>
</tr>
<tr>
<td>Large-scale storms and wind</td>
<td>Most affected areas are the British Isles, Iceland and the western coastal areas; Relevant for the whole continent; Strongest events occurring during winter months</td>
<td>Slight increase in most western, central and southern European regions for the 2020s, decrease over the inland Iberian Peninsula and eastern Europe; General decrease for the 2050s; Climate models disagree to some extent</td>
<td>Duration of several hours up to days; Warning times of days</td>
<td>Difficult driving conditions due to gusts; Obstacles on the road due to fallen trees and other objects</td>
</tr>
</tbody>
</table>
1.2 The spatial dimension of adverse weather events

Table 1 reveals that the current level as well as the potential future developments of weather threats to road transport, which strongly differ between regions. While some regions are characterized by specific events, such as the Mediterranean area that is threatened by increased heat waves, other regions are subject to multiple risks.

In the EWENT project, impact indices (thresholds) for different weather events affecting transportation were defined. The definition work was based on (1) a literature survey covering more than 150 research articles and/or reports, (2) a "media database" consisting of approximately 190 cases of different weather events affecting transportation, and (3) selected case-studies (Leviäkangas et al., 2011; Vajda et al., 2013). Three threshold values were defined for different weather parameters (see Table 2), based on the severity of identified impacts. In general, it can be said that when the first threshold is reached, harmful impacts are possible, while with the second and third thresholds imply likely and certain harmful impacts respectively.
Table 2: The impact thresholds for different weather events affecting transportation (Vajda et al., 2011 and 2013). Abbreviations: Rs = snowfall amount, Tmean = daily mean temperature, Tmax = daily maximum temperature, R = rainfall, WG = 3-second wind gust.

<table>
<thead>
<tr>
<th>EVENTS</th>
<th>THRESHOLDS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
</tr>
<tr>
<td>Snowfall</td>
<td>Rs ≥ 1 cm/24h</td>
</tr>
<tr>
<td>Cold spell</td>
<td>Tmean ≤ 0 °C</td>
</tr>
<tr>
<td>Heat wave</td>
<td>Tmax ≥ 25 °C</td>
</tr>
<tr>
<td>Heavy rainfall</td>
<td>R ≥ 30 mm/24h</td>
</tr>
<tr>
<td>Wind gust</td>
<td>WG ≥ 17 m/s</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
</tr>
<tr>
<td>Snowfall</td>
<td>Rs ≥ 10 cm/24h</td>
</tr>
<tr>
<td>Cold spell</td>
<td>Tmean ≤ -7 °C</td>
</tr>
<tr>
<td>Heat wave</td>
<td>Tmax ≥ 32 °C</td>
</tr>
<tr>
<td>Heavy rainfall</td>
<td>R ≥ 100 mm/24h</td>
</tr>
<tr>
<td>Wind gust</td>
<td>WG ≥ 25 m/s</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
</tr>
<tr>
<td>Snowfall</td>
<td>Rs ≥ 20 cm/24h</td>
</tr>
<tr>
<td>Cold spell</td>
<td>Tmean ≤ -20 °C</td>
</tr>
<tr>
<td>Heat wave</td>
<td>Tmax ≥ 43 °C</td>
</tr>
<tr>
<td>Heavy rainfall</td>
<td>R ≥ 150 mm/24h</td>
</tr>
<tr>
<td>Wind gust</td>
<td>WG ≥ 32 m/s</td>
</tr>
<tr>
<td>Blizzard</td>
<td>Rs ≥ 10 cm/24h, Tmean ≤ 0 °C, WG ≥ 17 m/s</td>
</tr>
</tbody>
</table>

These impact indices (thresholds) were then used to calculate the frequencies of different harmful weather events in different parts of Europe, in the present and future climate (Vajda et al., 2011). For example, the spatial and temporal variation of low temperature was studied using the three defined impact thresholds for daily mean temperature: 0 °C, -7 °C and -20 °C. The results are shown in Figure 1. Events fulfilling the first threshold, 0 °C, can occur in most parts of Europe, but naturally the frequency of these events increases when moving towards the northeast. Extremely cold days (Tmean ≤ -20 °C) are experienced mainly in Northern Europe. Based on the frequency analyses of the “high impact” weather events presented in Table 2, regions that show a similar behavior of adverse weather events can be separated, thus forming a basis for the classification of climatic regions in Europe from a transportation point of view (Figure 2). The regions considered herein are: (1) the Northern European (sub-arctic) region dominated by cold spells and frequent snowfalls; (2) the Maritime (oceanic) region - strong winds and floodings; (3) the Mediterranean region - heat waves; (4) the Alpine (mountainous) region - snowfall, extreme winds and heavy precipitation; (5) the Temperate Central and (6) Temperate Eastern European regions, characterized by the sporadic occurrence of several types of adverse weather rather than any particular weather phenomena (Vajda et al., 2013).
Figure 1: Average number of days per year with daily mean temperature below: (a) 0 °C, (b) -7 °C and (c) -20 °C, during the period 1971-2000 based on E-OBS data (Vajda et al., 2011 and 2013)

Figure 2 is based on the work done in EWENT and is from an article just published in Nat Hazards (Vajda et al., 2013). It shows in a general way the climatic regions in Europe from the transportation point of view.
Figure 2: Classification of climate regions based on the frequency analyses of different adverse weather phenomena affecting transportation (Vajda et al. 2013, in Nat Hazards).

2. Road Weather Management

Risk management is a process of identifying, understanding, managing, controlling, monitoring and communicating risk. Effective risk management is the key to facilitating and building resilience, particularly when driven at the corporate level to create a culture where resilience and business continuity management is embedded in operations. This creates “organizational resilience” — the ability of an organization to anticipate, plan and respond to uncertainties and disruptions to business operations (Cabinet Office 2011). For road managers this section highlights some key issues associated with the management of road networks in proportion to the risks faced.

2.1 Risk mapping for road networks

To ensure safe and comfortable travel, the road transport management sector must be prepared against adverse weather phenomena. This calls for a sufficient weather observation network and skillful numerical weather prediction models to forecast the expected weather and road conditions with high accuracy and sufficient warning times. Good co-operation and coordination between all involved authorities, as well as effective communication and exchange of information are needed to mitigate the impacts of harmful weather. Of importance is also the clear definition of responsibilities of all parties in emergency situations in order to achieve coordination and, not to lose time for mitigation measures. The awareness of the public on how to behave under extreme
weather conditions is also important. All these points have to be taken into account to establish an effective operational framework for road management and weather services.

The 2012 report of the World Road Association (PIARC, 2012) on climate change impacts on road pavements reveals that most countries are concerned with increased flooding. Overall, short and long term impacts of climate change may necessitate more frequent maintenance and reconstruction. Road owners should thus invest in systematic asset vulnerability assessment. Resulting from the risk mapping, design of new infrastructure, maintenance procedures for existing infrastructures as well as operational procedures and customer communication strategies may have to be adapted.

Recent research and support activities developed a number of risk assessment tools, which are available to road authorities and which provide advice on the usefulness and costs of various measures to improve resilience. These are the RIMAROCC methodology developed by the ERA-NET ROAD program (cp. RIMAROCC 2009) and the CAPTA model (NCHRP 2009) prepared by the U.S. Transportation Research Board. For practical applications, reference to a number of advanced countries is recommended as resilience planning starts at very basic levels of organizing information exchange between agencies or collection of fundamental asset condition data. Good examples can be found in Switzerland with its publicly operated but regionalized road network, and Finland with a system of public-private maintenance contracts. Moreover, the UK constitutes an interesting case as here the learning and adaptation process during the three consecutive harsh winter seasons 2008/09, 2009/10 and 2010/11 and following years have been documented by the Department of Transport (Dft 2009 and 2010, UKRLG 2009, RAC Foundation 2013).

According to PIARC (2012a) typical steps for assessing risks and vulnerability in the road network consist of five steps:

1. Assess climate trends and degrees of uncertainty with relevance for the regional road network.
2. Identify current and future vulnerability of the road network
3. Develop adaptation action plans by identifying and assessing available options to respond to risks
4. Implement adaptation action plans
5. Monitor and evaluate the interventions on a regular basis

Proper risk mapping is inevitable in particular for flood risks, but often lacking (SWAMP 2010). The study concludes that most countries prefer to adapt the design of new roads rather than elaborate concepts on how to deal with existing networks. Given the demographic development in Europe, which results in stagnating or even declining transport demand volumes, the maintenance of existing roads should gain more attention. Tools for analyzing risks of extremes on a local level are e.g. provided by the European Commission’s Joint Research Centre for floods (JRC ), the European Severe Storms Laboratory (ESSL) or the European Climate Assessment and Database (ECA&D).

