RIMAROCC

Existing methods for risk analysis and risk management within the ERA NET ROAD countries

- applicable for roads in relation to climate change

State-of-the-art

Report, Deliverable 1

June 2009

This project was initiated by ERA-NET ROAD.

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Project Partners:

EGIS, France

Deltares, the Netherlands

NGI, Norway

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Executive summary

To gather information on existing tools for risk analysis and risk management within the ERA-NET Road member states, with special reference to roads, a series of workshops have been arranged. As an important complement a request for information was sent out by E-mail to ERA NET Road contact persons with a presentation of the Rimarocc project. Four specific questions were asked:

- How do you work with risk analyses for roads in your country?
- How is climate change addressed?
- Are any special approaches in risk analysis and risk management used? References?
- How are the risk analysis carried out (short description)?

There is work going on in many ERA-NET countries and others with regard to risk analysis and climate change. From a state of the art research three methods seemed particularly interesting and need to be further examined. These methods are the French GeRiCi-project, the UK adaptation strategy and the Deltares approach.

The concept of risk is generally understood as a set of three questions; What can happen? How likely is that to happen? If it does happen, what are the consequences? The management of risks includes a set of steps that can be illustrated by the Highways Agency Adaptation Strategy Model (HAASM), shown in Figure 1-1.

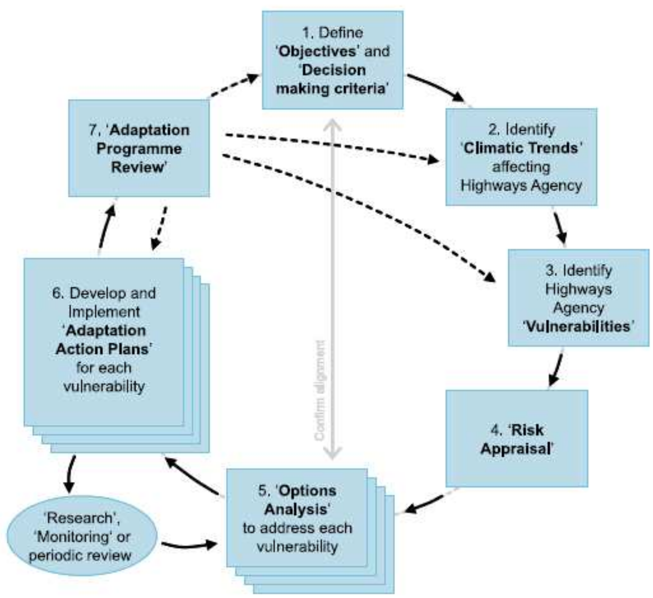

Figure 1-1: The Highways Agency Adaptation Strategy Model (Highways Agency, 2008).

An important question discussed within the Rimarocc project is; what should be in common and what should be specific for different regions and countries? It is important to take into account that the actual risks are significantly varying over Europe and that the end-user tools for risk analysis and management must be "site specific" to a certain degree, but the methods should also have much in common aiming, at being to a large degree independent of geographical location and scale and kind of climate factor in question.

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Preface

This report is part of the Rimarocc project with the objective to develop a common ERA-NET ROAD method for risk analysis and risk management with regard to climate change for Europe. The project is led by a Project Management Group with representatives from all partners SGI, Bo Lind (co-ordinator); EGIS, Michel Ray; Deltares, Thomas Bles; NGI, Frode Sandersen. The Project Steering Group from the ERA-NET Board, Åsa Lindgren (Project Manager), SRA, Sweden; Alberto Compte, CEDEX, Spain and Geoff Richards, HA, UK, have in a constructive way contributed to the project together with other persons from the ERA-NET organisations and other co-workers - they are all gratefully acknowledged.

1. Introduction

1.1 *Background and purpose of the project*

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" was a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) were United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.road-era.net). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research project are Austria, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Poland, Sweden and United Kingdom

1.2 *Definitions*

To understand the concept of risk, a definition can be helpful. Risk can be defined simply as "an effect of uncertainty on objectives" that reveals itself by ways of undesired events. When one asks, "What is the risk?" one is really asking three questions: What can happen? How likely is that to happen? If it does happen, what are the consequences? (Kaplan & Garrick, 1981). The answer to the first question is called a scenario; the answer to the second is the likelihood. The consequence can be measured for example in number of deaths or cost. Both the estimation of likelihood and consequences deal with uncertainties which is a key aspect of risk. One scenario with its corresponding likeliness and consequence constitute a triplet. All possible scenarios must be included to calculate the risk, so risk is defined as the complete set of triplets (Kaplan, 1997 and Kaplan & Garrick, 1981) or in other words the product of likelihood of an undesired event and the consequences of that event (van Staveren, 2006).

In the draft for ISO Guide 73:2009, Risk management — Vocabulary (ISO, 2009), a risk management framework is defined as a set of components that provide the foundations and organizational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management throughout the organization. The risk management framework focuses on the implementation of and working with risk management in organizations or within projects.

A possible definition of the risk management process can be written as follows. This is a method or procedure with several steps that are explicitly and continuously taken in order to control the risks within a project or organization with the objective to increase performance. Risk assessment is part of risk management and deals with the identification, analysis and evaluation of risks. For more information a reference is made to ISO 31000.

