CEDR Transnational Road Research Programme
Call 2012: Road owners adapting to Climate Change

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Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Climate projection data base for roads: CliPDaR

Report on the workshop held in Vienna at the ZAMG from the 6th to the 8th May 2013 'meeting the operators'

Deliverable D 2.1

The **CliPDaR** Consortium:

Deutscher Wetterdienst

ZAMG

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

Call 2012

Design guideline for a transnational database of downscaled climate projection data for road impact models

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Executive summary

The Viennese workshop extended over three days and dealt with the 'cold winter issue' (a question raised by the CEDR), the European transport system research, the requirements to be met by the data used, the impact of extreme events on the assets, maintenance and reinforcement efforts, climate change and traffic, etc. The minutes of these discussions are contained in this report as well as minutes from an interview conducted at the ZAMG some weeks later. This interview in the wake of the workshop will be contained in the term 'meeting the operators' henceforth. As such meeting the operators is essential for CliPDaR to accomplish its goals (e.g. the design of a guideline defining a basis for Europe wide risk assessment of traffic infrastructure in view of climate change).

A significant part of the workshop was made up by presentations given by the ZAMG-DWD consortium, which were used to transfer modes of climate research and to trigger brainstorming. Carina Herrmann from the BASt gave a presentation too that submitted the undertakings of a risk research institute towards a far sighted asset management. The presentations are contained in Annex C. The agenda of the meeting and the list of participants from BASt, BMVIT (Bundesministerium für Verkehr, Innovation und Technologie), DWD and ZAMG and, at an additional appointment, from ASFINAG (Autobahnen- und Schnellstraßen- Finanzierungs-Aktiengesellschaft) and ZAMG is given with Annexes A and B, respectively.

Two remarkable results of the meeting the operators are: (i) the isolation of relevant Climatic Indices (CIs), which exert an effect on transport infrastructure and (ii) the deepening of the scientific understanding between the capabilities and limits of climate research and the needs of transport science. Proper CIs display of this understanding and are of enormous relevance regarding risk assessment. Moreover the CIs will lead the operators through the guidelines helping them to understand the applied concepts required to derive meaningful aid when rendering decisions. Next to the CIs the 'cold winter issue' was ventilated. This topic is concerned with the alleged frequent occurrence of cold winters during the recent past. Strategies to quantify this claim and to identify regions in Europe that are affected most are debated. Feasible techniques to assess bygone and future probabilities of such events are introduced.

The findings of meeting the operators were substantially used for the presentation of CliPDaR at the FIRM13 (the FEHRL - Federal European Highway Research Laboratories - Infrastructure Research Meeting 2013) in Brussels in June (http://www.fehrl.org/?m=369). The presentation was rated rather well (9.4 from 10) and we are invited to submit a paper to be considered for publication in the FEHRL Infrastructure Research Magazine. The outcomes of the workshop were presented at the DACH 2013 (Deutsch-Österreichisch-Schweizerische Meteorologentagung) in Innsbruck in September as well (www.dach2013.at).

1 Preliminary remark

Concerning the CEDR Call 2012 "Road owners adapting to Climate Change" the Project CliPDaR ("Design guideline for a transnational database of downscaled climate projection data for road impact models" (long title)) refers exclusively to the objective "A.1 - Review, analysis and assessment of existing (regional) Climate Change projections regarding transnational highway networks (TEN-T) needs". Regarding the questions of this objective the project CliPDaR is engaged in

– Assessment of statistical/dynamical downscaling: to facilitate a proper procedure that deals with the uncertainties of the future climate with respect to the needs of future budgets and maintenance issues
– Assessment of ensemble simulations and climate projections as well as the definition of a pragmatic data provision for decision making
– Assessment of return periods of e.g. cold winters or hot summers.

Because of the given short time line a provision of data is not foreseen within the frame of this project and emphasis is given to the results from already ongoing projects, in particular VALUE and KLIWAS, to contribute to a paper of recommendations for the involved national road agencies.

The mission of CliPDaR is to issue a guideline setting a standard regarding data and methods that shall serve as a basis for pan-European traffic infrastructure risk assessments.

2 Introduction

The workshop (see the schedule in the Appendix A) was especially set up to exchange as much information between transport system research and climate research as possible. This was done by discussions.