Disruptions in the transport system often result in undesirable impacts for the road users. The importance of this fact is best reflected in cases of emergency, when people need to travel facing the least possible degradations of the system. Especially during extreme weather events instances, the components of a network gain additional importance, due to rising safety issues. It is therefore crucial for authorities to identify where the most vulnerable components of a network are, in order to protect or enhance their operation (Stamos et al., 2013). In this direction, Nagurney and Qiang (2008) propose a methodology for calculating criticality of network links, using the total demand of the network and the difference in the travel time as consequence of the closure of a link. Figures 1-3 show an application of this methodology in the road network of Peloponnesus, Greece, which was severely affected by the 2007 wildfires.
The left map in Figure 3 depicts the occurrence rate of each closed link of the road network for the four days the wildfires lasted. In addition, the right map depicts the efficiency (i.e., criticality) of each road network link that closed during 8 and 9 pm on the 26th of August, 2007.

A similar analysis has been conducted for the national road network of southern Peloponnesus, in an effort to identify the importance of each link and the extent to which the network would have been affected, had it been closed due to extreme circumstances. The outcomes are presented in Figure 4. These analyses are important at a planning level, as they provide authorities with a tool that identifies the network components (road links) whose operation has to remain uninfluenced, especially in cases of extreme weather events. As such, this tool can assist public authorities in preventing or limiting the negative impacts attributed to road closures, by ensuring traffic circulation through the identified critical road links (Mitsakis et al., 2013).
2.2 Road Weather Information Systems

Operational automated Road Weather Information Systems (RWIS) are an integral part of the road weather management and have been developed to provide precise real time information about prevailing local weather and road conditions. Road Weather Information Systems allow an automated collection of data, where the used types of RWIS (sensors) can be divided in more general and specialized ones. Regarding the gathered information the distinction can be made as follows (Papanikolaou et.al, 2011, PIARC 2010)

- General RWIS: measurement of key weather information, e.g. air temperature and humidity, road surface temperature and wind speed
- More specialized RWIS: besides the measurement of key weather information, they provide e.g. data of road depth temperature, road surface conditions and the intensity of precipitation, in some cases they are also equipped with video cameras

RWIS are used mainly for maintenance operations in winter time and can provide the following information:

Table 2: RWIS data (taken from Papanikolaou et.al, 2011)

<table>
<thead>
<tr>
<th>Weather data</th>
<th>Surface data</th>
</tr>
</thead>
<tbody>
<tr>
<td>air temperature</td>
<td>pavement temperature</td>
</tr>
<tr>
<td>amount and type of precipitation</td>
<td>subsurface temperature</td>
</tr>
<tr>
<td>visibility</td>
<td>surface condition (dry, wet, frozen)</td>
</tr>
<tr>
<td>dew point</td>
<td>amount of deicing chemical on the roadway</td>
</tr>
<tr>
<td>relative humidity</td>
<td>freezing point of the road surface</td>
</tr>
<tr>
<td>wind speed and direction</td>
<td></td>
</tr>
</tbody>
</table>

In the past, the decisions about necessary actions (e.g. on gritting and salting) were the responsibility of the road maintenance personnel. But this can be a stressful task and there is always a possibility for making the wrong decision (Gustafsson et al., 2008). With the development of the RWIS the decision making process was shifted to the weather service providers. However, timing of pre-salting of road surfaces, for instance, is a highly essential operation in this undertaking, which requires accurate road weather forecasts with sufficient warning times.

Concerning the preparedness against severe windstorms, the pre-warning time is preferably days instead of hours, so that enough staff can be on alert, e.g. for winter road maintenance or to remove fallen trees. Heavy rainfall can result in flooding and closure of roads. Then, alternate routes for the traffic flow should be suggested. In vulnerable areas it is helpful to classify areas based on indicators related to probabilities of flooding. In this case by-pass routes for run-off water should also be considered.

To ensure an efficient and effective road management, the establishment of a common crisis management (including businesses, public and private road users) and the introduction of contingency plans are necessary. An overview of the benefits of RWIS is given in Table 3 (cp. Papanikolaou et.al, 2011).
<table>
<thead>
<tr>
<th>RWIS-Enabled Practice</th>
<th>Associated Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-icing</td>
<td>Lower material costs</td>
</tr>
<tr>
<td></td>
<td>Lower labor costs</td>
</tr>
<tr>
<td></td>
<td>Higher level of service (improved road conditions), travel time savings, and improved mobility</td>
</tr>
<tr>
<td></td>
<td>Improved safety (fewer crashes, injuries, fatalities, property damage)</td>
</tr>
<tr>
<td></td>
<td>Reduced equipment use hours and cost</td>
</tr>
<tr>
<td></td>
<td>Reduced sand cleanup required</td>
</tr>
<tr>
<td></td>
<td>Less environmental impact (reduced sand runoff, improved air quality)</td>
</tr>
<tr>
<td></td>
<td>Road surfaces returned to bare and wet more quickly</td>
</tr>
<tr>
<td></td>
<td>Safe and reliable access, improved mobility</td>
</tr>
<tr>
<td>Reduced Use of Routine Patrols</td>
<td>Reduced equipment use hours and cost</td>
</tr>
<tr>
<td></td>
<td>Improved labor productivity</td>
</tr>
<tr>
<td>Cost-Effective Allocation of Resources</td>
<td>Increased labor productivity</td>
</tr>
<tr>
<td></td>
<td>Reduced weekend and night shift work</td>
</tr>
<tr>
<td></td>
<td>Improved employee satisfaction</td>
</tr>
<tr>
<td></td>
<td>Reduced maintenance backlog</td>
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<tr>
<td></td>
<td>More timely road maintenance</td>
</tr>
<tr>
<td></td>
<td>Reduced labor pay hours</td>
</tr>
<tr>
<td></td>
<td>Overall higher level of service</td>
</tr>
<tr>
<td></td>
<td>More effective labor assignments</td>
</tr>
<tr>
<td>Provide Travelers better Information</td>
<td>Better prepared drivers</td>
</tr>
<tr>
<td></td>
<td>Safer travel behavior</td>
</tr>
<tr>
<td></td>
<td>Reduced travel during poor conditions</td>
</tr>
<tr>
<td></td>
<td>Fewer crashes, injuries, fatalities and property damage</td>
</tr>
<tr>
<td></td>
<td>Increased customer satisfaction &amp; political support road maintenance authority</td>
</tr>
<tr>
<td></td>
<td>Improved mobility</td>
</tr>
<tr>
<td></td>
<td>Safer, more reliable access</td>
</tr>
<tr>
<td>Cost-Effective Summer Maintenance Scheduling</td>
<td>Higher labor productivity</td>
</tr>
<tr>
<td></td>
<td>Improved roadway surface</td>
</tr>
<tr>
<td>Share Weather Data</td>
<td>Improved weather forecasts</td>
</tr>
</tbody>
</table>
Dependent on the length of the road network, topography, geography and other factors the numbers of road weather systems vary within Europe. (Papanikolaou et.al, 2011) In Finland, the first automated road weather observation stations were introduced in late 1970’s / early 1980’s. Now the observation network consists of more than 500 observation stations, and more than 100 of them are equipped with optical DSC111 instruments, which give an estimate of the prevailing road surface friction coefficient Cf. The variable Cf is a measure of the grip between tires and road surface. Cf has a scale from 0 to 1; on bare road Cf has a value of ca 0.8 and on ice ca 0.2. The information from all stations is gathered into the RWIS, and the system can e.g. warn about slippery conditions by colour coding. In Figure 5 the RWS locations in Finland in 2010 are shown.