To gain understanding in the difference between risk analysis and risk management Table 1-1 can be used.

Table 1-1: Differences between risk analysis and risk management.

Risk analysis	**Risk management**
Technical product focus	Integral project / organization focus
One specific phase	All project phases
One problem approach	Multi problem approach
One stakeholder	All stakeholders
Mono disciplinary	Multi disciplinary
Intrinsic uncertainties	+ Extrinsic uncertainties

1.3 *Methods for risk assessment*

Risk management is used to address a wide range of risks of different nature. A wide spectre of methods for risk assessment with different scope and detail level are available to assess these risks. Some are better for comprehensive risk analysis while others are more suitable for detailed studies of a limited system. The risk assessment methods can be divided into groups based on data type, ranging from qualitative to quantitative analysis (van Staveren, 2006).

Quantitative methods focus on numbers and frequencies rather than on meaning and experience. The calculations include statistics to address inevitable uncertainties in models and raw data and the results are presented in probability functions or risk curves. Examples of quantitative methods are *Quantitative Risk Assessment (QRA)* and *Probabilistic Risk Assessment (PRA)*.

Qualitative methods are ways of collecting data which are concerned with describing meaning, rather than with drawing conclusions from statistics. Qualitative methods are primarily used to identify risks and can be used to rank the risks on an ordinal scale, e.g. from “low” to “high”. Examples of qualitative methods are *HazOp*, *“What if?”-analysis* and *checklists.*

Semi-quantitative methods lead to some kind of quantification of risks without using for example probability distributions or data analysis as described at the quantitative method. The quantification is reached by using meaning and experience for scoring the probabilities and consequences. Semi-quantitative methods are useful when on the one hand not many data are available but still a detailed and well thought of classification is necessary with somewhat quantitative content.

2. Methods for risk analysis and risk management

2.1 *Background*

This state-of the art report is limited to the situation within Europe and the ERA-NET Road countries. To gather information on existing tools for risk analysis and risk management within the ERA-NET Road member states, with special reference to roads, a series of workshops have been arranged. As an important complement a request for information was sent out by E-mail to ERA NET Road contact persons with a presentation of the Rimarocc project. Four specific questions were asked:

- How do you work with risk analyses for roads in your country?
- How is climate change addressed?

- Are any special approaches in risk analysis and risk management used? References?
- How are the risk analysis carried out (short description)?

2.2 *General methods, traffic and transport*

From gathered documents and information a summary of how some Road Authorities within the ERA-NET Road countries deals with general aspects of risk analysis and risk management with regard to traffic and transport is presented below.

2.2.1 The situation in France

In France, the Ministry of Ecology, Energy, Sustainable Development and Land Planning (MEEDDAT) is entrusted with the **prevention of sanitary, technological and natural risks**. The overall policy related to prevention and management of risks consists in collecting as much information as possible to improve the present knowledge on risks, identifying and assessing the risks (e.g. through inspection operations), controlling and organising the monitoring of risks, promoting risk reduction measures, elaborating new regulations, and informing the public to develop a collective culture of safety.

Transport infrastructures are taken into consideration when preparing Prevention Plans for Technological Risks (PPRT). In this framework, transport infrastructures are considered through risk exposure of the drivers to a technological hazard (i.e. a nearby hazardous industry) and the possibility of using these infrastructures to convey first aid and to evacuate the exposed population. The analysis focuses on the infrastructure role in the territory (function, users, traffic…) and on the technico-economic feasibility of alternative solutions to provide the same service (e.g. transit). This analysis is carried on in tight relationship with the infrastructure operator, which provides most of the required data. There is no general methodological approach due to the diversity of situations.

The vulnerability of the infrastructure users is usually assessed through the following indicators: frequenting (number of exposed persons), degree of fragility of the considered population (children, disabled, aged persons …), degree of protection (building quality and specificities). It is to be noted that in this characterisation of the vulnerability, the exposure duration is supposed to be more than a few minutes. As a consequence, with regard to technological risks, the vulnerability of transport infrastructure users is considered as relatively low.

For the time being, **risk management for roads is mainly limited to issuing design standards** (e.g. according to vehicle velocity) **and controlling drivers' behaviour** (alcohol, speed, belt …). Climate parameters are taken into account when designing transport infrastructures, but climate changes are not yet considered.

Infrastructures are designed on the basis of regulations and calculation codes which supply typical intensity data for climatic phenomena (wind speed, rainfall, snow depth, temperature variations, etc.), associated with a return frequency (ten-year rainfall, hundred-year flood, etc.). The choice of the return frequency expresses the risk level accepted by the public authorities with respect to a financial cost deemed reasonable.

The intensities (and frequencies) have been defined correlatively with meteorological phenomena experienced in the past, and are readjusted according to corresponding changes recorded: this was the case in particular concerning snowfall, following the exceptional data recorded in France during the 1990s.

The Climate Plan, adopted in 2004, is aimed at tightening and accelerating measures to reduce emissions and improve adaptation to the impacts of climate change. Numerous studies concerning transport have already been conducted on reduction of GHG emissions (especially through the PREDIT Programme), but studies dealing with adaptation are scarce.