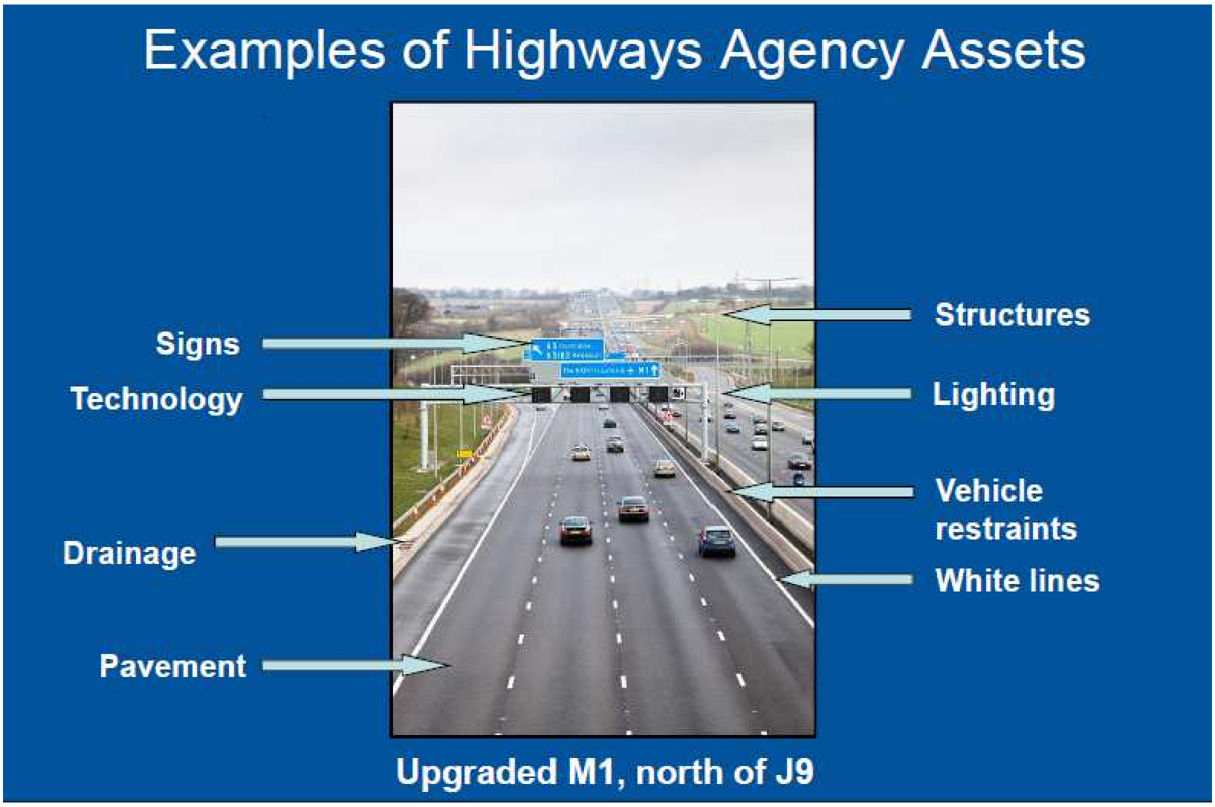


Figure 1: *The picture shows a typical assemblage of transport infrastructure elements, which are affected by climate variability (e.g. uncommonly long and intense precipitation events). They are part of the 'Cause-Effect Matrix' (CET2), displayed in Figure CET2.*

The central goal of CliPDaR is the creation of a basis for a trans-European uniform assessment of the impact of climate change on the transport system (Matulla et al. 2013). This affects the planning of new of roads and the reinforcement of infrastructure already in place with the involvement of changing frame conditions as lined out in the Strategic European Road Research Program V (FEHRL 2011) that are to come throughout the 21st century. The **SERP V** challenge is to generate a concept how to design, construct and maintain future roads. This philosophy is a long-term and forward-thinking approach to the way roads are going to be flexibly designed, built, operated and maintained throughout the century ahead. The 'Forever Open Road' is adaptable, automated and climate change resilient. The DoRN 2012 Call, within which CliPDaR is funded, is designed to contribute to SERP V.

Figure 1 shows some infrastructure elements that are part of the Cause-Effect Matrix (CET2), which is the central element combining infrastructure assets and climate events and as such an important toolkit to set up design guideline handling with measured and projected climate data. CET2 contains infrastructure elements and climate events. Based on CET2 relationships between assets and climatic indices (CIs) are isolated and a functional formulation is defined. Once the CIs are known their possible future changes can be calculated. The strategy behind the generation of the projections, the involved mathematical techniques and datasets are elaborated in guidelines to be issued by CliPDaR. These CliPDaR guidelines are designed to help decision makers to derive better problem-specific solutions.

3 Relationships between climatological elements and infrastructure assets

3.1 Temperature

In Germany there were tests carried out with roads in order to determine efficient ways to store thermal energy during the warm season and to release it when it is cold. One experiment was with large tanks located underneath the road surface (which is crossed with pipes), filled with water and gravel. The gravel-bed was 15 m deep and as wide as the road. In summer, when the sun heats the ground the water from the tank cools the surface and helps against rutting (see **Figure 2**). Rutting arises whenever road surface temperatures exceed a threshold which is about 55° C. When the surface temperature and the water in it is about 50°C the stored liquid in the tank reaches 30°. The idea is to use the thermal energy, which builts up over the summer months, in winter to keep the road surfaces free of ice by pushing the (still warm) warm water through the pipes in the surface. Moreover a geothermal heat pump system could supply energy to close-by residents. The experiment worked but it was too expensive. Two kilometres of such a stretch costed about 80 Mio. Euros. The tank was most expensive with about 77 Mio. Euros. Covering the road with solar panels would deliver much more energy at considerably lower construction costs. Besides it would help to prevent rutting during summer and icing during winter too.

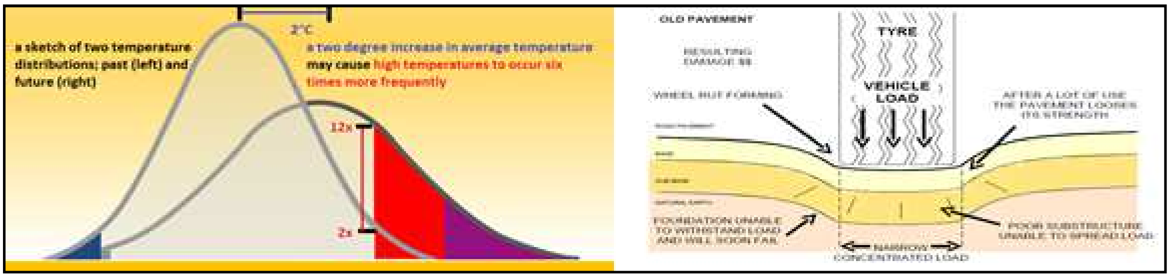


Figure 2: *The left panel shall indicate that a mean temperature rise of about 2 degree Celsius can give reason to a major change in the number of threshold exceedances (here 2 to 12).*