Later the RWIS were developed further to Maintenance Decision Support Systems (MDSS), initiated in the USA by the Federal Highway Administration in 1999 (Chapman et al., 2010). In addition to the weather observation and forecast data, the MDSS provide the following recommendations:

- temporal character of activities (when to perform activity)
- geographical extent of activities (where to perform activity)
- types of activities

It is also worth mentioning that Road Weather Forecast Models (RWM) are required to overcome e.g. the timing issue. The primary function of the forecast model is to estimate the road surface temperature, the hydrological state and the slipperiness along the road network. Typically, a RWM is based on the solving of an energy balance equation at the ground surface. A RWM uses external forcing input from an operational atmospheric Numerical Weather Prediction (NWP) model. One widely used RWM is METRo (Model of the Environment and Temperature of Roads), which was originally developed in Canada. For example in the USA, METRo is used as a source of road weather forecast information in MDSSs (Linden and Drobo, 2010). Different RWMs have been developed in many countries during past decades (for example in Denmark). In Finland, a RWM was developed by the Finnish Meteorological Institute (FMI) in the late 1990’s and it has been running operationally since the year 2000. The present output parameters of FMI's RWM include e.g. surface and ground temperatures as well as thickness of water, snow and ice layers on the underlying surface (in equivalent mm), from which the state of the road (snowy, icy, wet etc.) can be derived. A novelty forecast parameter, road surface friction, was also introduced recently.
An overview of the current state of road weather management throughout the world is provided by the World Road Association (PIARC), e.g. by their Snow and Ice Databook (latest edition 2010: PIARC 2010). For Europe the ERA-NET ROAD program managed by the European Commission and funded by the Member States issued a series of related studies in 2009, e.g. the RIMAROCC (2009) or SWAMP (2010) projects. Relevant issues can be summarized as follows:

In order to provide more detailed (trans-boundary) information and to facilitate the sharing of data, there is a need for European or even international standards regarding the exchange of information as well as for:

- the technical characteristics of RWIS,
- site installation recommendations,
- Common criteria on selecting appropriate sites for road weather stations (RWS)
- Communication standards (especially for information available to the general public)
- Metadata standards

International or European standards can be useful in order to facilitate data sharing for:

- Road administration operations centers that might be interested in regions that border on their own road network or that compile data for an inter-regional or national system.
- Public or private organizations, such as contractors, who can use the data to provide higher quality service; municipalities, who can use them to create a denser and more seamless information system between rural and urban areas; traffic managers, who can better inform the public or manage traffic problems; the police, who can better manage incidents and emergencies; and forecasters, who can improve their product by anticipating road weather events.
- Road administrations in other countries, which view the alliance as an opportunity to provide drivers with continuous information pertaining to road conditions and certain road weather details.

Taking into account the above-mentioned characteristics, research on matching the information out of RWIS with the spreading of information (e.g. to the public) is necessary to ensure a most efficient use of available data. To obtain detailed road weather information it is also useful to capture real-time weather data by vehicles traveling along the routes. As the sensors have to be maintained as well, further research on diminishing the number of sensors is also needed. So a decreased number of sensors can result in decreased maintenance work and costs (PIARC 2010). For further developments nevertheless the exchange of data and related technologies is essential for all (European) countries.

2.3 User Communication Strategies

Different countries have developed various good practices and methods that aim at improving the service provided to road users. All respondents to a survey issued by the World Road Association indicated that information is provided to road users regarding wintertime road conditions, winter maintenance or both in their respective countries (PIARC 2008). The satisfaction felt by road users in the winter condition and maintenance of roads in the Canadian Quebec, the UK, Estonia, Finland, France, Japan, Norway and Walloon (Belgium) is established through customer satisfaction surveys plus accompanying other means of user feedback collection. In urban areas
good road maintenance can have the potential to have a major impact on peoples’ mode choice as demonstrated by the city of Oulu (Box 1)
Table 4: Scope and usefulness of media channels (source: PIARC 2013b)

<table>
<thead>
<tr>
<th>Medium</th>
<th>Scope of media</th>
<th>Before driving</th>
<th>While driving</th>
<th>Delay / incident information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web</td>
<td>Medium</td>
<td>Useful</td>
<td>Useful</td>
<td>Medium</td>
</tr>
<tr>
<td>Radio</td>
<td>High</td>
<td>Useful</td>
<td>Useful</td>
<td>High</td>
</tr>
<tr>
<td>RDS-TMC</td>
<td>Low</td>
<td>Useful</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>SMS</td>
<td>Low</td>
<td>Useful</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>VMS</td>
<td>High</td>
<td>Useful</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Police</td>
<td>Road segment</td>
<td>Useful</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>High</td>
<td>Useful</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Of increasing importance is the information exchanged between vehicles, road operators and drivers. Car-to-car or car-to-Infrastructure communication systems are not anymore pure research subjects, but are installed in vehicles and roads today. These new technical developments bring about a new understanding of the link between automobile manufacturers and road authorities, as pointed out by a joint task force of the World Road Association and the International Federation of Automotive Engineering Societies (PIARC / FISITA 2012).

2.4 Adaptation strategies by road administrations

The above sections have already highlighted a number of actions road administrations can take to mitigate the risks of weather extremes and natural hazards to their own asset and operating costs as well as to the users. In brief, these can be listed as follows:

**Active risk management**: implement a risk management process in the organization, including the tasks: risk mapping, risk assessment, control activities, internal and external communication and information strategies and monitoring. This strategy has to be initiated on all management levels and has to be reviewed on a regular basis.

**Weather information**: Another topic of certain relevance is the standardization of information. In particular in the EU there is a lack of consistency in meteorological information, which makes emergency operations across borders difficult. Moreover, meteorological services should keep track of chain reactions for weather extremes. This particularly holds for urban areas, where systems and impacts are more inter-connected than in long-distance transport.

**Preparedness**: Based on the local weather conditions and hazard risks, topography and infrastructure assets road administrations would carefully establish and regularly update extreme weather events maps (e.g. flood maps) accounting for prevailing land-use and development plans.

**Asset management**: In case risk maps indicate long-term hydrologic changes, protecting and strengthening of sea walls and creation of buffers (e.g. floodplain buffers for river systems), delineating floodplains and alluvial fan boundaries are to be considered. This could be supported by the design and investment in new assets with “quick restoration” capability and the changing and improving highway maintenance activities.

**Legislation**: the prevention of future losses for citizens through various programs (e.g. “Hazard Mitigation Home Buyout Program”, “We are Home”) should be considered. More important, however, is to modify existing building codes and design standards with updating permitted limits on the reconstruction and in the new construction of premises in flood plains.

**Communication**: Regarding communication, efficient and timely user communication systems with easy access and simple-to-remember phone hotlines are to be considered. The use of social networks will help enlarging the scope of messages and to personalize information.
3. Passenger Transport

3.1 Main Vulnerabilities

Road Safety
The allocation of traffic incidents and casualties to single causes is difficult and sometimes even impossible. While an experienced and attentive driver, as should be the case for commercial taxi, bus, coach or truck services, will be able to navigate even difficult road conditions, unexperienced or distracted driver will much more likely be involved in accidents in such situations. The ETAC study lead by the International Road Union unveiled that human factor is responsible for 85% of all road accidents, while is the main cause for only 4.4% of accidents on European roads (ETAC 2013). A compilation of European accident and road condition data by the European Road Safety Observatory (ERSO, 2008) shows that most accidents under non-standard weather conditions, happen during rains.

Figure 6: Left: main causes of accidents in Europe 2008 (ETAC, 2013), right: road conditions with accidents in Europe (ERSO 2008).

Multi-year data for Germany, however, suggests that winter conditions in mid Europe may strongly impact total accident records. In Table 5 the harsh winters 2009/2010 and 2010/2011 are indicated by weather-inflicted incidents rising by 87 % and total accidents increasing by 28 % in 2010 related to 2009 figures.

Table 5: Annual accident statistics by main course, Germany, 2009 - 2012

<table>
<thead>
<tr>
<th>Year</th>
<th>Accidents due to driver failures under adverse weather conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet pavement</td>
</tr>
<tr>
<td>2012</td>
<td>7095</td>
</tr>
<tr>
<td>2011</td>
<td>7150</td>
</tr>
<tr>
<td>2010</td>
<td>6698</td>
</tr>
<tr>
<td>2009</td>
<td>8503</td>
</tr>
</tbody>
</table>

The degree of severity which the different road conditions entail is different. According to U.S. multi-annual statistics wet pavement and rain, followed by visibility entail most injuries and fatalities (Table 6).
Table 6: Severity of accidents by weather condition (U.S. data)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Indured / crash</th>
<th>Fatalities / crash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet pavement</td>
<td>40%</td>
<td>0,5%</td>
</tr>
<tr>
<td>Rain</td>
<td>41%</td>
<td>0,5%</td>
</tr>
<tr>
<td>Snow</td>
<td>27%</td>
<td>0,4%</td>
</tr>
<tr>
<td>Ice</td>
<td>29%</td>
<td>0,4%</td>
</tr>
<tr>
<td>Sleet / mud</td>
<td>25%</td>
<td>0,3%</td>
</tr>
<tr>
<td>Mist</td>
<td>38%</td>
<td>1,6%</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>37%</td>
<td>0,5%</td>
</tr>
</tbody>
</table>

The bandwidth of assumptions on the share of accidents caused by weather or weather extremes applied to recent European studies is wide. The EWENT research project assumes 10% of all accidents induced by adverse weather, which includes human failure which could just be avoided in case road conditions were normal. The WEATHER project in contrast was more cautious by attributing just around 1% of accidents to extreme events.

