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Climate change risk assessments and adaptation for roads – results of the ROADAPT project

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Abstract

Infrastructure is the backbone of our society. Citizens, companies and governments have come to rely on and expect uninterrupted availability of the road network. Extreme weather is an important factor for the reliability of the road network. At the same time it is generally understood that the climate is changing and that this will have significant effects on the road infrastructure. Since road infrastructure is vital to society, climate change calls for timely adaptation. Immediately, questions arise how to deal with the large uncertainties involved in the projections of future climate, how to assess their effects on the road infrastructure and related socio economic developments, and how to integrate adaptation into decision making. The ROADAPT project was commissioned under the CEDR Call 2012 'Road owners adapting to climate change'. It adopts a risk based approach using the RIMAROCC framework (Risk Management for Roads in a Changing Climate, developed under a previous ERA NET ROAD project). The approach addresses cause, effect and consequence of weather-related events to identify the top risks that require action with mitigating measures for climate change adaptation. Output of the ROADAPT project is a single ROADAPT-RIMAROCC integrating guideline.

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1. Introduction

Although there are considerable uncertainties involved in both the projections of future climate change and related socio economic developments and in estimations of the consequences of these changes in transportation requirements, there is a constant need for decisions and development of the road transport system. As stated in the CEDR 2012 Climate Change call for research: 'Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network.'

The ROADAPT project is part of this CEDR Call. ROADAPT has an integral approach following the RIMAROCC (Risk Management for Roads in a Changing Climate) framework that was developed within the ERA NET ROAD climate change programme in 2010. ROADAPT aims at providing methodologies and tools enabling tailored and consistent climate data information, good communication between climate researchers and road authorities, a preliminary and fast quickscan for estimating the climate change related risks for roads, a vulnerability assessment, a socio economic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management.

The outputs of the ROADAPT project are guidelines (available at www.cedr.fr) that address all these topics. In the main guideline an overview of all topics is provided. In five subsequent parts the specific topics are addressed in detail. These five parts are:

A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

All the ROADAPT guidelines can be used individually, but should be seen as interdependent and fitting within the broader RIMAROCC framework. The guidelines are primarily written for National Road Authorities to gain insight into the steps to take for a climate change risk assessment on roads. However, the guidelines will be beneficial for a broad range of professionals, including road engineers (geotechnics, hydraulics, pavements, traffic management), asset managers, climate change adaptation professionals, innovation managers and project managers. Although the guidelines focus on roads, the topics and methodology are applicable for other infrastructure assets such as railways or electricity networks as well.

2. Climate change effects on roads

2.1. Extreme weather effects on roads

The ROADAPT guidelines deal with the way road authorities could adapt to the effects of climate change. It is the extreme weather that affects the road infrastructure and the level of service offered to their users, and climate change may result in changed frequencies of extreme weather. Already from the time that the first roads were constructed, the weather influences the performance of the road infrastructure. Therefore, it is important to have an overview of how the weather can threaten road infrastructure and/or road users. Within the ROADAPT guidelines such an overview has been developed as a starting point for all risk and vulnerability studies to the effects of extreme weather on roads. The following items from the overview can be used in studies for both today's and future situations.

- At first the threats are described. They are grouped into 12 main threats and subdivided into 40 sub-threats. The threats can either originate outside the road asset (for example in the case of a flooding or landslide) but can also originate within the road asset (for example wind damage to lightning fixtures or a decrease in driving ability due

to splash and spray). Many of the threats are described in more detail in Part E (selection of an adaptation strategy) of the guideline.

- For each sub-threat information can be found regarding the weather that accompanies or initiates the threats. This climate information is described by the climate variable(s), the unit that is normally used and the time horizon.
- Vulnerability factors are identified for all sub-threats. These factors indicate to what extend the road and/or their users are vulnerable to the threats. Contextual site factors provide information on the area surrounding the road. Infrastructure intrinsic factors provide information on the roads/assets themselves.
- The final part of the table provides information on the impact of a threat if it occurs. Estimates of both the duration and warning time horizon are provided.