The rutting issue will be used as part of an example to analyse so called 'unacceptable risks' later in the text. Let us assume here that rutting presently happens twice a year (in nowadays climate) and that road managers classify this situation as acceptable. If climate change continues as expected a two degree increase in mean temperatures throughout the decades ahead at any specific traffic spot in Central Europe is feasible. This could result in a distinct change of threshold exceedances (in this example six times more exceedances; see **Figure 2**). Road owner may judge this situation as not acceptable anymore. One possible reaction is to plan new roads or reinforce roads already in place with asphalt compositions that can withstand higher surface temperatures (above 55°C) without rutting. Solar radiation is often mentioned in connection with rutting and it is closely related to temperature. The 2m temperature is a good estimator for tire and surface temperature (BASt); there are PhD theses on modelling temperatures in concrete (down to 4 m into the ground) and asphalt (available from BASt).

Modelling icy conditions has been done by the help of GMA (automated sleekness monitoring stations - 'Glätte Melde Anlagen') and a model called 'SWISS' (road condition and weather information system - 'Straßenzustand- und Wetterinformationssystem').

Falling rocks are often caused by frequent freeze-thaw cycles. We discussed the fact that a changing climate may cause a situation similar to the example given for rutting (see **Figure 2**). Roads presently planned (meaning construction starts within the next few years), which are running through complex terrain as for instance through ravines or along-side to steep slopes, should be in place for a half-century or so (that's what the consortium thought). Therefore it is necessary to consider climate change in the planning and design process. Regions within which presently falling rocks are no issue (since temperatures are rather low and there are almost no zero temperature crossings) may become within the next half-century regions known for falling rocks. (Interestingly Mr. Juznic said that the road owners are prepared to accept a relocation).

Another point that was discussed refers to the 'cold winter problem', which is one central question raised by CEDR and addresses the alleged frequent occurrence of cold winters during the recent past. The reasons are not understood well and are presently under discussion. First attempts to explain this phenomenon are based on observed changes in the frequency of planetary waves. As a result such periods that may last for some weeks occur more often. Thus, winters (averaged over the three months December, January and February) in northern Europe are not as warm as global warming may suggest. ASFINAG offered to check the maintenance costs of the past two decades or so in order to find out if there actually occurred a set of harsh winters in the recent past.

3.2 Water, snow, ice and droughts

In order to control the water on roads they are built with a so-called super elevation ('Querneigungswinkel') which allows water fallen on the road to flow off rapidly (water drain). Critical stretches of roads are to be found wherever curves ('Querneigungs-wechsel') occur and water is not able to effectively drain off the road surface. In such cases a gradient in the direction of paving ('Längsneigung') helps. That means critical parts of roads regarding flow-off conditions are often located in flat terrain and curvy sections.

Landslides are controlled by the hillslope, by precipitation with a focus on long term rain, perhaps also by heavy precipitation events together with thaw-freeze cycles (piled up snow). They further depend on the vegetation (sloped with trees or grass-land), on the ground-water level, the soil composition and layering, land use and geology. Other effects of extreme events coming along with precipitation (either long term rain or heavy precipitation events or rapid ablation of snow cover) are for instance torrents undermining roads and causing erosion (countermeasure: torrent and erosion control 'Wildbachverbauung') or avalanches (countermeasure: averlance dispersion; serious incidents: Grindlwald, Galtür); Another problem coming along with extreme precipitation is the so-called 'bridge scour problem' (Auskolkung von Brücken). Bridges across *big* rivers do not suffer so much from flooding events as transport currents (transport of matter) at the bottom of the rivers close to the ground are relatively calm during such events. This means that bridge foundations are generally not harmed. During low water/tide conditions bridge fundament/piers are undermined by passing water as matter is eroded away (by swirling waters). High waters are not that problematic as high waters leave the sediment transport, taking place close the bottom of the riverbed, unchanged (compared to regular conditions). Floating material or trash carried by floods represents a threat for small bridges - not so much for large bridges as they are built to withstand even impacts by vessels out of control. The causing mechanism (of floods) can be far away from the place the damage occurs. Long-term rain in the Czech Republic, for instance, caused flooding in the estuary of the river Elbe.