In the framework of the Climate Plan updating, the Government validated the **National Strategy for Climate Change Adaptation**, prepared by the National Observatory of the Effects of Climate Warming (ONERC) in July 2007. Under this strategy, several actions are currently being implemented, such as: definition of scenarios for simulating local climate conditions during the 21st century; census of critical situation management procedures related to climate; analysis of climate change vulnerability of the various activity sectors … Concerning transport infrastructures, the national strategy report emphasizes that neither public transport companies nor motorway companies have already carried out studies on their sensitivity to climate change, with the notable exception of the GERICI project (see hereafter). The sole recommendation provided by the National Strategy for the transport sector is about the creation of an information exchange forum on climate changes between the administration and the infrastructure operators. This forum would facilitate the assessment of climate change effects and would improve the adaptation policies.

The National Strategy report mentions that only the RGCU (Civil Engineering and Urban Network), with co-financing by the public works ministry, has launched a research programme (in 2003) on the impacts of climate change on transport infrastructures. The main outcome of the programme was the elaboration in 2007 of a specific tool, named **GERICI** (Risk Management related to Climate Change for Infrastructures), developed for infrastructure operators by the engineering Egis group, with the assistance of two motorway operators (Sanef, ASF), Météo-France, LCPC and Esri France. The GERICI approach is further described in Section 3.1.2.

Besides the GERICI approach, two other risk management experiments are to be noted:

A **Seismic Risk Assessment Tool for Existing Road Networks** has been developed by SETRA, SNCF and CETE specialists in recent years, when new seismic codes were published. Initiated in 1997 under the supervision of the Directorate of Roads of the French Ministry of Public Works and Transportations, the SISMOA method was created in order to estimate the vulnerability of existing bridges under seismic actions. Based on geometrical and typological criteria, this qualitative method resulting from the vulnerability assessment of the different parts of bridge structures such as the deck, abutments, piers, foundations…, was tested with success on several seismic critical areas of the French territory, chosen to be representative of a certain type of construction as well as social and economical aspects: the county of Nice in the South of France, the city of Grenoble close to the Alps Mountains and the Caribbean French Island of La Martinique. The purpose at that time was to get a tool able to determinate which bridges should be retrofitted in priority in order to meet seismic requirements.

In 2002, the Directorate of Roads decided to extrapolate the method, from isolated bridges approach to road sections approach. This significant development supposed to perform the same kind of analysis on other structures like retaining walls and tunnels and also to deal with other types of seismic induced hazards than code accelerations, such as liquefaction hazard, site effects, landslides, rock fallings etc. From a purely structural engineering issue, SISMOA therefore moved to an issue gathering knowledge and experience from structural engineers, geotechnical engineers as well as seismologists and geographic information systems (GIS) experts and was renamed "SISROUTE". In addition to the establishment of retrofit priorities for bridges, the objective became the global risk assessment of a road being cut off for different earthquake scenarios including code seismic zoning as well as deterministic and probabilistic local seismicity approaches. Currently, the methodology SISROUTE is at a stage where it is tested and calibrated on a small road section in the area of Nice. It will then be upgraded in order to be able to provide a synthetic visual representation of the risk assessment on any given road network.

Climate change vulnerabilities and adaptation possibilities have been investigated for the French energy infrastructures by the Climate Mission of the Caisse des depôts (CDC). The energy infrastructures considered concern the energy production, storage, and the energy grid. The vulnerabilities to climate change were analyzed taking into account both the seasonal and the extreme events. Two models of the IPCC (A2 and B2) were considered to explain the expected temperatures increases and rainfall patterns in France. The conclusions show that the major difficulty in adapting to climate change is the uncertainty regarding climate change impacts at the local and regional level and thus one should be sure to build in some flexibility that will prevent losses in the case that a climate event does not occur as predicted. However, a panorama of adaptation possibilities for the energy infrastructures in France is proposed as well as some comments on financing adaptation actions.

Two research programmes on infrastructure risk management are currently being developed by the Service of Technical Studies for Roads and Motorway (SETRA) and the Centre of Technical Studies for Equipment (CETE). One is devoted to the analysis of risks on sensitive infrastructures (e.g. bridges) and the other is a global thought on the integration of natural and technological risks in building conditions. Climate change is supposed to be briefly dealt with in the two approaches. Final issues should be released by the end of the year.

2.2.2 The situation in Ireland

As an answer to the request sent out (see Section 2.1) the following information has been received from Ireland (O'Keeffe, 2009):

Special documents concerning risk analysis and risk management within the Road Administration are not available today. Risk is mostly associated with environmental factors e.g. risk of accidental spill, risk of surface or groundwater contamination, risk to protected areas (SAC,s). Climate change is addressed in drainage design – rainfall intensity is increased and climate change is addressed in air quality CO2 emissions from traffic.

The approaches in risk analysis and risk management used are:

For drainage design DMRB HD33/06 is followed (HD 33/06: SURFACE AND SUB-SURFACE DRAINAGE SYSTEMS FOR HIGHWAYS).

For Risk assessment; DMRB HA 216/06: ROAD DRAINAGE AND THE WATER ENVIRONMENT is followed.

For Air Quality NRA website

"Guidelines for the Treatment of Air Quality during the Planning and Construction of National Road Schemes"

How the risk analyses are carried out is described in detail in the above documents.