2.2. The world's climate is changing

The weather is variable from day to day, year to year and from decade to decade. To deal with extremes, knowledge about the current climate (averages and the return times of extremes) should be obtained. The climate has already changed and it will change further in the future, but it is not known exactly how much. To deal with extremes in the future, knowledge about natural variability and uncertainty on future change is needed as well.

It is generall understood that the climate is changing. Average global temperature has increased by 0,85 °C (0,65 to 1,06) over the period 1880–2012 (IPCC, 2013). Figure 1 provides an example. Other climate variables changed as well. Both intensity and frequency can change and it is very location specific what the change will be. In order to estimate effects of climate change for roads it is necessary to compare the current vulnerability to extreme weather and the changing future vulnerability. Part A of the ROADAPT guidelines provides information on how to estimate the possible climate changes and which data, information and tools exist to help in this respect.

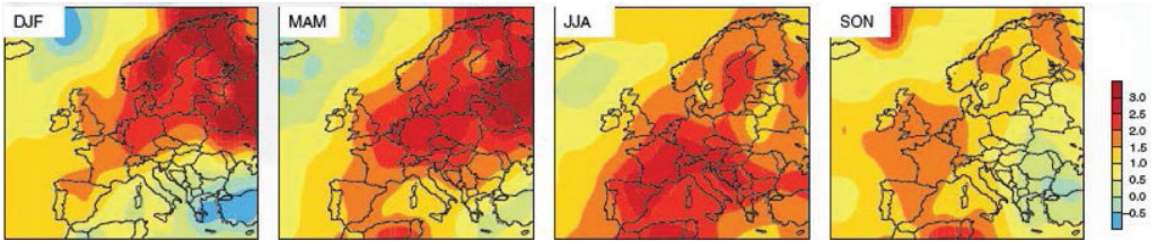

Fig. 1. Observed trends in average temperature over the period 1950-2007 (local temperature increase per degree global temperature increase) in the meteorological seasons: December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON). Data: CRU/Hadley Centre. (Van Oldenborgh et al., 2009).

3. Risk management for roads in a changing climate

3.1. Road owners' demands

There is a constant need for decisions and development of the road transport system and it is understood that a change in climatic conditions may have significant effects. As stated in the CEDR 2012 Climate Change call for research: *"Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network. The prioritization of measures in order to maximize availability with reasonable costs is one of the most important tasks of the road owners"*.

Basically, the main questions of road owners and operators are:

- Is climate change really affecting roads?
  This question is probably already answered by most of the road operators and owners in Europe. It is generally accepted that climate change is affecting road infrastructure or the level of service, one way or another.
- How and where will climate change affect roads?

The underlying question here is about the vulnerability to extreme weather conditions. For road owners and operators it is important to know which unwanted events might happen in the future due to climate change, but also today the weather poses a risk to road transport.

- How likely is it to happen? And if it does happen, what are the consequences?
  When knowing which unwanted events might occur on a road network, it is important to know the likelihood and consequences in order to gain insight in the risk profile. Already in the current climate conditions large uncertainties are present that make it difficult to estimate the probabilities and consequences of unwanted events. When looking into the future the uncertainties will increase even further. The uncertainties make a risk-based approach a worthwhile approach.
- What should be done to mitigate the risks and when?
  If unwanted events are present with an unacceptable risk profile, mitigation actions need to be taken. Road owners and operators need a methodology that assists in the prioritization of measures.

Given the high uncertainties of climate change, there is no straightforward answer to those questions that is valid in all circumstances. On top of this, uncertainties also exist in changing demands for road infrastructure, originating in socio economic developments and changing technologies. In situations with high uncertainties a risk management approach is generally accepted as a way to stay in control.

3.2. The RIMAROCC framework

In the ERA NET ROAD call (2008) “Road owners getting to grips with climate change” the topic of climate change and the way road authorities should deal with it was examined. RIMAROCC (Bles et al., 2010) was one of the results of that call, providing a risk management based framework for decision support for road owners dealing with climate change. Seven main steps and 22 sub-steps help road owners and operators in identifying, analyzing, prioritizing, evaluating and mitigating climate change risks. For a detailed description of the different steps a reference is made to the RIMAROCC guidebook (Bles et al., 2010)

The RIMAROCC framework is adopted as being the risk management framework within the ROADAPT guidelines. The reasons are that it is a basic risk management framework that is in line with the ISO 30001 on risk management and the fact that road owners in Europe are already familiar with RIMAROCC. Also, the RIMAROCC framework is a method that exists of different ‘building blocks’ that can efficiently be updated or changed in a specific situation. This allows the ROADAPT guidelines to be plugged into the RIMAROCC framework, providing a ROADAPT-RIMAROCC integrated approach.