Under bad weather conditions, accident risks increase for those remaining to drive in a similar habit than under normal conditions (cp. Box 2). But people adapt and drive more slowly, adjust routes or skip trips at all. Higher risks per trip thus might not necessarily be reflected in higher casualty records. Main reasons behind deadly accident reported by statistical offices around the world are alcohol and drugs (with increasing tendencies) and the non-use of safety belts and helmets.
Although not the primary cause of crashes and fatalities, weather conditions encourage accidents and thus need to be tackled in a vision of halving death casualties on European roads. The measures to be put forward to prevent from weather-related fatalities partly coincide with general safety programs, and partly focus on different aspects. There are principally two ways to do that:

- Foster the technical development of assistive technologies with particular capabilities to navigate difficult weather conditions and push their implementation in cars. These may be passive systems warning the driver of critical situations, or active systems taking over vehicle driving functions. Today already over 60% of cars are equipped with ESP (electronic stability program), which is compulsory for new cars from 2012 on. The technologies themselves, e.g. active cruise and brake control, light assistants, etc. are available now. But they need to find their way from premium cars to standard and low price vehicles too. A side benefit may then be more fluent traffic and thus better capacity use from existing infrastructures under all weather conditions.

Box 2: The massive car crashes on 3 February 2012 in the Helsinki metropolitan area

During the first days of February 2012, harsh winter conditions prevailed throughout Europe, with snowfalls at many places and temperatures well below the freezing point. On 3 February 2012, the temperature was between -15 and -20 °C in southern Finland. Sea-induced snowfalls spread from the still partly ice-free Gulf of Finland onto the Finnish coast. The most intensive snow band was located over the Helsinki metropolitan area for several hours, causing a simultaneous worsening of visibility and grip on the roads. Pile-ups occurred in many locations and several hundreds of cars were crashed and 43 injured persons were taken to hospital. The main crashes occurred around 11:45 local time and the traffic was badly jammed until the evening, some of the main highways being totally closed for most of the day. It took several days to remove all the crashed cars from the roadsides.

Preventing such cases from occurring calls for good co-operation between weather service providers, road authorities and maintenance contractors. Up to date road weather information and recommendations should be delivered to contractors via a Maintenance Decision Support System (MDSS). The increased usage of variable speed limits and warning messages along the roads may also increase safety and reduce even costs in the long run.

Encouraging the use of these technologies may be via vehicle tax or insurance fee deductions for cars properly equipped, or to regulate technical standards of new cars. Regulation on new cars, of course, will have the most rapid impact on the vehicle fleet. Yet such a regulation may be difficult to implement and one needs to be careful not to push particular technologies and suppress others, which may be more efficient in the long run. To avoid these, fiscal incentives for safer vehicles may be considered.

Besides all technical solutions, drivers’ skills need to be adapted to local weather situations. As for car technologies, driver trainings could be incentivized or enforced by regulation. As people tend to lose their skills when not actively used, regular refreshments are essential.

Under critical ambient conditions the use of passive safety features, such as helmets or safety belts, is essential. E.g. time series of fatality rates reveal a clear impact of the introduction of safety belt regulations worldwide. What needs to be considered, however, are rebound effects as more passive safety may provoke more risky behavior.

**Congestion and delays**

Reduced travel speeds and congestion on roads commonly have several causes. We speak of “recurring” congestion when demand is regularly exceeding road capacity and thus speeds and journey time reliability drop below an acceptable level. On the contrary, non-recurring congestion is caused by specific incidents, i.e. construction sites, accidents, technical problems at vehicles or weather conditions. Estimates on the impact of these conditions on road congestion and reliability are rough by nature and differ across countries. German and US figures suggest that 40 % of congestion on highways is recurring, i.e. caused by excess demand, 25 % are due to accidents and construction works add another 10 % to 30 %. Only the U.S. statistics spell out the impact of weather extremes by 15 % of total congestion (see Figure 7). According to regular travel time reliability measurements of the U.K. Department for Transport, all year reliability of above 80 % usually drops in winter months below 70 %.

![Share of causes of inter-urban road congestion](image)

1) UNiv. of Kassel (2008), Statistica.com; 3) FHWA (2007)

*Figure 7: Congestion causes in Germany and the U.S.*

An in-depth analysis of the impact of different weather phenomena on speeds, road capacity and safety can be found in WEATHER Deliverable 2 (Enei et al., 2010), Annex 3.

From the above compilation we follow that more research in the causation of congestion and travel time (un-)reliability better understanding of the underlying phenomena the integration of en route weather information systems in route planning systems should be fostered. In particular for commercial coach and truck transport such a reliability feature seems promising. Psychological issues behind this technology then could be how to best present travel time probabilities or delay risks to travelers such that they are helpful for decision making.
3.2 Decision making process of private travelers

Pre-trip decisions: Daily mobility behavior is commonly driven by routines. Behavioral patterns people got used to are therefore not questioned or re-evaluated prior to each trip. This steadiness holds in particular for mode choice decisions; information on transport modes is thus rather ignored by travelers. Exceptions are, however, groups of travelers more vulnerable to weather, including motor cyclists, cyclists and pedestrians.

According to research conducted by the UK Highways Agency, 49% of drivers overlook severe weather warnings, while 29% do not prepare vehicles for the (winter) season (Highways Agency 2013). The danger perception in particular by younger drivers is rather low and weather warnings are often perceived as a disturbance to peoples’ personal daily itinerary. These perceptions add to the habit of ignoring warnings. Weather information requirements of each user community are highly specialized, varying by age, time of day and responsibilities and reactions may be biased emotionally. Motorcyclists, cyclists and pedestrians commonly react much more on weather warnings and prevailing adverse conditions than other traffic participants by shifting modes, travel times or by adjusting clothing. However, research suggests that the behavior of cyclists and pedestrians gets more risky in adverse weather. There is a strong tendency to use of public transport (PT) instead of walking or cycling in case of bad weather, some statements call PT the "umbrella of the cyclists", while steady PT users are less impacted by weather phenomena.

On-trip impacts – travel time: The impact of rain on roadway capacity probably constitutes the best documented weather phenomenon even going into road investment manuals. Speed reductions on arterial routes may range from 10% to 25% on wet pavement. Freeway speed drops by 2% to 13% under light rain and by 3% to 17% under heavy rain conditions. The impacts are particularly expressed during rush hours in congested areas. Floods may have strong economic impacts due to long detours required. The 2007 UK summer floods e.g. caused detours and delay costs estimated at 22-174 m UK£. For cycling and walking we can suspect that due to safety concerns, travel times will go up considerably in any type of adverse weather conditions. An exception may be people walking faster under heavy rain. Although bus and coach services can operate under various weather conditions (with the exception of snowy or icy roads), delays and cancellations in PT under adverse weather conditions are frequent.

On trip impacts - safety: In 2009 34500 people were killed in road accidents in the European Union of which around 80% were caused by drivers. In particular, under bad weather conditions good driving skills may reduce crash and fatality rates significantly. Due to the strong seasonal variation of cycling activities, cycling fatalities during winter months in Europe account only for 14% of all annual cases. However, the case of the city of Oulu in northern Finland constitutes a positive example of how the level and safety of cycling can be maintained throughout the winter season (see box). Further, studies report people walking more risky under heavy rain.

Based on expert judgments the following table gives an indication of how relevant extreme weather situations are for pre-trip decisions (cancellation, shift in time and mode shift), for the quality of transport (delays and comfort) and for travel safety. The indicators distinguish between the basic types of individual and collective road passenger transport.
Table 7: Impact of weather extremes on different passenger transport modes

<table>
<thead>
<tr>
<th>Mode of travel</th>
<th>Pre-trip: cancellation / shift of trips</th>
<th>On-trip: delays and comfort</th>
<th>On-trip: accident probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual car travel and taxi services</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Behaviour change not very likely. Trip cancellations only during cyclones and large scale icing and heavy snowfall.</td>
<td>Most relevant: winter conditions and low visibility. Some slight capacity reductions in rain.</td>
<td>Heavy rain most relevant source of accidents; indifferent results for winter conditions: more but less severe crashes</td>
</tr>
<tr>
<td>Non-motorised mobility (walking and cycling)</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>More sensitive than car drivers. Most relevant: mode and departure time shift.</td>
<td>Little information. Probably slightly slower riding / walking</td>
<td>Increasing due to lower visibility and more risky behaviour e.g. when crossing roads.</td>
</tr>
<tr>
<td>Urban bus and inter-urban coach travel</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Most relevant for non-frequent PT users): shift from walking and cycling to PT</td>
<td>Most relevant: ice and heavy snow. Service maintenance mostly possible, but frequent delays</td>
<td>Less relevant due to high safety preference of PT operators</td>
</tr>
</tbody>
</table>

Reference and symbols: Expert judgment by the project team. “+” to “+++”: strength of impact of weather extremes on the respective criteria/indicator for the respective mode

3.3 Driver and passenger Information Systems

The precision of user information systems shall not be over-emphasized: while for most event types their most extreme extension can be well forecasted, the exact time and location of this often stays vague. Personalized information may compensate for this shortcoming. This personal information, however, then needs to be specific by prevailing travels purpose and time rather than conveying blanked information. Real time and projected information linked to warning, route guidance and other information systems via map services appears inevitable.