2.2.3 The situation in the Netherlands

Risk Management

All big infrastructural projects in the Netherlands are realized, based on a risk management approach called RISMAN. Risk management is important in every project phase. It is a cyclic process that is passed through continuously (see Figure 2-1). Each project phase starts with a risk analysis to identify all relevant risks for this project phase and the phases to come. Subsequently the next steps in the cycle are passed through repeatedly until the end of the project phase. The next phase again starts with a risk analysis, followed by the other steps.

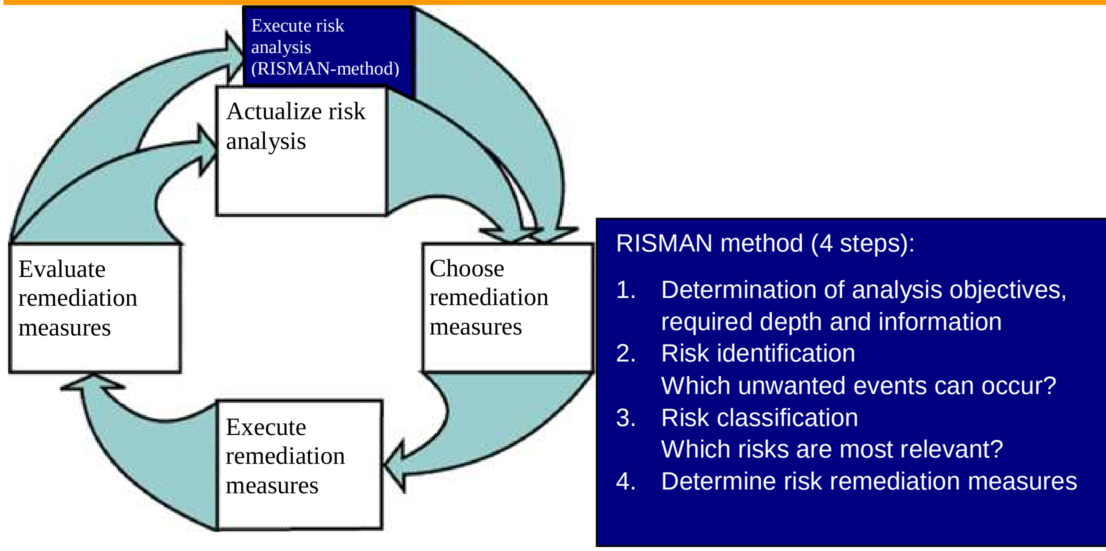

Figure 2-1: The risk management approach RISMAN (www.risman.nl).

One can use different tools when executing a RISMAN analysis, such as:

- A risk matrix in order to identify and classify risks in a systematic way. (making use of stakeholder analyses or 7 identified aspects (RISMAN-glasses): technical, organizational, spatial planning, political/governmental, legal, financial, social)
- Diagrams such as fault/event trees of influence diagrams in order to keep overview over all identified risks
- Software to be able to perform (if necessary) quantitative risk analyses and check the feasibility of the planning

The complexity and size of a project determine how much effort should be put on risk management. More information can be found on www.risman.nl (Dutch). Here is also described how one can organize risk management in a project.

The described risk management method mostly deals with the design and realization of infrastructural projects. The demands for design of road infrastructure (geometrical design, i.e. cross sections, radius of curves, longitudinal and transverse slopes, evenness, factors of safety of slopes, etc.) are described in standards and guidelines. The basis of these standards and guidelines is based on experiences and research (risk analysis).

Decision support tools

In recent years, a tool is developed called *MRoad*. The model explicitly links realization and maintenance costs, sustainability and traffic nuisance during construction and usage of the road. MRoad helps clients by gaining insight in a realistic budget, construction time, influence on surroundings and future maintenance related to functional demands of the road. Furthermore, MRoad helps clients by making risks of construction on soft soils transparent. Contractors can make a fast design during the tender phase that fits with the demands. MRoad helps them by showing this to the client.

Together with many participants Deltares developed a Decision Support System called *Balans* (Balance) for municipalities. This system makes it possible to take into account all the generic factors of influence on the decision making between traditional or alternative rehabilitation methods for roads based upon optimal life cycle costing and -management. The program is available through a web application and consists of three separate modules:

- A module to determine the expected future time schedules of rehabilitation of various traditional and alternative road constructions entered in the program, underground infrastructure included.

- A module to determine costs, like costs for rehabilitation, but also environmental impact translated into costs, costs of transportation etc.
- A module in which the most optimized rehabilitation method is determined by comparing costs, but in which also a multi criteria analysis is used to compare aspects that cannot be expressed in costs (like influences on the direct surroundings and recurrence of nuisance in the streets due to maintenance).

2.2.4 The situation in Norway

In Norway there is an ongoing research and development programme with the main objectives to investigate the effect of climate change on the road network and recommend remedial actions concerning planning, design, construction and maintenance with the goal to sustain safety and accessibility. The 4-year programme named “Climate and Transport” was started in 2007 by the Norwegian Public Roads Administration (Statens vegvesen) and will be carried out with the help of a large number of partners, mainly Norwegian research institutes and Government institutions. The programme spans from monitoring climate research and updating of design values to adaptation of emergency plans and implementation of changes in operation and maintenance contracts. Considered risks include flood, erosion, avalanche, landslide and extreme snow, wind, and temperature conditions.