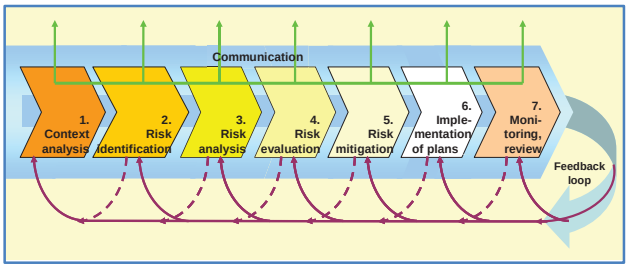

Fig. 2. The RIMAROCC framework.

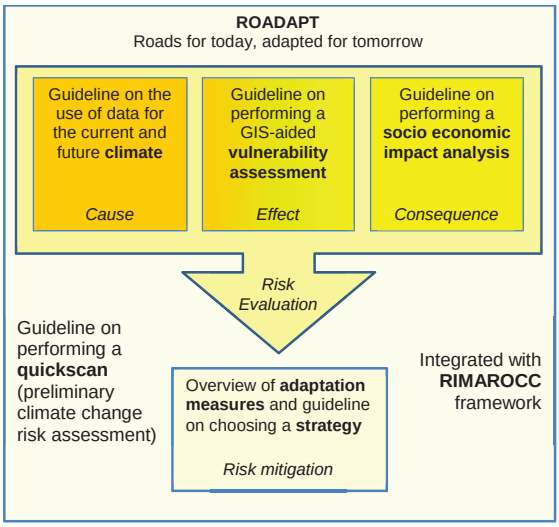

Fig. 3. Structure of the ROADAPT guidelines.

3.3. The ROADAPT structure

The RIMAROCC framework provides all the steps required to perform a climate change risk assessment for roads in a changing climate. However, the number of steps can be perceived as being complicated and difficult to execute. Within the ROADAPT guidelines therefore another scheme is introduced that visualizes all basic aspects that need to be considered in a climate change risk assessment. These aspects can be connected to the RIMAROCC steps; note the matching colours in figures 2 and 3.

Basically, when performing a risk assessment one needs to know something about the unwanted events, their likelihood and consequences.

- In a climate change context, the **cause** of threats (unwanted events) lies within the changing climate. Climate change may be the cause of new threats or a change in the frequency of occurrence or increased intensity of threats to the roads.
- In order to know the **effects** it is necessary to know the vulnerability of the road or road network. By carrying out a vulnerability assessment one gains insight in locations on the road or road network that are susceptible to a certain threat and to what extent.
- The cause and effect together determine the **probability** of a threat on a certain location. The exact determination of the probability often is difficult to assess given the high uncertainties both in the climate change scenarios and the vulnerability assessment.
- By performing a socio economic impact analysis one gains insight in the **consequences** of the threat if it happens on a certain vulnerable location.
- All ingredients for a risk profile are assembled when knowing the cause, effect (together providing the probability) and consequences. This makes it possible to do a **risk evaluation**. In the evaluation the level of acceptable risk is important to define.
- Only the threats above a certain unacceptable risk level need to be **mitigated**. By applying adaptation measures within a certain adaptation strategy, the risk profile of the threats will decrease and should reach the acceptable risk level.

For all the blocks in figure 3, guidelines are developed in the ROADAPT project. An additional guideline deals with a **quick scan** approach to perform a climate change risk assessment resulting in an action plan for adaptation. This quick scan method incorporates all the blocks that are shown and described above, but in a shorter version. All guidelines and other output of the ROADAPT project can be downloaded at www.cedr.fr.