With the wide spread of smartphones we now have the technology available for providing such services. The challenge now is more to appropriately filter information and to create data packages suitable for different user needs and expectations. While existing information systems concentrate on individual road traffic, powerful information systems should include all modes and provide multi-modal recommendations. The main challenge is the establishment of attractive business models for service providers.

With ever improving hazard warning system it can be suspected that travelers' behavior gets more inattentive and risky. On this point this potential trade-off should be no question to hold back information. A crucial point is the feedback between vehicle and driver.
<table>
<thead>
<tr>
<th>Operator</th>
<th>Area covered</th>
<th>Time</th>
<th>Event types</th>
<th>Sectors</th>
<th>Information options</th>
<th>Web link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Scotland</td>
<td>Scotland</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.trafficscotland.org">www.trafficscotland.org</a></td>
</tr>
<tr>
<td>Weather.com</td>
<td>USA</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.weather.com/activities/driving/international/roadconditions.html">www.weather.com/activities/driving/international/roadconditions.html</a></td>
</tr>
<tr>
<td>Frixo</td>
<td>England &amp; Wales</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.frixo.com">www.frixo.com</a></td>
</tr>
<tr>
<td>Integrierte Verkehrslitzentrone Stuttgart</td>
<td>Stuttgart</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td><a href="http://www.stuttgart.de/verkehrslage">www.stuttgart.de/verkehrslage</a></td>
</tr>
<tr>
<td>Verkehrsinfo.de</td>
<td>Germany, Belgium, Switzerland</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.verkehrsinfo.de">www.verkehrsinfo.de</a></td>
</tr>
<tr>
<td><a href="http://www.verkehrsinformation.de/">http://www.verkehrsinformation.de/</a></td>
<td>Germany</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td><a href="http://www.verkehrsinformation.de">www.verkehrsinformation.de</a></td>
</tr>
<tr>
<td>ADAC</td>
<td>Germany, Austria, Italy, Switzerland</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.adac.de/reise-freizeit/verkehr">www.adac.de/reise-freizeit/verkehr</a></td>
</tr>
<tr>
<td>Michelin</td>
<td>Western Europe</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td><a href="http://www.viamichelin.de/web/Verkehr">www.viamichelin.de/web/Verkehr</a></td>
</tr>
<tr>
<td>Tom Tom</td>
<td>Western and central Europe</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td><a href="http://www.tomtom.com/livetraffic">www.tomtom.com/livetraffic</a></td>
</tr>
<tr>
<td>Bison futé</td>
<td>France</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.bison-fute.gouv.fr/maintenance.html">www.bison-fute.gouv.fr/maintenance.html</a></td>
</tr>
<tr>
<td>Italian Highways Agency,</td>
<td>Italy</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td><a href="http://www.cciss.it">www.cciss.it</a></td>
</tr>
</tbody>
</table>
Turning from private road users to professional transport service providers, the basic needs towards a good hazard management is to prioritize the clearing of routes and crossings to emergency stations, hospitals, and for public transport, extending across the boundaries of municipalities. Good practice is illustrated by the Lyon/Macôn case in Box 3). For planning services, reliable 3–4 day pre-warning periods would be favorable. According to Dutch practice, travel times in public transport may be adjusted flexibly according to expected conditions. Such warning systems could remain local as European systems are expected to face considerable challenges in terms of data availability and conversion, language, and culture. Finally, the business case for such systems is to be explored.

**Box 3: Inundation of Lyon Macôn country roads in France, 2001**

In March 2001, a flood warning was sent by the Rhône Saône Navigation Service (NSS), registering rainfall twice as high as normal accompanied by a variety of significant impacts. The entailed flood affected 108 communities along the Saône River and 234 communities along tributaries.

After information by Météo France and Service Navigation Rhône Saône, the prefecture Lyon then requested the Service Inter Defence and Civil Protection (SIDPC) to set up a crisis management centre. They collected and analysed information, evaluated the likelihood of possible consequences of the phenomenon, they proposed protection and mitigation measures, activated an existing contingency plan and collaborated with various government agencies.

The Société Lyonnaise de Transports en Commun (SLTC) which controls the public transportation network in Lyon, first failed to communicate the ‘SLTC flood plan’ in a proper way; staff was short and internal as well as external communication and coordination with the municipal police was not working properly. However, many communities benefited from existing contingency plans, specifying the procedures in the case of a flood. If not, cities developed such plans after the flood. In Lyon, special road diversion plans were created taking into account public transportation as well as freight transportation.

*Figures: Precipitation in March 2001 (left) and mobile pedestrian bridges in Lyon (right)*

See details of the case study on [www.mowe-it.eu](http://www.mowe-it.eu).
3.4 Public Road Transport Operations

The impact of weather extremes on international long-distance coach services appears less severe as the driver can choose alternative routes. Important is, however, reliable and early emergency information services. However, the capacity of road passenger transport is considered not sufficient to absorb vast amounts of stranded rail or air passengers.

Market opening and the fostering of private capital engagement should increase the profitability and service quality in public transport. However, concerns are that this market environment decreases the companies' will to co-operate under hazardous situations. Moreover, the system redundancy and with is the availability of resources declines. The net effect of the resulting decrease in transport system resilience for the users and for society, however, is debatable.

Despite constant efforts to privatize the public transport sector, the market is still heavily regulated. Further barriers to inter-company co-operation arise from legal settings, including competition legislation, passenger rights aspects, liabilities or social and licensing regulations for drivers. Obstacles put in place by competition law may be detoured via the engagement of private third party companies.

On the co-operation between companies one can constitute that this already happens in a number of sectors. Examples are local bus companies and rail in many countries, but these could be improved. Priority is seen for the improvement of passenger information across the competition between services and operators. The Munich case outlined in Box 4 gives examples for good communication management in local transport.
3.5 Conclusion: Policy and Market Structure Challenges

**New mobility systems**, namely the connection of urban modes of transport, walking, cycling, bike- and car-sharing, etc. are currently fostered by the European Union, Member States and municipalities. However, one could suspect that, due to harsh climatic conditions, there are not equally feasible in all European cities. But exceptions are possible: among the very Nordic cities in Europe we find some with quite high cycling shares, such as Oulu (Finland) with 21% and Västerås (Sweden) with 16%. By floods, high winds, extreme cold and snow nearly all road transport modes are affected equally. Due to the high safety standards the impact is much more delays and cancellations of services than safety in public transport.

**Response strategies**: Important is a minimum service to be guaranteed, providing a challenge to EU and international legislation. In the US a number of state transport authorities initiated risk management communications involving all relevant bodies. The participants see a need for national and worldwide information exchange on response strategies.

**User behavior**: Little is known on the use of information by travelers. Moreover, the details behind the general idea of personalized information are to be researched and enriched with concrete tools and services. Eventually, viable business models behind these services are to be identified.

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**Box 4: Munich Emergency Bus System**

The Munich municipal transport system is frequently hit by heavy storms and huge amount of snow leading to about 100 short term interruptions per year. These nearly exclusively affect the suburban train network (S-Bahn) connecting outer areas to the centre of Munich. Heavy snowfall in winter and strong storms in autumn cause problems with the electricity supply. Fallen trees especially on the rail tracks due to heavy snow weight interrupt the train service.

To maintain service levels for passengers, the Munich transport authority (MVV) has developed a flexible system of emergency bus services. Core elements of the strategy are measurements to achieve better communication between service operator and passengers and clarifying the general processes and responsibilities. Emergency buses are acquired through contracts with private bus operators. In order to react as fast as possible the emergency bus service is supplemented by taxis in the early stage of network interruptions. The system works successfully since several years and is well appreciated by passengers.