Already existing within the Norwegian Public Roads Administration are guidelines for risk assessments in road traffic, which are described in a handbook; Handbook 271 “Risk assessments in road traffic” (Statens vegvesen, 2007a). The guidelines focus on road safety and the risk for accidents. The content of the handbook includes:

- General model for risk assessments in road traffic
- Risk assessment of plans
- Risk assessment of existing road
- Risk assessment of crossings for pedestrians and cyclists in population centres
- Risk assessments in operation and maintenance

The risk assessment is initiated by the decision-maker needing information about risks linked to different choices. The risk assessment ought to be undertaken in a group of at least three people with various backgrounds, to highlight the problem from different aspects and to obtain a fruitful discussion. Relevant competences would be traffic safety, road planning, road management, operation and maintenance, road-user behaviour and vehicles. A person with competence in risk assessment ought to lead the process. The general model for risk assessments in road traffic consists of five steps as described in Figure 2-2.

1. Describe analysis object, purpose and criteria for assessment - Demarcation, purpose and demands
↓
2. Identify safety problems - What unwanted events can occur and why?
↓
3. Assess the risk - How often can the unwanted actions happen and what are the consequences?
↓
4. Propose measures - Which are effective risk reduction measures?
↓
5. Documentation - Describe ground data, procedure and results of the assessment

Figure 2-2: The five steps of a risk assessment (translated from Statens vegvesen, 2007).

In step 1 the analysis object is geographically marked off with regard to road-user groups, types of accidents, special risk factors or similar. The decisions the risk assessment should form the basis of must be defined and what the results should be valuated against (e.g. what is low risk and high risk?). In step 2 safety problems are defined as the dangerous conditions by the road or in the traffic that can lead to unwanted events. Firstly an assessment is made of which possible unwanted events that can occur and then a choice of which unwanted events one wants to study. An assessment of the risk in step 3 should give an indication of the size of the problem i.e. how often the identified unwanted events are expected to happen and what impact they are expected to have. Risk could be represented in a risk matrix showing the assessment of how often an unwanted event is expected to happen and what impact it will have. This gives an overview of the risk picture of the whole analysis object. The colours are a choice by the risk assessment group, which shows how serious different events are assessed to be. In step 4, possible risk reducing measures are assessed based on the ranking of the dangerous conditions that have come to hand. A rough assessment of the risk reducing effect of the measures in relation to costs ought to be made by the group. In step 5 base data, assessments and conclusions ought to be documented and to be searchable to be able to be used as a basis for decisions by others.

Risk matrix

Frequency \ Impact	Lightly injured	Severely injured	Killed	Several killed
Very often (at least once a year)				
Often (once every 2-10 years)				
Rarely (once every 10-30 years)				
Very rarely (more rarely than once every 30th year)				

The colour codes show an assessment scale for risk that can be interpreted as follows:

Measures not necessary

Measures ought to be assessed

Measures must be assessed

Measures necessary

Figure 2-3: Example of a risk matrix (translated from Statens vegvesen, 2007).

2.3 *Guidelines for roads*

2.3.1 Guidelines in Norway

In the Norwegian guidelines for risk assessments in road traffic described in section 2.2.4 (Statens vegvesen, 2007) there is one chapter dealing with risk assessment of existing roads. The chapter focuses on road safety and the risks for accidents. The risk assessment follows the general model with 5 steps described in the guidelines.

In step 1, sections are chosen based on expected frequency of degree of damage, analyses of accident data from a certain register (the STRAX register) and local knowledge. An assessment of relevant length of the stretch is done. The purpose of the risk assessment is to identify measures that give most reduction in amount of killed or seriously wounded.

In step 2, three possible procedures are traffic safety inspection, thematic inspection or open risk assessment. Traffic safety inspection is a thorough survey used when there are many types of problems and accidents. Thematic inspection is a demarcated traffic safety inspection, used when one type of safety problem or accident is dominating and an open risk assessments can be used for longer stretches with several types of safety problems.

In step 3 the identified safety problems are assessed in relation to their contribution to accident risks to gain a prioritization of the problems.

In step 4, the measures are prioritized from the group's assessment of what will give the most effect.

In step 5 data and assessments are documented in a report.

2.3.2 Guidelines in Sweden

In Sweden, instructions for overview risk analysis of the road transport system have been developed to create a uniform method for inventory of physical dangers along a chosen road stretch. The instructions (Swedish Road Administration, 2005a and 2005b) primarily deal with analysis of accident type risks that affect roads and bridges, together with risks associated with construction that affects the surroundings. The guidelines consist of two parts (two documents): one general part describing the methodology and one in-depth part which is an application support, with the focus on: landslide and collapse risk; risk for damage of roads and bridges caused by high water flows; risk of flooding; and risks caused by accidents with dangerous goods. In the future the in-depth part should be supplemented with a description of the dangers, e.g. frost damage, snow and ice obstacles.

The method is an application of the scenario model, which is the general model used within the Swedish Road Administration and which is described in "Risk management and safety in the Swedish Road Administration". In this model the analysis emanates from interest/asset and thereafter identifies which dangers can affect the interest/asset negatively and which risks factors can cause the dangers. Possible outcomes of damage are described for the interest/asset. The model for risk management within the Swedish Road Administration is presented in Figure 2-4.