Some remarks on the ROADAPT structure are as follows:

- Based on the steps 1 to 4 in the RIMAROCC framework (context analysis, risk identification, risk prioritization and risk evaluation) a simplified method is developed in order to gain insight in the vulnerable spots of transnational highway sections. Performing the so-called QuickScan provides a substantial first impression on the risks for roads related to climate change.
- The QuickScan method results in an action plan for adaptation. The action plan includes global adaptation strategies for high risk threats that have appeared from the risk assessment. Part E of the guidelines helps in selecting a proper adaptation strategy. RIMAROCC steps 5.3 to 7.3 can be used to further implement the measures.
- Within the ROADAPT guidelines, vulnerability only includes the effects on the road and not the effects of a degraded road. This means for example that an unimportant road without users can still be vulnerable. Poor maintenance can result in a higher vulnerability. By using this definition there is a clear distinction between the socio economic impacts and the vulnerability assessment, or in other words between the effect and consequences of an unwanted event. This way it becomes easier to perform the assessments, since different disciplines are involved. The ROADAPT-RIMAROCC context ensures integration between the vulnerability assessment and socio economic impact assessment.

4. The ROADAPT guidelines

The following chapters provide a summary of the different parts of ROADAPT.

4.1. Part A – Guidelines on the use of data for the current and future climate for road infrastructure

In order to know and understand the effects of climate change for roads, it is of the utmost importance to have proper insight in the current climate and climate change itself. This is the working field of climate scientists. They can provide tailored information to the end users. This implies making interpretations and suggestions for use in a setting of already large natural variability in the current climate and even larger uncertainties when considering future climate.

Climatologists all over the world may use somewhat different data, methods and tools to provide this information to end-users. As a consequence neighbouring countries may use different climate (change) information, leading to discrepancies for cross-border projects. For risk assessments on roads close to borders or especially in border transcending assessments this will lead to incompatible results. ROADAPT aims to provide methodologies and tools enabling tailored and consistent climate data information. Part A of the ROADAPT guidelines deals with this topic.

ROADAPT Part A provides 4 steps to obtain practically feasible climate change information:

Step 1: Determine threats and related climate variables, the reference period and the relevant time horizon;
Step 2: Collect data on the current and future climate for these climate variables and check the quality and usefulness of the data;
Step 3: Determine which projections/climate scenarios to use with the help of the suggestions in the guidelines on the use of climate data;
Step 4: Perform additional processing, if needed, to get the climate data with which the risk analysis can be performed.

The guidelines provide recommendations on how to perform the steps. Information is provided on all aspects that need to be taken into account when working with climate data. The guidelines can be used by NRAs to gain understanding of the work of the researchers and consultancies that work for them. This will improve communication between them as well.

The most important questions that are answered in the guidelines are:

- What datasets on the current climate are available?
- What period to use as a reference to describe the current climate and natural variability?
- How to check the quality and usefulness of climate data?
- How to get consistent climate data with similar quality for all regions of Europe?
- What climate model data and climate scenarios are available?
- What time horizon to use in vulnerability studies?
- How to determine climate change from climate model data?
- What downscaling methods are available and which one to use?
- What methods are available to generate time series for the future from climate model information?

4.2. Part B – Performing a QuickScan on risk due to climate change

Based on the steps 1 to 4 in the RIMAROCC framework (context analysis, risk identification, risk prioritization and risk evaluation) a simplified method is developed in order to gain insight in the vulnerable spots of highway sections. Performing the so-called QuickScan provides a founded first impression on the risks for roads related to climate change, including an action plan for adaptation.

The QuickScan method is applicable in all European countries and therefore probably all over the world as well. This posed challenges to the development of the method since the number of possible threats is very high (see paragraph 2.1) and the fact that road design, maintenance procedures and level of service are different in all (and within) countries as well as road surroundings and characteristics.

The QuickScan method uses all existing data, knowledge and experiences for the studied road network in a structured and explicitly risk based approach. Workshops are the core of the QuickScan method (figure 4). The QuickScan starts covering all possible threats and continuously narrows the focus within an ongoing process.