*Figure: clear signing of Munich Emergency Bus System*

See details of the case study on [www.mowe-it.eu](http://www.mowe-it.eu).
4. Road Freight Transport and Logistics

4.1 Introduction

The majority of climate change related research activities in the transport sector focus on mitigation, i.e. on identifying and applying measures that will reduce the effects of transport systems on climate change. Less, but increasingly important, research efforts have been placed on adaptation that is on the creation of robust, resilient and less vulnerable transport systems in view of the climate change phenomena. The above are also true for the logistics and freight transport sector. The adaptation of logistics and freight transport to climate change, also referred to as “adaptive logistics”, considers how such systems can better respond to the impacts of climate change. The field is not to be confused with “green logistics”, mainly targeting to assess the impacts of logistics and freight transport operations on the environment. Coping with the impacts of extreme weather events for several modes simultaneously is one of the main challenges to be addressed for the freight and logistics sector. The multimodal character and the wide geographic extent of supply chain operations and trade routes accounts for impacts due to events of various natures (e.g. sea-level rise impacts on ports and rain floods affecting road freight transport) in one or several geographic parts.

In its Global Risks 2014 report the World Economic Forum (WEF 2014) ranks the two sides of climate change and economic activity right next to each other. After fiscal crises and unemployment, water scarcity and income disparity, the report names the failure of climate change mitigation and the severe weather events the 5th and 6th most challenging threats for the global economy. Our social and technical networks get more and more complex and interdependent, their level of resilience depends on whether they become “bulwarks of global stability or amplifiers of cascading shocks”. Given the multitude of risks, the challenge of finding strategies to lower the overall risk level of companies is considered more than challenging.

4.2 The magnitudes of risks

Economic Impacts

The impacts of weather extremes on freight transport and logistics regard service disruption, economic losses, trip re-scheduling and re-routing and delays in deliveries. Among other extreme weather events, floods and severe rainfalls can lead to accidents, transport infrastructure disruptions and closures. The economic impacts on the overall industry can be in the order of millions of euros. According to the World Bank’s Logistics Performance Index LPI (World Bank 2012), in low income countries natural disasters, together with geographical barriers and sometimes armed conflicts restrict these countries’ access to markets, thus constraining their ability to participate in global supply chains (World Bank 2012).

In some cases, as in the 2007 UK floods, the impacts can lead to the paralysis of entire economic sectors, whose economic activities depend on an operational supply chains supported by efficient transport infrastructures. The 2012 Italy winter storm case resulted to the closure of highways to freight transport, hindering goods deliveries for several days. Similarly, the Attica extreme rainfalls in February 2013 significantly affected the road network operations for private, public and freight transport. The latter faced disruptions in its operation (in terms of reduced average speed of freight vehicles) up to 37% and decreased freight vehicles’ circulation (due to closure of routes) up to 32% (compared to business-as-usual vehicle-kilometers).
Table 9: Summary of the most significant impacts of certain extreme weather events on freight transport and logistics.

<table>
<thead>
<tr>
<th>Weather</th>
<th>Economic losses</th>
<th>Delays and trip rescheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heavy Floods</strong></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><strong>Winter weather events</strong></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>(e.g. heavy snow and rain)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><strong>Wind and Storms</strong></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Damage of perishable goods</td>
</tr>
</tbody>
</table>

Economic losses relate to the costs for transport operators, industry and distribution sector from goods and services not provided may be significant. Delays and trip rescheduling may result to additional congestion costs, increased travel times and distances.

Box 5: Winter 2007/2008 impacts on logistics in Washington State, USA
In the winter of 2007-2008, in the US, due to unusually heavy storms that winter, interstates I-5 and I-90 were each closed for four days, disrupting freight and passenger movements across the state and the West Coast. A 20-mile section of I-5 was closed due to floodwaters. The Washington State Department of Transportation (WSDOT, 2008) identified $75 million in total losses from the freight delays in the two corridors and the loss of the equivalent of 460 jobs, for one year. Lost sales tax was estimated at $3.81 million, and reduction in personal income was estimated at $23.15 million.

Traffic safety
Traffic safety is generally an important topic in commercial road transport. However, weather does not play a major role for truck safety as vehicles are heavy, speeds are lower than in car travel and drivers are trained. Main reasons for crashes and fatalities are turning with under-estimation of the blind angle, fatigue and alcohol. Many human failures at the turning wheel leading to fatal incidents are caused due to long driving times, short breaks and time pressure. Two measures could help reducing these risks:

- Driver assistance systems help with better coping with human failure particularly under stressful situations. Fatigue control and the active observation of blind angles should be improved and installed in all commercial vehicles. Secondary benefits are congestion relieve less fuel use due to improved driving dynamics.

Delays and congestion
Statistics on the causes of delays particularly for commercial road vehicles are not available. With reference to the U.S. causes in Figure 7 (Chapter 3) suggests around 10 % of delays are attributable to weather. Translated to the milder conditions in Europe and the more stable driving cycles in road haulage we may estimate weather share at truck delays below 5 %. These figures, however, do not contain trip cancellations or shifts in time.
Contemporary speed-flow functions for roads suggest that car speeds and driving comfort is much more impacted by the number of goods vehicles on the road than vice versa. Thus, for an overall mitigation of congestion it is essential to keep trucks moving. Under extreme weather conditions this can be achieved by variable road-side message sign, permitting the use of side lanes or by access control to the infrastructure in question. All of these measures require timely information for truck drivers, their undertaking of the measures planned and the suggestion of alternative routes. Warning and recommendations should be spread by a multitude of channels, including radio, standard route guidance systems and internet.

4.3 Risk portfolio at company level

Climate change, weather extremes and natural disasters range among several risks which businesses, and among this the transport sector with elevated intensity, have to bear. Mitigating these risks will prevent from potential losses, but will most likely cost money. Balancing these two sides of the equation in order to take informed decision on company strategies requires at first hand understanding the risk pattern the company is exposed to.

Asking different U.S. companies for supply chain risks with greatest concern, a large number named interruptions of supply chain in different points of view (Marsh & McLennan Companies 2013). Besides the pricing risks, which seem to be the greatest risks to face at, natural disasters remain on the third place. (Figure 8) Hence the traditional responsibilities of risk managers have to be extended in order to react to new kind of risks.

![Figure 8: Which supply chain risk areas are of greatest concern? (Marsh & McLennan Companies 2013)](image)

The high importance of risk management in the transport sector in general raises the question of the relevance of different transport risks. According to Figure 9 the most relevant transport risk is delayed delivery. The major influence for that can be weather extremes as well as capacity bottlenecks in infrastructure leading to lower transport speed and hence longer transportation times.
As a matter of fact the importance of risk management is high and will even be higher in future. Logistic delays as well as natural disasters are risks of great concern of both, companies in general and transport service providers. The most important transport risk is delayed delivery. All the transport risks are related to disruptions of supply chains. These can be caused by bottlenecks of the infrastructure, political instability in certain regions or natural disasters. A standardized risk management could help to react as fast as possible in such situations, as demonstrated for the 2013 flood in south-east Germany (Box 5).
4.4 Short-term coping strategies

A rising number of supply chain risks in the past decade lead to an higher importance for risk management in general (Figure). E.g. with regards to 2015 transport companies in the Baltic area, asked within the Cash-project, assume a very high importance of risk management. Compared to the medium importance value of 2005 the increase is significant. Reasons for this trend are on the one hand a higher complexity of the supply chain due to globalized production networks and on the other hand the rising numbers of supply chain risks, such as political instability of countries or natural disasters.
The listing of the multitude of potential threats challenging supply chains indicates that risk management needs to address several targets. Calling for reducing the risk of climate change and weather extremes alone is not sufficient to meet business requirements. Proper risk analysis needs to take into account short term and local risks as well as long term and global threats – depending on the situation of the entity in question. Rather than the application of ready-to-go risk assessment and mitigation recipes, risk management is a continuous task consisting of observation, assessment, communication and education at various company levels.

The review of academic literature on supply chain security (e.g. Ghadge et al., 2012), and the analysis of empirical data sets, such as the case of the US chemical industry (Kleindorfer et al., 2005), shows that the strategy to cope with supply chain disruption management, for specific sectors and archetypes of supply chains, may present important challenges for research going forward. It has been stressed in fact that vulnerabilities to disruptions (including natural disasters) are, by their very nature, more difficult to identify. Several research fields converge in the attainment of an effective framework for intervention:

- industrial risk management
- supply chain management
- industrial ecology
- theoretical insights from engineering, operation and finance

On the conceptual side, an holistic framework providing the integration of risk assessment and risk mitigation is needed. Such a framework can be labeled as the “SAM-SAC” Framework, denoting the three main tasks at stake: a) risk Specification of sources and vulnerabilities, b) Assessment, and Mitigation, and c) the Strategies with dual dimensions: Actions and necessary Conditions for their effective implementation.