Part	Stage
• Inventory • Description	Risk - Identification
• Rough estimate • Order of precedence • Calculation • Action proposal	Risk - Evaluation
• Decision • Execution • Follow-up • Evaluation	Implement-ation -

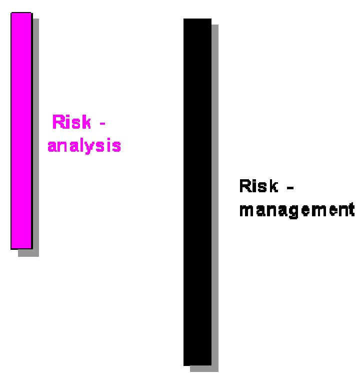

Figure 2-4: The model for risk management within the Swedish Road Administration (Swedish Road Administration, 2005a).

The road transport system is divided in the following types of interests/resources:

- Person (employees and road-users, third party)
- Property (road-, bridge- and tunnel constructions, vehicles, land, buildings, installations etc.)
- Environment
- Finance (costs for travel time, traffic accidents, vehicles, emissions, indirect cost increase for society due to delayed and cancelled road transportation etc.)
- Intangible (damage to reputation etc.)

The risk level is described with a risk matrix. For ranking of risks in the overview risk analysis the matrix is divided into three risk levels as shown in Figure 2-5.

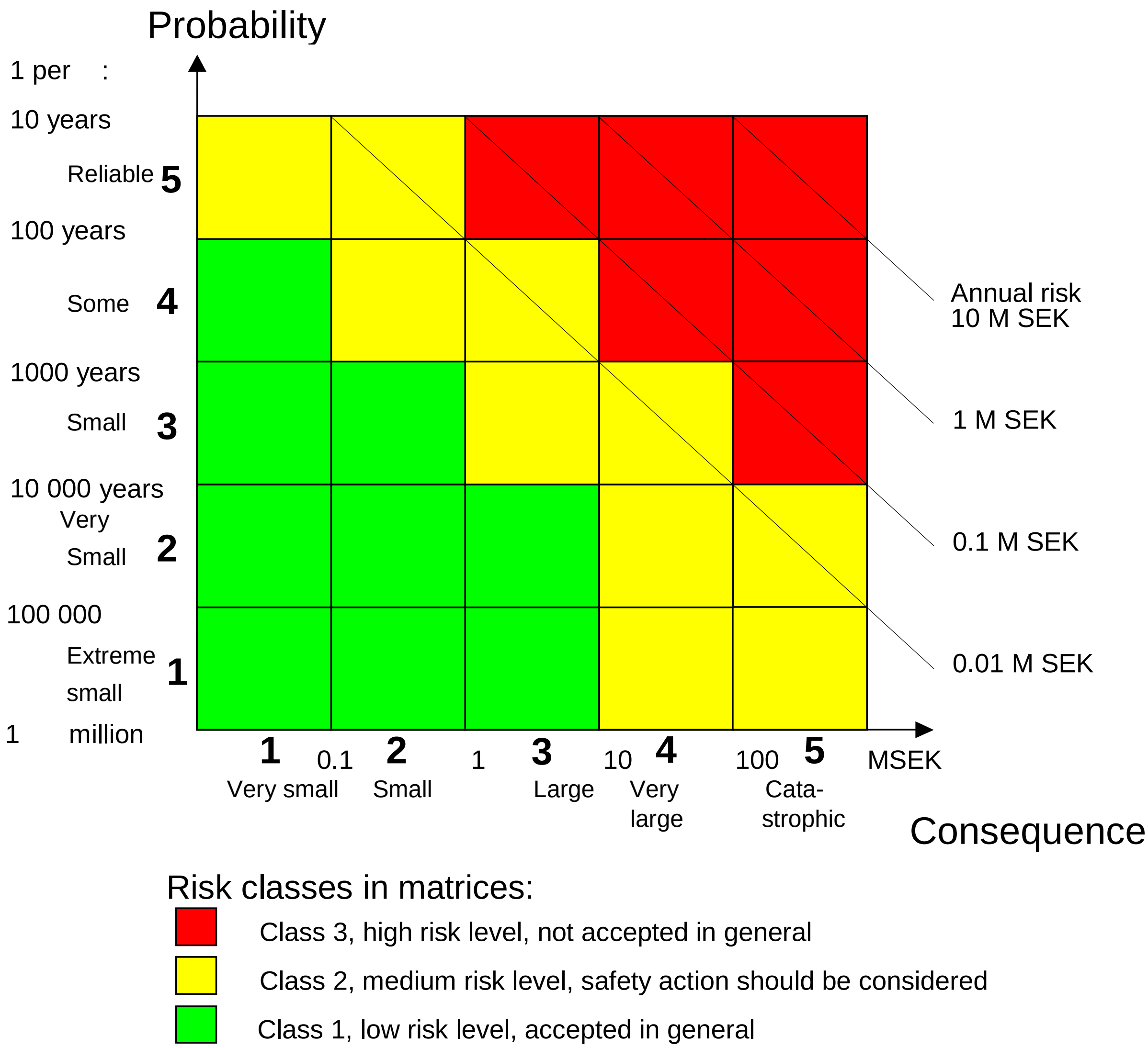

Figure 2-5: Risk matrix with risk levels (Swedish Road Administration, 2005a).