The stakeholders are brought together in around-the-table-sessions and are asked to provide input regarding the consequences and probabilities. This is done in a semi-quantitative risk analysis using stakeholder defined criteria, both for the probability and consequence. It is recommended to use the following criteria to score the consequences since these parameters are often used by NRAs in their asset management process: availability, safety, surroundings, direct technical costs, reputation and environment. Locations are only identified for threats that are evaluated as having a high risk profile (high combination of probability and consequence, fig. 5).

Quickscan phases

- Workshop 1, **determine consequences**
  Participants: understanding of consequences of undesired events on roads
- Workshop 2, **determine probabilities, top risks and locations**
  Participants: technical know-how of threats
- Workshop 3, **determine action plan for adaptation**
  Participants: combination of workshop 1 and 2

Each workshop has a duration of approximately half a day.

Fig. 4. QuickScan phases.

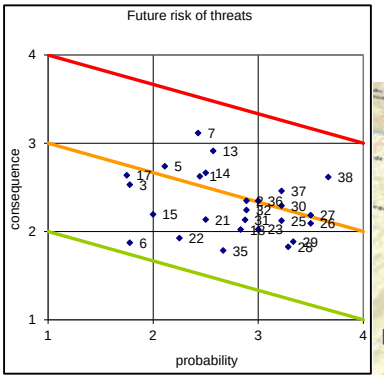

Fig. 5. Risk evaluation using a risk matrix.

Fig. 6. Result of a QuickScan, risk locations.

After the risk evaluation, the threats are identified that have an unacceptable risk level. For those threats an action plan for adaptation can be developed. Since the QuickScan mainly uses qualitative information in workshop settings, many actions will probably be in the field of extra research by performing detailed vulnerability analyses or socio economic impact assessments. The RIMAROCC steps are then followed again but more in depth. Direction can also be provided to the type of adaptation measures by comparing the maintenance frequency or lifespan of the threatened part of the road with the expected time in which climate change becomes relevant. By doing so, adaptation action can be balanced with regular maintenance.

Benefits of the QuickScan method exist due to its capability to narrow the scope of climate change threats, enabling focus of costly detailed analyses on only those locations and threats that appear to have a high risk profile. At the same time, due to its interactive nature with active involvement of road authority staff at all management levels, awareness is obtained within the road authorities itself. During case studies it even proved to work as a team building exercise. Finally, a strong point of the method has proven to be the use of a risk matrix that can be adapted to the existing risk language and risk matrices that are already used within daily practice of the road authorities, enabling the positioning of climate change risk next to other risk.

4.3. Part C – Performing a GIS-aided vulnerability assessment for roads

The objective of Part C is to describe efficient existing tools for assessing vulnerabilities within TEN-T Network roads. In addition, a new comprehensive vulnerability assessment methodology is suggested, based on and compatible with the RIMAROCC method. The vulnerability maps created in the process can be combined with detailed climate change projections. Using the tools and methods described, users can assess vulnerability to all climate change-related threats within the TEN-T road network.

The approach has been to use existing detailed GIS-aided vulnerability assessment methods as far as possible. Vulnerability to different threats is assessed using different methods and what is provided is really a guide to identify and select the appropriate vulnerability assessment method for the threat that needs to be analysed, and a guide to transnational GIS data sources. Vulnerability will be assessed for each threat in a geographic area using a simple three-step method.

The results from the inventory of existing methods show that GIS-aided vulnerability assessment methods are missing for a large number of the climate change-related threats that the TEN-T network is facing. In response, a draft version of a new method, ROADAPT VA, has been outlined in this project. ROADAPT VA calculates a vulnerability index for a selected threat independently of probability and consequence analyses. Therefore this guideline is connected to ROADAPT guidelines part A and part D primarily through RIMAROCC step 3 Risk Analysis.

ROADAPT VA can also be used stand-alone for vulnerability mapping, however, to assess the risk for a certain threat, probabilities and consequences must also be assessed. The output of ROADAPT VA is a list of classified vulnerability factors (contextual site factors and infrastructure-intrinsic factors), vulnerability score maps for each vulnerability factor, and a resulting vulnerability index map. ROADAPT VA is connected to ROADAPT part E through the expected effects of the selected adaptation strategies. There is a range of adaptation measures that are aimed at reducing vulnerability to threats. The expected effects can be visualized by updating the vulnerability index maps accordingly.