A review of current literature on supply chain security shows that two key dimensions emerge as fundamental in guiding management practice of disruption risk in supply chains. The first dimension consists of strategies and actions aiming at reducing the frequency and severity of risks faced, at both the firm level and across the supply chain. The second element focuses on increasing the capacity of supply chain participants (whether a separate firm or a subsidiary facility) to sustain/absorb more risk, without serious negative impacts, or major operational disruptions.

There are several ways for companies to undertake risk mitigation plans. These might be basic or advanced and may follow one of the existing ISO norms on supply chain security. In any case risk mitigation strategies should lead to a better preparedness for certain (negative) events from the top management to lower staff levels within a company. An example of different levels of risk taken from WEATHER Deliverable 4 (Doll et al., 2011) is provided by the IBM Business Group (Figure 1).
The international standardization organization (ISO) provides several standards in order to organize and handle risk situation within companies. The first and most general standard is the ISO 31000:2009 (Risk management – Principles and guidelines), which provides principles, framework and a process for managing risk. It can be used by any organization regardless of its size, activity or sector. Another important advantage of the application of this standard is the availability of an international recognized comparison and benchmark of a specific risk management application within a company.

After the introduction of ISO 31000 on the management of risk, a new technical report was established in 2013. The new ISO/TR 31004:2013, (Risk management - Guidance for the implementation of ISO 31000), aims at helping organizations to smoothly align their risk management practices to ISO 31000. The assessment of risk in general is part of the IEC 31010:2009, which supports standards for ISO 31000 and provides guidance on selection and application of systematic techniques for risk assessment.

To sum up, the main targets of the ISO standards could be described as a clarification of responsibilities in case of risks combined with early assessment of risks and last but not least a guidance for implementation. As the standards do not include specific best practices for different kind of risks, these cannot be used as a guidebook. (ISO 2014)

The Carbon Disclosure Project, Supply Chain program, (CDP, 2013) provides a comprehensive overview of practices and strategies addressing climate change and weather extremes risk assessment and risk mitigation at company level. The program provides a platform for companies and other purchasing organizations to collect business-critical climate change information from their suppliers. The program currently has 54 members including leading companies worldwide. The majority of members are located in Europe (22) and North America (19). Seven members are located in Latin America.

Although members and suppliers perceive the importance of increased supply chain vulnerability due to physical risks such as precipitation extremes, hurricanes and flooding, and water shortages, only a quarter of those companies (over a sample of 2500 companies) has engaged in the work to identify risks at the level of detail necessary to mitigate potential supply chain disruptions.

Questionnaire respondents have seen precipitation and temperature extremes, droughts, weather events (hurricanes, typhoons), and the rise in sea levels as having major cost implications. Other concerns have included the potential for reduction or disruption in production capacity, reduced demand for goods and services, and even the inability to do business.

Details are shown in the next table (related to a 459 observations).
Table 11: Potential impacts of change in precipitation extremes or droughts on business operations (Source CDP, 2013)

<table>
<thead>
<tr>
<th>Potential impacts of change in precipitation extremes or droughts on business operations</th>
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<tbody>
<tr>
<td>44% Reduction/disruption in production capacity</td>
</tr>
<tr>
<td>31% Increased operational costs</td>
</tr>
<tr>
<td>11% Inability to do business</td>
</tr>
<tr>
<td>6% Reduced demand for goods/services</td>
</tr>
<tr>
<td>4% Increased capital costs</td>
</tr>
<tr>
<td>3% Other</td>
</tr>
<tr>
<td>1% Wider social disadvantages</td>
</tr>
</tbody>
</table>

Consistently with the insights summarized in section 4.2, the table shows that about 75% of the companies identify in the reduction/destruction in production capacity and increased operational costs as the key impacts in precipitation extremes or droughts. As stressed in CDP (2013) several companies responding to the questionnaire have specified some of the potential effects of precipitation extremes on their operations. For example, the beauty products company L’Oreal has stated that extreme rain and extreme dry weather can both adversely affect operations and the company’s supply chain. As experienced in the case of the Thailand 2011 floods, the company has reported to face risks in terms of supply chain interruption.

Another important related environmental concern has to do with water risks which can put the entire supply chain at risk. In fact, more than half of the members surveyed rank water-related supply chain risks as either high or medium. Yet, it must be stressed that only a quarter of those companies have engaged in the work to identify risks at the level of detail necessary to mitigate potential supply chain disruptions. Potential risk mitigation strategies to be established in a cooperative way with local policy and business was developed out of the 2013 flood in Athens (cp. Box 6).
Among the exceptions, the Johnson & Johnson multinational group, which is taking actions to mitigate water risks through tools such as the World Business Council on Sustainable Development’s Global Water Tool (WBCSD 2014), in order to analyze its current and future water scarcity risk. After identifying regions that may experience these risks, the company has actively worked to reduce its risk by decreasing water consumption and implementing risk management programs. Although somewhat outside the transport logistics sector, implementation details of this case should be illustrative for haulage companies and logistics processes in all undertakings.

**Box 6: Impact of flooding in Athens 2013 on logistics and warehousing**

On February the 22nd, 2013, a storm started over the Athens basin as a result of a low barometric. Until the late evening of the 21st, there was no storm outbreak reported over Athens. Intense precipitation was firstly recorded in the western part of the city, yet the system expanded eastwards relatively quickly, affecting the central and north-eastern parts of Athens basin. According to, documentary data regarding the effects of the storm and the resultant flooding on the road network of Athens (press and electronic media), five zones where identified as the ones being mostly affected.

The impact of the flooding event was considerably different depending on the study zone, ranging from lower impacts in Zone 1 to higher impacts in Zone 5, where the average speed dropped by up to 25 km/h (67.8 % difference) during the course of the event. The duration of the impact was also different depending on the zone, ranging from 3 to 12 hours. At individual freight vehicle level, the analysis shows that certain regular routes of Friday the 22nd, 2013, were significantly different compared to the preceding Fridays.

![Vehicle Speed](image)

Figure: Hourly speed analysis per study zone for freight vehicles (left) and diverse freight vehicle detours due to flooding (right) (Mitsakis et al, 2014)

Although the detours are obvious, leading to a higher distance travelled by the freight vehicles (in order to avoid closed roads or heavy congestion due to the rainfall), in all depicted cases, the overall distance travelled by the vehicle fleet is reduced, leading to the conclusion that a significant amount of planned trips were cancelled or postponed due to the high intensity storms.

See details of the case study on [www.mowe-it.eu](http://www.mowe-it.eu).
4.5 Long-term adaptation strategies

Planning towards future freight transportation requires the consideration of both mitigation and adaptation to climate change. The first refers to the reduction of the major cause of climate change (GHG emissions from human activities), while the latter refers to the minimization of potential impacts on the freight transportation system form climatic changes such as increased intensity of storms, rising sea levels, rise of average temperatures and increases in overall climatic variability.

Yet a significant number of freight transportation agencies and businesses are not currently seeking to incorporate climate change adaptation plans and strategies into long-term planning. Although there is an overall recognition on their behalf that climate change is present and already poses a considerable threat on freight transport operations, most of them believe that the significant impacts are at least several decades away. There is therefore no need for urgency towards taking adaptation measure. Uncertainty regarding the location and magnitude of impacts also adds to their reluctance on taking major actions.

The involvement of civil society and business communities, promptness of meteorological warnings and the set-up of pre-emptive plans should be part of successful adaptation strategies, as specified below by key domains:

Business community:
- **An informal approach could be appropriate.** For example, SMEs’ executives may not be able to use as structured decision-making processes as those used in larger companies, or they have to justify their actions and decisions to shareholders etc. Nevertheless it is important to integrate climate and weather risks in ad hoc decision-making.
- **Integration in core business-affairs.** Although the mitigation of the causes of climate change and the adaptation to its consequences are both critical issues, the combination of mitigation and adaptation causes confusion. In this case it is more useful to integrate adaptation issues in similar business areas, such as business continuity planning, risk management, health and safety arrangements, flood plans etc. But it may be less helpful to treat it as an aspect of environmental management.