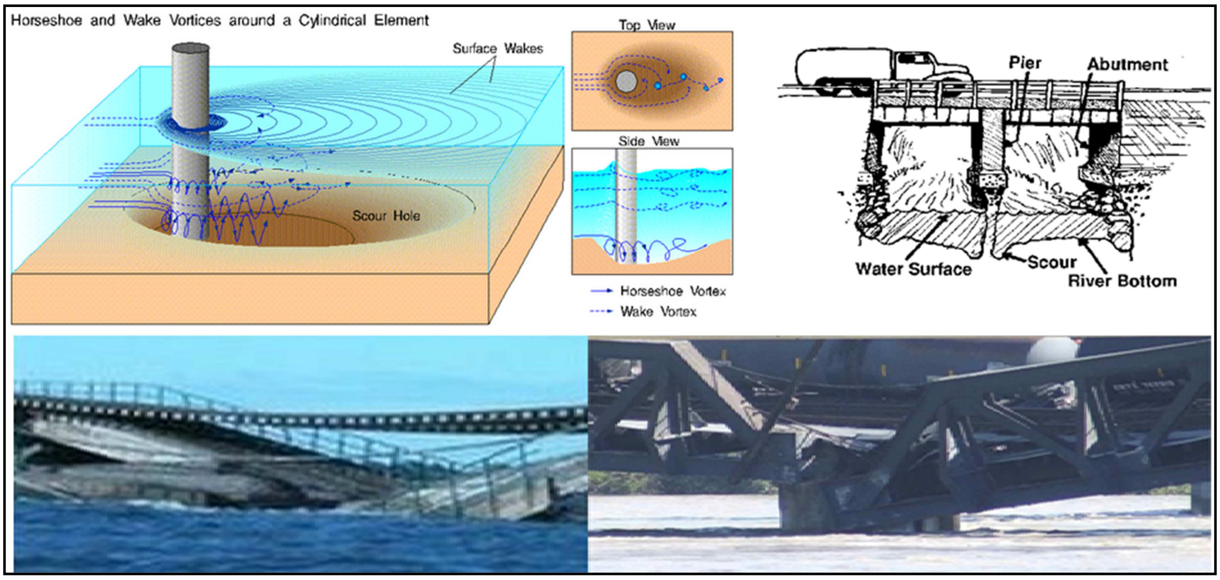


Figure 3: *First row: a sketch of the way scouring affects the foundations of bridges. Second row: Accidents caused by scouring; left: Malahide Viaduct, Irland in 2009, Ireland; right: Bonnybrook Bridge, Calgary, Canada in 2013.*

Figure 3 shows two examples of the destructive force of scouring and a sketch of its functioning. The Malahide Viaduct running over the Broadmeadow estuary north of Dublin collapsed after tidal scouring of its foundations in August 2009. This incident has triggered the establishment of an accident investigation unit, looking at the adequacy of the railway's inspection procedures for bridges over water. In 2013 Bonnybrook Bridge collapsed and six freight cars derailed. Canadian Pacific Railway said that it conducted inspections beyond regular procedures. However, politicians remarked that many people had lost their jobs at CP Rail through the past years and asked how many bridge inspectors were let go.

The BA (Bundesamt für Wasser) runs physical models simulating sediment transport in river beds by the application of the Reynolds numbers used to translate known flow behaviour to unknown flow situations.

Flooding of roads may be caused (i) undersized or by (ii) clogged drainage systems. (i) Climate change may be the reason for undersizing - a corresponding analysis for Hamburg revealed that the canal system of Hamburg may not be able to take up and manage future rain burdens. (ii) Clogging may be caused by weather as hail, storm, thunder storm, heavy precipitation events or torrents carrying material with them. All mentioned occurrences are bringing eroded soil or any kind of sundry items to the system entrances which are then blocked. Fluids are held back unable to drain off and consequently roads are under water. Such events can also affect well dimensioned systems.

Road erosion or the erosion of road embankments/shoulders can be caused by heavy precipitation events following a hot and dry period (soaked subsurfaces were mentioned as well). A dried out embankment can take only the first several mm of precipitation. The rest flows off horizontally sweeping away matter. A soaked shoulder gives to some extent reason for the same (medium conditions seem to be best to protect the embankments). The subsoil is important and often consists of sand or clay. The stability of the bed/foundation/substructure depends on the structure of the subsoil. The CEDR P2R2C2 (Pavement performance and remediation requirements following climate change) project dealt with water on roads and underneath the road surfaces and hence provides more information on that.

Icy conditions normally occur in wet weather with temperatures below freezing. It was discussed that not much precipitation is needed to allow for icy conditions. A dominant Siberian high for instance, which is not accompanied by much precipitation but with rather enhanced atmospheric flow conditions causes icy conditions just as well as rain followed by temperatures way below. Strong winds may also give reason to snow drifts blocking roads. Icy conditions and snow drifts are maintenance issues (e.g. sending out the road service vehicle fleet fitted with snowploughs and salt). Changes in the climate would give reason to changes in e.g. the frequency of such measures or the need to enlarge/shrink the fleet.

The 'snow-water equivalent' (measured in 1/10 of the depth of water covering the ground if the snow was in a liquid state) helps to estimate e.g. the load of roofs or avalanches.

There was a discussion on a landslide killing a road user earlier this year (**Figure 4**). On this tragic occasion a retaining wall was falling on the vehicle and the driver was killed.

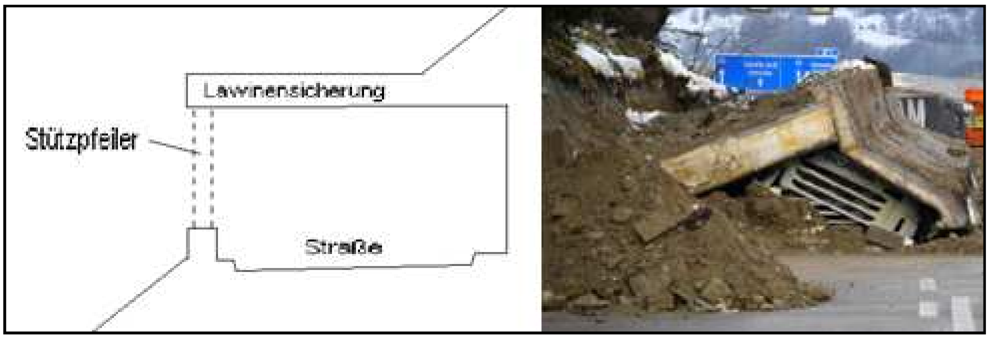


Figure 4: *(Avalanche) galleries protect roads and traffic against avalanches, landslides or falling rocks. They are often located in complex terrain and should be of robust construction as they have to withstand excessive forces.*

There are several possible factors causing such incidents. The water pressure that builts up along hillslopes is getting too high as the soil is soaked with water from e.g. long term or heavy rain events or snow melt (all meteorological processes exceeding a certain threshold in mm). The mandatory planning requirements, which are based on observations, demand such walls to withstand pressures like this. The crucial point is that a changing climate potentially introduces new meteorological situations that were never experienced before. Such situations may be the reaching of higher precipitation totals within an e.g. three day precipitation period producing water pressure values larger than those defined by the regulations. Other reasons relate to (i) planning and engineering errors, which would be an insufficient dimensioning/sizing of the wall in our example, and (ii) constructional defects. A constructional defect would be the presence of damages from corrosion through faulty workmanship.