4.4. Part D – Performing a socio economic impacts analysis

The part D of the ROADAPT guidelines is related to the socio economic impact assessment in the RIMAROCC-ROADAPT framework. The impact assessment addresses traffic events caused by adverse weather conditions.

The threats will either affect the infrastructure (eg. deterioration of the pavement or landslides) or directly the traffic conditions (e.g. heavy rain or snow) and therefore both cases reduce the road level of service. For road users, the level of service is generally characterised by three main criteria: safety, efficiency and comfort. It is rather impossible to measure the degradation of safety, as safety is dependent on many factors and the most important being the user's behaviour. Comfort is also more a qualitative criteria. The predominant criterion in socio economic assessment in transport is efficiency which is measured by the costs of travelling from A to B. Cost includes energy consumption, vehicle amortization, taxes and tolls together with the value of time spent per passenger or goods that are transported. In general, other externalities like emissions and noise need to be considered and monetised as well.

There is a high level of uncertainty on the occurrence and real impact of weather events. Therefore, the travel time is considered to be the key indicator for the impact assessment. When translating the travel time in monetary value, the other indicators are anyway of second order.

Selection of the threats is based on the outputs of part B and/or C of the guidelines. It is the choice of the NRA or road network operator to decide what threats deserve to be assessed. Usually, the threats that are evaluated as being of high risk need to be assessed. Based on the vulnerability assessment it can be decided which locations of disruption of the road need to be taken into account. Also, the more frequent ones and/or those generating the most severe impact on traffic preferably are assessed. Combinations of threats can be considered by developing a scenario approach, the results not being an addition of the impact of individual events, but a combination of impacts.

Once this choice is made, it is necessary to characterise the potential consequences on the level of service, namely:

- Reduction of speed
- Held up traffic due to for example lane restrictions
- Access restriction with rerouting or storage of vehicles (eg. Heavy Good Vehicles). In this case the degradation of level of service is not directly due to weather events on the assets but to the measures that are taken to minimize the impact of the event to the asset (lower axle weights preventing damage to the pavement).

For a simple network and limited event, a rough estimation of the time lost by all network users can be made and translated in monetary value. The HEATCO project (Harmonised European Approaches for Transport Costing and

Project Assessment; HEATCO, 2006) recommends harmonised values to be used in Europe. But in general, the consequences of a major weather event will impact a large part of the network. It is then required to use a traffic model. A typology of traffic models is presented in the guidelines and recommendations for use are made.

Depending on the shareholder's point of view the socio economic impact will be evaluated at different levels. The guidelines propose three levels of analysis:

- The network level: only the impact on travel time of road users network is estimated
- The territory level (territory which is irrigated by the network): impact on the travel time on the various liaisons that are ensured by the network is estimated
- A wider perimeter which we have named the economic system as a whole and which extends the analysis not only in terms of geography but also in terms of economic activities that can be impacted.

4.5. Part E – Selection of adaptation measures and strategies for mitigation

Part E of the ROADAPT guidelines presents an overview of adaptation measures and helps in selecting an adaptation strategy. This part of the guidelines provides practical support in RIMAROCC step 5: Risk Mitigation. This assumes that the previous RIMAROCC steps have been performed or that the QuickScan approach and the ROADAPT Vulnerability Assessment have been conducted (parts B and C of the guideline), and that relevant climate change threats, asset types under threat and vulnerable locations are known.

ROADAPT has developed a 10 step approach to answer to the road owner's needs for selecting an adaptation strategy. This approach provides a structure for decision making, gives an overview of decisions that should be taken in the adaptation process and factors influencing the choices, and clarifies which techniques to apply, when and why.