Management strategies:
- **Importance of preparation.** The presence of an well-structured emergency plan, with defined roles and responsibilities as well as maintenance instructions is the key to a successful emergency management. A lack of preparation can provoke the failure (or lower success) of an emergency plan, as can be seen in the case study of hurricane “Katrina”. Risk and response assessment, including prediction tools, products and strategies for potential maintenance, system planning, safety management and emergency preparedness issues arising from global climate change.
- **Promptness of meteorological notices.** Delays or a lack in meteorological communication can be critical for freight transportation, because lorry drivers are not able to make the right decisions in advance or to redefine their itineraries if necessary.
- **Learning from the past: repair and adaptation.** In one of the US case-studies, Louisiana had experienced hurricanes in previous years whereby the Federal Emergency Management Agency (FEMA) and the Department of Transportation (DOT) had gained several knowledge to use it in future cases. For example new loading techniques had been implemented in the reconstruction. At the same time the emergency plan was modified in general, making necessary changes to the entire emergency system.
- **Avoid undifferentiated / unnecessary closure of routes.** The case study of the Italian winter storm illustrates the importance of discrimination of closures, depending on the kind of goods and loads. Vehicles which were properly equipped with snow chains and snow tires could have continued without any danger.
Strategy and investment decisions

- Relocation of goods’ storages and warehouses, vehicle fleets’ depots and maintenance facilities out of flood plains. Elevation or relocation of at-risk infrastructure and key facilities (e.g. above projected flood levels)
- Design and investment in new assets with “quick restoration” capability
- Promotion of redundancy in terms of freight transportation routes and facilities
- Development of practices and policies that shorten delivery time and provide alternative for goods movement (e.g. coordinated intermodal transport). Enhancement of the integration and connectivity of the freight transport network.

5. Summary of Recommendations

The following brief sections show the main recommendations of the previous chapters, enriched by the findings of the MOWE-IT Road Workshop held August 19th in Brussels. The recommendations are grouped by potential recipients to ease the navigation process for special readers.

5.1 Recommendations for policy

European and national policy

- Establish networks of urban, regional and national stakeholders: transport companies, authorities and users, to encourage mutual support in case of an emergency and the exchange of experiences.
- Support road authorities and transport service providers by issuing guidelines, leaflets and other education and information material on maintenance, good preparedness, contingency planning and procedures in emergency cases. PIARC and UKRLG guidelines provide excellent starting points, but need to be translated to national and regional contexts.
- Foster the operational-, physical-, technical-, procedural- and institutional integration of weather and traffic control services (e.g. the UK National Traffic Control Centre).
- Evaluate the possibility of compulsory safe driving training for all drivers. Furthermore support the training of drivers and other staff in the transport sector. While the trainings and certificates could be issued by private players or associations, e.g. automobile clubs, the contents should be defined by public authorities to ensure regional consistency and completeness.
- Pave the legal and knowledge grounds for innovative procurement and supply models for road authorities. These could be on de-icing salt, sand bags, snow ploughing equipment, etc. Insurance solutions could be an option.

Local policy

- Develop risk maps for the local area and derive appropriate action plans according to the risk mapping. This should ideally be supported by national or European risk mapping activities.
- Establish priority plans for road clearance with regard to maintain access to emergency stations, hospitals and for public transport within and beyond city boundaries.
- Provide sufficient shelter for non-motorized transport (bike parking, waiting facilities) against the most relevant local hazards.
- Conduct public campaigns to raise the awareness on local hazard situations to the general public. The aim of such campaigns should be to raise awareness for good technical preparedness of vehicles and for higher levels of pre-trip information.
Organize the supply of trapped drivers / passengers with the help of volunteers and aid organizations. To be prepared, collaborative contingency plans and contracts should be established beforehand.

5.2 Recommendations for the transport sector

Road infrastructure managers
- Prepare timely and broad communication on disruptions and alternatives with the public, using different communication channels (radio, internet, social networks, etc.)
- Consult and co-ordinate with other highway authorities, subcontractors, suppliers and key stakeholders to adjust strategies, e.g. when defining strategic maintenance networks or materials and equipment supply.
- Implement appropriate risk management procedures in order to be prepared to adverse conditions. This includes risk mapping, staff training, communication structures and the identification of actions.
- Review maintenance contracts and procedures to be flexible and effective even under rapidly changing weather conditions. Regularly clearing of cycle lanes and sidewalks in winter- or communication of alternative strategies.
- Prepare for sufficient salt stocks and road clearing equipment availability before and during winter or storm seasons. UK winter experience e.g. recommends 12 days salt stocks. Innovative and / or collaborative procurement models could be interesting.
- Define priority routes for road clearance in case of large scale impacts, such as icing, snowfall, flooding, landslides or storms. These should include all strategic roads and access to key facilities. Strategic routes should be selected on seasonal rather than average annual traffic volumes.

Road weather data providers
- Standardize weather information and hazard warnings across Europe. These should ease the co-operation of meteorological institutions and support suppliers of trans-European transport services.
- Keep track of chain reactions of weather extremes, in particular in agglomeration areas.

Passengers, car drivers, cyclists and pedestrians
- Use different channels of information for a regularly check of emergency warnings and recommendations. Select and adapt the source of information which suits best to your personal habit and mobility style. However, do not over-emphasise their precision.

Public road transport undertakings
- Establish procedures to enable adaptations of timetables and service intensities under inclement weather for the hazard prone regions.
- Explore options of co-operation with competitors under adverse conditions, including the formulation of cost and burden sharing for a fair allocation of risks and benefits.
- Assess the company’s risk exposure and establish appropriate adaptation measures, emergency response plans and emergency preparation. Inform and train the staff on a regular basis.
- Prioritize the establishment of efficient passenger information strategies, including current and potential clients.
- Provide reliable, instant and - if feasible – personalized information on duration of the incident and on travel options in public transports.
Goods forwarders and shippers

- The freight marketplace is characterized by the presence of several companies, often SMEs with self-employed owners. The success of warning alerts and communications policies of public authorities to reduce the impact of extreme weather episodes, rely on timely communication and on coordination plans which involve stakeholders and freight operator associations.
- Freight transport is linked to a complex infrastructure-network, and to multimodal links over vast territories. The effectiveness of policies depend on the coordination of emergency plans amongst transport modes (infrastructure managers) and networks, e.g. national, regional and local roads, ports and the rail network.
- At company level, in particular for SMEs which might lack business continuity and financial means (in comparison to larger companies), the public policies aiming the reduction of underinsurance and the provision of services and information (via internet and social network), may improve the resilience of the company's supply chain against extreme weather events.

5.3 Recommendations for research and technical development

Understanding user behavior

- Explore user needs for personalized emergency warnings and travel recommendations
- Rebound effects of safety technologies: explore the impact of increased passive and active safety technologies on driving habits in critical situations and on drivers’ readiness to prepare for adverse weather conditions.

Technology development

- Improve the liability of driver assistance systems with regards to fatigue control, the recognition of non-motorized traffic participants in the blind angle at low speeds or skid control on slippery (icy or wet) pavements.
- Develop intelligent feedback systems in vehicles keeping the users’ attention even despite possible frequent false alarms, etc.

Economics and incentives

- Develop sustainable business models for the provision of high quality, multi-modal and personalized emergency information systems.
- Work out guidelines for benefit cost assessment of increased reliability of transport undertakings, for the company itself and for the society as a basis for defining appropriate public support schemes.
References

In the following key literature source which have been cited in this booklet or which provide further information are presented by topic area.

CHAPTER 1: WEATHER AND CLIMATE INFORMATION AND FORECASTS

ECA&D – European Climate Assessment & Dataset. Website operated by the Royal Dutch Meteorological Institute KNMI: www.eca.knmi.nl.


ESSL (European Severe Storms Laboratory) C/O DLR, Wessling, Germany. URL: http://www.essl.org/


van der Linden, P, F.B. Mitchell and P. Gilbert (2009): ENSAMBLES - Climate change and its impacts at seasonal, decadal and centennial timescales. Final Report. Project co-funded by the
CHAPTER 2: ROAD WEATHER MANAGEMENT SYSTEMS AND MANAGEMENT PROCEDURES


SWAMP (2010): The Blue Spot Concept – Methods to predict and handle flooding on highway systems in lowland areas. SWAMP project summary report 1. ERA-NET ROAD. Danish Road Institute (DRI) and Swedish National Road and Transport Research Institute (VTI). (www.eranetroad.org)


CHAPTER 3: IMPACTS AND RESPONSE STRATEGIES IN PASSENGER TRAVEL AND SERVICES


CHAPTER 4: RISK ASSESSMENT AND MANAGEMENT AT COMPANY LEVEL


Marsh & McLennan Companies (2013): Question 2: Which supply chain risk areas are of greatest concern to your company? Online: https://www.mmc.com/knowledgecenter/viewpoint/Tackling_the_Rising_Supply_Risk_Threat.php (last access 14/03/17)


Mitsakis E., Stamos I., Diakakis M., Salanova Grau JM (2014) Impacts of high intensity storms on urban transportation: Applying traffic flow control methodologies for quantifying the effects, International Journal of Environmental Science and Technology, DOI: 10.1007/s13762-014-0573-4


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