This example could be used to highlight the innovative character of the Forever Open Road concept of SERP V. This concept includes the climate change resilient road and the corresponding potential is reflected by the involvement of changing frame conditions. Let us make the reasonable assumption that similar accidents are going to happen in the future again. From the past we know that landslides are (not solely but often) triggered by long term rainfall. So, long term rain is a relevant CI when it comes to landslides damaging transport infrastructure. The CliPDaR approach (Matulla et al. 2013) is to evaluate an ensemble of regional scale climate change projections (e.g. the so called KLIWAS-8 ensemble, Imbery et al. 2013) with regard to this CI. If the analysis indicates that such events will occur more frequently in the future together with larger precipitation totals, the planning requirements, which are presently in effect, would have to be adapted to the changing frame conditions.

This makes perfectly good sense in particular if account is taken of the fact that transport infrastructure is in place for many decades.

Earlier this year (May 2013) an important national north-south link through Austria (the 'Felbertauernstraße') was interrupted by a landslide. One part of the road, which is protected by an avalanche gallery, was hit at a width of 100 m. Luckily no one was hurt but the road and gallery was devastated (see **Figure 5**). Authorities said that the route is checked twice per day by employees and all two years by experts. It was suspected that changes in heavy precipitation regimes caused by climate change are responsible. Road owners are now demanded to implement adaption measures as rerouting or relocating the roadbed, to build half-tunnels or other impact reducing construction works.

Figure 5: *The Felbertauernstraße in May 2013, hit by a landslide. In this context it was said that half-tunnels might work as an adaption measure. A total relocation, abandoning the road is only an option if there are other ways to guarantee the supply of remote regions.*

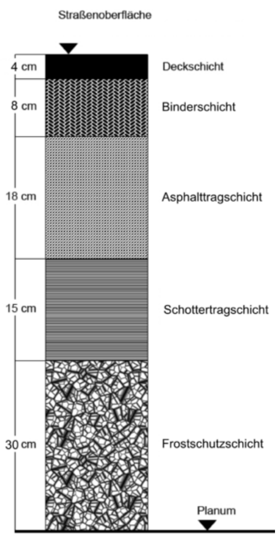
Regarding planning requirements ASFINAG focuses more on precipitation than on temperature. HZB (Hydrograpisches Zentral Büro) delivers the data used to define the dimensioning of e.g. drainage systems pipes. No quality check is performed with the HZB data. For the calculation e.g. threshold values ten years of data are used. ASFINAG assesses the risk of damages to roads by expertise. However, ASFINAG also keeps a log of damage events and analyzes some of the most prominent casualties.

Road accompanying elements e.g. noise protection walls are often mounted in the ground (on a concrete foundation, which is about a half meter deep) next to the runway separated from the e.g. asphalt surface by a gravel part (verge). This (gravel) part is quickly filled with water from heavy precipitation events and destabilizes e.g. the noise abatement wall by erosion (causing changes in density, which is not homogeneous anymore; ‘Bankett macht zu’); Lower ranked roads as common roads (Landstraßen) - are accompanied by verges (Böschungsschulter) which are affected by heavy precipitation as well. In other regards heavy precipitation events are of help. They clean road surfaces from dust and dirt enhancing the tyre adhesion on different road surfaces. The building of new embankments or rebuilding of embankments should be done during the growing season as otherwise the flora planted on it is not growing. So called ‘nature protection’ (protection by nature instead of protection of nature) is important in this regard. Nature projection determines the composition of seeds, which in turn regulates the pace of growth and the function of the seeding (depth of roots, evaporation rate). Excavators sometimes smooth surfaces by squeezing too much and erosion results. Landslides are precipitation controlled (long lasting precipitation events; lasting bad weather conditions; soaked slopes). If there is slowly growing vegetation having little evaporation on a hill, the ground and slope waters are high. If slope waters cannot run off at the lower bottom part of the embankments the risk of slipping processes increases, especially together with flysch sediments. Countermeasures are for instance anchoring bodies (Ankerkörper).

Concrete walls of 2 m height located next to the roadway represent an effective protection against falling rocks. Such protection measures are to be found, in the Inn valley, west of Innsbruck or at the Arlberg.

Snow avalanches represent a serious hazard potential too. North of the highway A10 close to Villach there is an avalanche cone, which is constantly monitored and piled up snow is blasted in case of danger. The CI to picture the appendant risk potential would be maximum snow height.

A project of the Ministry of Life and ÖBB and ASFINAG deals with risk mapping (up to now just spots are evaluated but no areas are covered). Mountain torrents and avalanches will be investigated as well as the temporal change of such maps through time (the first derivative).



Salt damages to road surfaces cause together with frost and thaw processes cracks in the surface. Leachate is a consequence. In the event water penetrates through the surface into the body of the road the entire construction (see **Figure 6** on the left) crumbles and the material bursts. Salt harms roads, vehicles and nature. The spreading of loose gravel is not allowed as well.

Foggy conditions and fog belts pose a risk for road users. Temperatures are typically around freezing and locations known for misty conditions are often exposed. Icy conditions are a risk as well.