<table>
<tr><td>STAGES</td><td>PRO-ACTION</td><td>PREVENTION</td><td colspan="2">PREPARATION</td><td colspan="2">RESPONSE</td><td>RECOVERY</td></tr>
<tr><td></td><td></td><td></td><td>In preparation of an extreme event</td><td>Just before an extreme event</td><td>During an extreme event</td><td>Just after an extreme event</td><td>After an extreme event</td></tr>
<tr><td>OBJECTIVES</td><td colspan="2">Enable smooth and safe traffic</td><td>Support disaster consequence reduction</td><td>Evacuation route, life supply route</td><td>Minimizing loss of functions</td><td>Supply route for repairs and humanitarian aid</td><td>Supply route for recovery of affected area</td></tr>
<tr><td>Planning for CCI&EWE</td><td rowspan="3">Pro-active attitude</td><td></td><td></td><td colspan="3" rowspan="2">Extreme event management</td><td></td></tr>
<tr><td>Robust construction</td><td colspan="2" rowspan="2">Prevention</td><td></td></tr>
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<tr><td>Resilient construction</td><td></td><td colspan="2">Upgrade, retrofit, new construction</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Traffic management for CCI&EWE</td><td></td><td colspan="6">Traffic management</td></tr>
<tr><td>Capacity building</td><td colspan="7">Capacity bullding</td></tr>
<tr><td>Monitoring</td><td colspan="7">Monitoring and prediction</td></tr>
<tr><td>Research</td><td colspan="7">Research</td></tr>
</table>

Fig. 7. Policy matrix for adaptation

The guideline gives specific information to complete the 10 step approach for all climate change threats. Steps 0 to 3 provide background information on the road owner's needs, impacts and current and future resilience of the assets. Steps 4 to 8 deal with the selection of adaptation measures and strategies. The selection process involves selecting a combination of measures that constitute an adaptation strategy and ranking of the measures according to

their consequences for operation and sustainability. Steps 9 and 10 provide an outlook on research that will help climate change adaptation, also estimating the time-to-market to support compilation of research road maps.

The approach uses a policy matrix (figure 7) to identify combinations of measures (policies) that are the building blocks of an adaptation strategy. In this matrix, measures are categorized according to the safety chain (prevention, preparation, response and recovery) and includes hard (eg. robust or flexible construction) and soft measures. (eg. planning, or capacity building). A database of more than 500 adaptation measures supports the use of the Part E of the guideline. The database allows easy selection, ranking and presentation of the measures in the policy matrix.

5. Conclusion

It is likely that climate change will cause both an increase in frequency and intensity of many unwanted weather events that can harm road infrastructure and/or transport using the roads. The changing climate therefore forces national road authorities to think about maintaining service levels. Due to high levels of uncertainty a risk based approach is necessary to identify a proper adaptation strategy.

Within the ROADAPT guidelines a scheme is introduced that visualizes all basic aspects that need to be considered in a climate change risk assessment. The RIMAROCC framework is a method that exists of different 'building blocks' that can efficiently be updated or changed in a specific situation. This allows the ROADAPT guidelines to be plugged into the RIMAROCC framework, providing a ROADAPT-RIMAROCC integrated approach.

Beside these guidelines other practical information is assembled. This includes a table of weather induced threats for roads that might change due to climate change (integrating guidelines), a database with adaptation measures and strategies (Part E) and an overview of climate data requirements of National Road Authorities for the current and future climate (Part A2).

The products and guidelines have been used in three case studies, namely the Öresund region, the Rotterdam Ruhr corridor and the A24 in Portugal. It is concluded that the guidelines are useful, useable and provide valuable input for NRAs to adapt to climate change.

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References

Bles, T., Y. Ennesser, J.J. Fadeuilhe, S. Falemo, B. Lind, M. Mens, M. Ray & F. Sandersen, 2010. Risk management for roads in a changing climate. A Guidebook to the RIMAROCC Method. ERA NET ROAD project

HEATCO, 2006, Harmonised European Approaches for Transport Costing and Project Assessment. Deliverable 5: Proposal for Harmonised Guidelines

IPCC, 2013. Climate Change 2013: The Physical Science Basis, Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. www.ipcc.ch/report/ar5/.

ROADAPT deliverables, 2015, available via www.cedr.fr

Van Oldenborgh, G.J., S.S. Drijfhout, A. van Ulden, R. Haarsma, A. Sterl, C. Severijns, W. Hazeleger & H. Dijkstra, 2009. Western Europe is warming much faster than expected. Climate of the Past, 5, 1, 1-12, doi:10.5194/cp-5-1-2009