The overview risk inventory and risk analysis ought to be carried out by a small group of people with different competences, deep knowledge and local experience. The following steps are followed in general for a chosen road network:

1. The assets/objects that may be damaged are identified.
2. The dangers that can damage the assets/objects are identified.
3. The risk factors that can cause danger are identified and a collected assessment of the probabilities of the occurrence of the danger and the incident development are done.
4. The extent of the damage/consequence for the respective asset type if danger occurs is described.
5. The total risk level is described.
6. Possible risk minimising measures are stated.

2.4 *Guidelines for tunnels*

2.4.1 Guidelines in France

The French Road Directorate has developed *Guide for road tunnel safety documentation*, a series of booklets describing risk assessment and documentation methodology for tunnels longer than 300 metres. The following section is a synthesis of the French Road Directorate's *Guide to road tunnel safety* documentation - Booklet 3 - *Risk analyses relating to dangerous goods transport* (Direction générale des Routes, 2005).

In France the decision to allow dangerous goods transport (TDG) in a tunnel can only be made after an objective assessment of the risks. Risks are assessed for the human beings who use or live close to tunnels by modelling the frequency and severity of these accidents with specific QRA (Quantitative Risk Assessment) software. Major hazards include explosions, large-scale release of toxic gas and violent fires.

The model is built on the following basis:

- selection of a limited number of representative dangerous goods,
- selection of a few representative serious accident scenarios involving these goods,
- determination of the probabilities of occurence of these events,
- assessment of effects of scenarios on road users and local population.

The risk assessment process consists of two stages with the result of the first stage determining whether it is useful to conduct a more detailed risk analysis in the second stage. A flowchart for the activities in each stage is shown in Figure 2-6.

Stage 1: Assess tunnel's intrinsic risk and determine whether alternative routes exist

Data gathered in this stage include characteristics of the tunnel and meteorological data. The owner confirms the data and the intrinsic risk is calculated using the QRA model. If the intrinsic risk is low, the tunnel is not considered a criterion for selecting TDG grouping for the route, and the risk assessment process is finished.

If the tunnel's intrinsic risk is not low, alternative routes are identified. If the tunnel is the only choice the analysis will concentrate on limiting the risk. If there is at least one alternative route, the assessment continues to stage 2.

Stage 2: Compare routes

This stage is only performed if the results of stage 1 show that it is useful to do so. A large amount of data is needed concerning the characteristics of the route with the tunnel and of each alternative route. The first step is to compare the expected number of fatalities of each route, which is provided by the QRA model. In some cases his criterion may be sufficient to decide between routes, although in other cases other criteria may need to be applied as well.