Figure 6: *Cross section through a road.*

3.3 Information, regulations, costs

In Germany there are about 53.000 km of federal roads, 12.000 km highways and over 40.000 km other public roads with over 76.000 bridges and 220 tunnels. The corresponding asset value exceeds 360 Billion Euro. It was unclear to us how much money is needed every year for planning and construction and maintaining the transport system. The layout of roads is destined for at least 50 years, those of bridges and tunnels for over 100 years. On such timescales the consideration of climate change is indispensable.

In Germany there is a new set of guidelines for road maintenance staff[1] all ten years. Up to now the problem of climate change is not very prominent in this regard (setting up the regulations) and changes reasoned by climate change (alterations in the dimensioning of infrastructure) are not carried along. This could be achieved rather easily by introducing an additional term into the formulas. Wherever temperature, for instance, enters a formula the value derived from the actual measurements[2] could be adjusted by the expectation value of the climate change signal valid for the future period that is to be covered by the regulations.

For construction purposes the German territory is divided into wind- index zones of four different levels of wind load. This is important for planning issues e.g. bridges. A changing climate may cause these wind-*regions* to change (as was shown for precipitation throughout the 20th century, Matulla et al. 2003) and so the construction regulations would have to change as well. Wind load regulations are based on the fiercest gusts.

Efforts on the European scale (which may become important in the context of future EU funding of road maintenance or reinforcement/etc. works) were mentioned: In the Netherlands a so called ‘key roads’ and ‘blue spots’ infrastructure prognosis was developed; in Denmark an inventory of the adaption measures was conducted; French authorities are in contact with the BASt (TEN-T traffic axes; guidelines) in order to establish a framework for cross border vulnerability analyses.

Concerning predictive design and planning: all 35 to 40 years ASFINAG completely overhauls traffic infrastructure; all two years or so (on schedule) renovation measures are carried out - e.g. cleaning the drainage basins, the gravel in the bed, etc.

[1] ‘Leitlinien für Strassenmeistereien’

[2] In this context ASFINAG considers the observations from the past 10 years as representative for the current climate

3.4 Some hints for a Questionnaire

Please note that the following paragraphs contain central questions and remarks, which are results of the discussions with ASFINAG and BMVIT. They can be assembled and used in a questionnaire, which will be not carried out within the frame of CliPDaR. Such a questionnaire might be of help establishing parts of CET2 (Fig. 7) - which is the very centre of risk analyses regarding climate and transport infrastructure. CET2 together with the modelling of climate change due to human activities allows for the assessment of risk propagation (into the future). This is the basis for a far sighted, cost effective and efficient planning of future transport networks, which is important for the FEHRL Forever Open Road initiative.

Relevant questions popping up from the discussions are:

– Data used and gathered by the road authorities:

Which data are needed and what (spatio-temporal) resolution is applied? What kinds of data have the traffic authorities on hand? Which period of time do they refer to? Traffic surveys/inventories rely on which data? Which impact models are used? What is calculated from the data? To which extent is uncertainty included e.g. in the establishment of construction regulations or in asset modelling? Do logs of damages exist and if so, how far do they reach back in time, etc.? Are there further damages? How long takes the restoration (depending on the damaging event)? What are the logistic costs? What does that mean for the availableness (downtime)?

– Asset management, documentation of infrastructure lifecycles and segments of lifecycles; maintenance and quality assessment of road infrastructure:

Which process follows the assessment of the infrastructure? In which way is the status of assets assessed? What are unacceptable risks? Is there a link to certain infrastructure elements? Have we forgotten something to mention? Infrastructure and related consequences; norms (international /national/-instructions/-emergency plans/plan of action - What is needed? … e.g. a fleet of vehicles of size X). What do the norm plans rely on and how often are they updated? (all 10 years in Germany); What are warning tools based on (e.g. short term weather forecasts)? How does a plan of action look like? What are the: threats, vulnerabilities and consequences (and all the related instances - see the CliPDaR risk definition)? Where are the most vulnerable spots located? Have you experienced the ‘cold winter problem’ during the last ten years? Increased the maintenance costs (%)?

– Defensive measures:

This measures can be roughly subdivided into construction and design (c&d), maintenance (m) and operation (o): the ‘c&d’ measures refer to timescales of years to decades in this context, ‘m’ to weeks up to months and ‘o’ to hours and days. Set up a matrix of climate hazards versus the c&d-m-o measures. How will this matrix change in the near and farther future? For drainage systems: do you get the data from the HZB?

– Damages and consequences:

The following questions (regarding damages, CIs and infrastructure elements) are deemed suitable: How often do damages occur? What kinds of damages are differentiated? How long are consequences in place? Measures of/schedule of (a) warning, (b) damage recovery? What are the economic costs in case of down times? What is the period and frequency? How do the overall costs needed for maintenance and repair works distribute over all damages to infrastructure and temporary interruption of the transport/traffic flow? Which way changes the overall budget through time? Are there time series of percentages referring to different kinds of damages? Damage/disruption events: how long does it take to fix them? How often do they occur? What kinds of damages affect which values (reliability, trust …). Do you have time series of financial losses through time? How do these losses distribute over the categories of damage; address the expenditures to the categories damages/disruption (how much machinery, employees are needed to fix).

3.5 The Cause-Effect Matrix

Traffic infrastructure is of upmost importance to economy as well as to people. The supply of daily goods or the accessibility of hospitals, for instance, heavily relies on the trafficability of roads all year long. Today about 70% of the total freight is carried across roads and this number is expected to significantly increase in the decades to come. The volume of traffic is estimated to grow by 85% of its current value within the next 25 years. Aside from this enormous increase there are other challenges to future road networks that have to be considered such as climate change, demographic development or new advances in technology. All these changes will affect road infrastructure elements. Changing needs for maintenance and reinforcement works require far-sighted planning. Rutting of asphalt surfaces or 'blow ups' of concrete roads are safety issues. They are related to climate indices (CIs) characterizing heat days coming along with tropical nights, which may become more frequent in the future. Changes in the frequency of freeze-thaw cycles or altering precipitation patterns result in different profiles of risks to e.g. road surfaces, slope support or drainage systems.

Bridges, tunnels, supporting structures, through constructions, slope protection measures, road surface, drainages, and pump systems are stationary assets belonging to the road network (see Figure 7). If an individual asset fails the whole system is at risk. As such it is important to know the probability of damages to such infrastructure elements. In this study we focus on climate related risks determining the committed resources to prevent losses. In this context it is relevant to note that strategic decision making on transport issues (planning and designing, construction and reinforcement works and substantial changes in maintenance and budget strategies) refers to periods of some decades, which is the characteristic time scale on which climate change emerges. Infrastructure cycles are on the same time scale as climate change. Hence, climate change has to be considered in today's plans for future transport networks.

Relationships between CIs and road infrastructure elements are of central importance (see **Figure 7**). An objective way to isolate them is to analyze the functional dependency between time series of damages and climatological variables (e.g. road surface damages and temperature evolution). Another way involves expert knowledge on physical processes and experience. As no time series of damages were on hand expert knowledge was gained through workshops and interviews. Above we describe quite some infrastructure elements together with CIs potentially harming them (Figure 7 shows a collection of them). Concerning climate change this 'cause-effect tensor' (CET2) is the very centre of the whole task scope ensuring the smooth functioning of transport networks in the future.

The opportunity to estimate changing risks depends on the capacity of climate change projections. In the following the generation of local scale climate change projections is elaborated. Therefrom the future behaviors of the CIs are calculated, which are needed to assess the impact on transport infrastructure. CIs vary in space, time and complexity. Depending on the climatic phenomena CIs can be valid for regions extending from hectares to thousands square kilometers and can be made up by one or more parameters averaged over different periods of time.

CET2 together with the simulation of climate change caused by the release of greenhouse gases into the atmosphere permits the assessment of future risk evaluation. This allows the design of transport networks which are resilient to climate change and effective. Such an approach meets the requirements of the FEHRL Forever Open Road concept. CliPDaR defines the framework allowing a uniform assessment of the risks of damages to the European transport system (Matulla et al. 2013). This refers to the design, construction and maintenance of transport assets taking into account the involvement of changing conditions, which will emerge throughout the decades to come. The **SERP V** challenge reflects just that (FEHRL 2011, Strategic European Road Research Program V). As such CliPDaR contributes substantially to the Forever Open Road approach. The 'Forever Open Road' is adaptable, automated and *climate change resilient*.

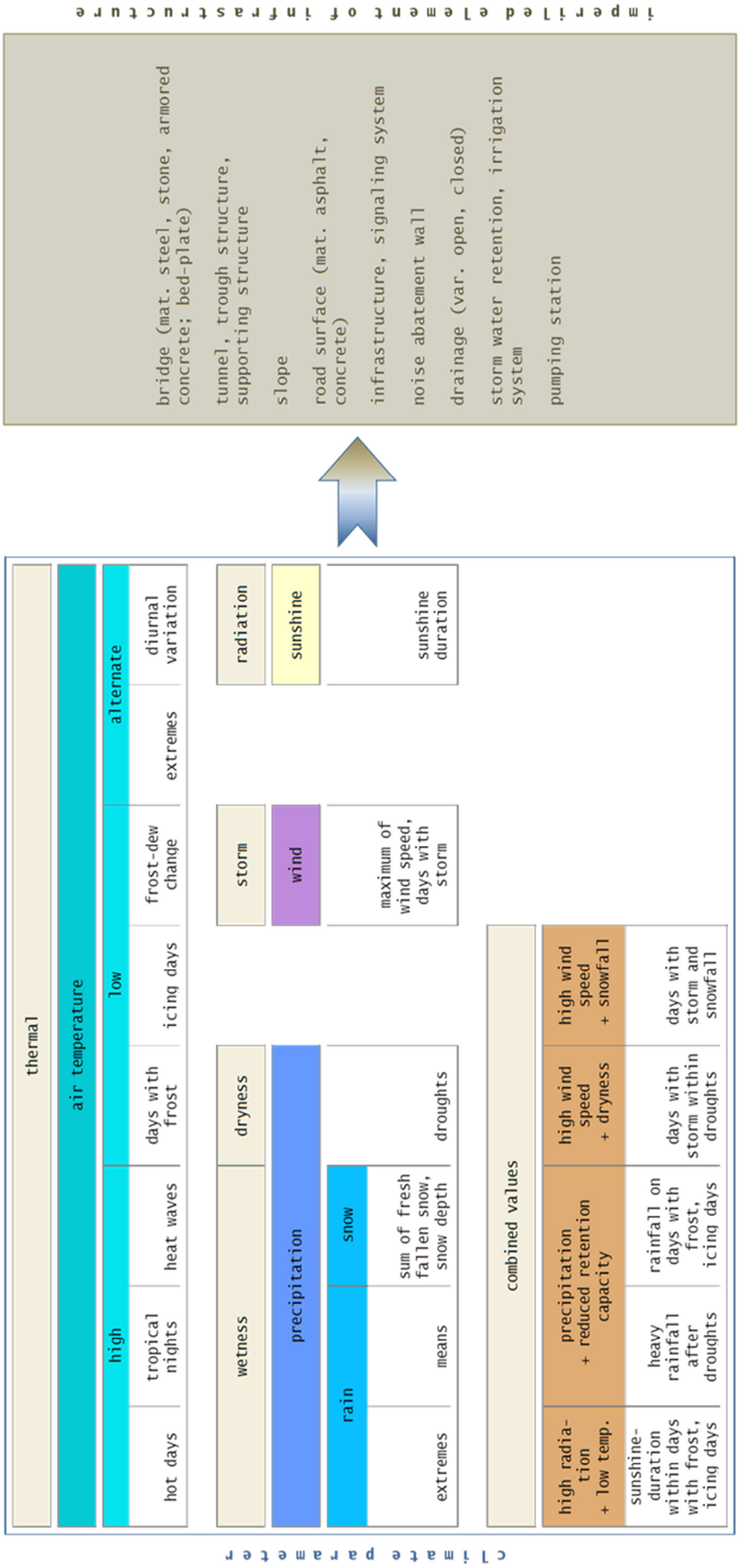


Figure 7: *Some infrastructure elements and climatological indices (CIs) causing financial and other loss (after AdSVIS 2012).*

4 Concluding remarks

CliPDaR will establish a design guideline treating climate change scenarios, downscaling techniques and statistical methods necessary for the generation of regional scale scenarios across Europe. This sets the basis for consistent, Europe wide risk assessments of road infrastructure regarding climate change.

As such it is important to identify climate indices (e.g. long term rain events, hear spells) harming road assets. This is to be done in cooperation with the road administrations, people in charge and constructional engineers. The Austrian - German Workshop in Vienna (6th to 8th May 2013) is devoted to that. Additionally, interviews with road experts have been arranged. Thus CliPDaR will address this with workshops, interviews and participation in international meetings (e.g. FEHRL FIRM13 in Brussels). Next to that, KLIWAS and VALUE as well as the German Adaptation Strategy (DAS), the Austrian Adaptation Strategy and the IPCC Recommendations (IPCC 2007) regarding adaptation measures will be taken into account.

These sources will be completed by the German Federal expert discussions on "Climate impacts" and on "guidelines 'dealing with climate projection data'". All these documents will be considered when preparing the CliPDaR guidelines.

5 Acknowledgements

The research within CliPDaR is carried out as part of the CEDR Transnational Road research Programme Call 2012. The funding for the research is provided by the national road administrations of the Netherlands, Denmark, Germany and Norway. Nathalie Nosek (ZAMG) helped to organize the workshop and ensured that the event is a success. Christine Hagen (ZAMG) assisted us in preparing this report.

6 References

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Matulla C., J. Namyslo, K. Andre, B. Chimani, and T. Fuchs 2013: Design guideline for a Climate Projection Data base and specific climate indices for Roads: CliPDaR accepted for publication by the *FEHRL Infrastructure Research Magazine* (FIRM).

7 List of Figures

Annex A: Time Schedule

Project "Climate Projection Data base for Roads - CliPDaR"

Workshop (WS) 'Maintenance issues of road owners concerning climate adaption needs' (CliPDaR-M2.4) – Working Title 'Meeting the Operators'

Place: Vienna (ZAMG)

Duration: From Monday, 06.05. (09:00 hrs) until Wednesday, 08.05.2013 (15:00 hrs)

Agenda

	Monday 2013-05-06	Tuesday 2013-05-07	Wednesday 2013-05-08
morning	**9:00-12:00** Coordination meeting and preparation of the facilities	**10:00-12:00** Climate change and Impacts on the transport infrastructure II Spatio-temporal scale of damaging climatic events Projects designed for traffic infrastructure research at BASt Maintenance, reinforcement, restoration plans and costs The data needed by the Transport Authorities Current emergency plans, warning tools, maintenance planning	**10:00-12:00** Road quality parameters and climatic indices Climate change and Impacts on the transport infrastructure III Reinforcement and repair costs depending on the infrastructure element Changes in temperature and precipitation Maintenance cycles, regions of special interest and possible adaption measures The necessary and achievable grade of detail of the projection data
afternoon	**13:00-17:00** The CliPDaR project Climate change and Impacts on the transport infrastructure I Traffic axioms, unacceptable risks and costs Climate change challenges to be handled by the Road Authorities Traffic infrastructures, most vulnerable spots, hazardous terrain European traffic system research Construction codes, norms, safety strategies and policies Questionnaire	**13:00-17:00** Extreme events possibly harming transport routes Safety, durability, reliability/cooperation between the transport Authorities The 'cold winter' problem Available data and impact models used by the Transport Authorities The interface between strategic transport research and climate research Hazards causing the most significant damages	**13:00-15:00** Data exchange infrastructure - climate Norms, (inter)national regulations in road and railway network avoiding down time Wrap up and farewell

Annex B: List of Participants

Name	Company	Mon, 2013-05-06	Tue, 2013-05-07	Wed, 2013-05-08
Konrad Türk	ZAMG	x	x	x
Roland Juznic	BMVIT	x		
Ingeborg Auer	ZAMG	x		
Carina Herrmann	BASt	x	x	x
Barbara Chimani	ZAMG	x		
Christoph Matulla	ZAMG	x	x	x
Joachim Namyslo	DWD	x	x	x
Franziska Strauss	ZAMG	x		
Markus Auerbach	BASt	x	x	x
Ernest Rudel	ZAMG	WELCOME		
Nathalie Nosek	ZAMG	BETREUUNG		

List of participants of an additional appointment (May 30th 2013):

Name	Company
Christian Mlinar	ASFINAG
Konrad Andre	ZAMG
Christoph Matulla	ZAMG
Roland Juznic	BMVIT

Annex C: Powerpoint Sheets (pdf-Format) of the presentations

"Climate change research and a focus on traffic infrastructure (I)"

"Road damages and changes in the climate system"

"The 'cold winter' problem" (a CEDR claim)