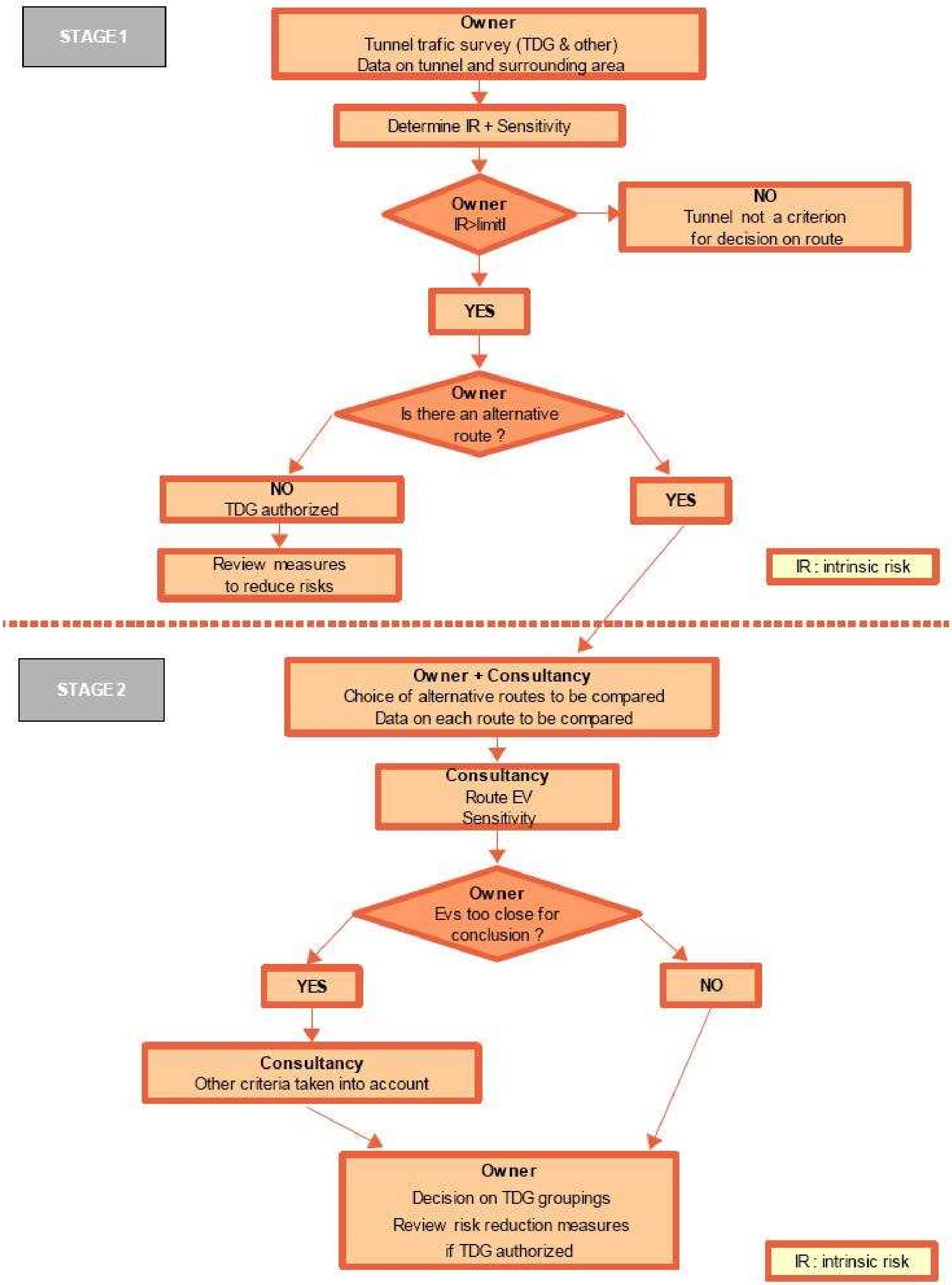

Figure 2-6:The flowchart describes the TDG risk assessment process for tunnels in France. It shows the tasks to be performed, who is to perform them and the decisions to be taken by the owner (Direction générale des Routes, 2005).

2.4.2 Guidelines in Germany

Currently the common minimum requirements for equipping and operating road tunnels in Germany are defined by the regulations “Directives for equipping and operating road tunnels” (RABT 2006) and the requirements of the European Directives (2004/54/EC). To make the demands in the directive more specific and facilitate practical implementation a quantitative method for safety evaluations of road tunnels was developed (BMVBS, BASt, draft 2008). The method is based on a risk-analysis approach, i.e. essential accident scenarios are defined and evaluated according to their probability of occurrence and the expected damage.

The purpose of the guidelines is:

- To provide a brief summary of the principles for performing safety evaluations of road tunnels.
- To give a practical description of the procedure and the tasks for performing safety evaluations.

The basic procedure of safety evaluations, shown in Figure 2-7, includes a preliminary analysis in which the level of detail required for the analysis is determined and the actual safety evaluation.

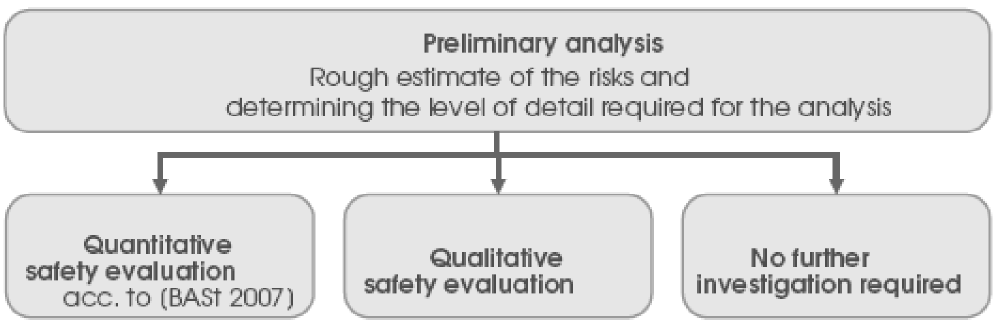

Figure 2-7: Procedure diagram for safety evaluation (Federal Ministry of Traffic, Building and Urban Affairs, BMBVS, and Federal Highway Research Institute, BASt, draft 2008)

The practical implementation requires a preliminary analysis to determine the level of detail appropriate for the main analysis of a given problem. Based on the results of the preliminary analysis the further procedure is determined:

- *Quantitative safety evaluation*. Detailed safety evaluation based on a method described in (BASt, 2007).
- *Qualitative safety evaluation*. Such an evaluation is sufficient when the preliminary analysis shows that the deviations from the specifications in (RABT, 2006) are minor with regard to the risks expected or that the tunnel only shows special characteristics to a limited extent.
- No further investigation required. A further safety evaluation can be omitted when the preliminary analysis shows that the deviations from the specifications in (RABT; 2006) with regards to risks are insignificant and when the tunnel show no special characteristics.

In the preliminary analysis a risk indicator for the two scenarios types “collision” and “fire” is determined by using a pragmatic method based on the most important, tunnel-specific, risk-relevant factors to determine the level of detail required for the analysis. The detail level of the analysis is determined from these risk indicators and a supplementary assessments by experts.

The procedure for performing a quantitative safety evaluation includes several individual steps that can be grouped into three main areas:

- Risk analysis, which identifies the risks and quantitatively estimates the expected frequencies and extents of damage;
- Risk evaluation, including concepts of acceptability of damage and the readiness to deploy means to prevent them;
- Planning of measures in several steps, from the evaluation of risk-reducing measures to the evaluation of these measures based on their effectiveness for risk reduction and their costs.

A qualitative safety evaluation the general steps for a risk-oriented safety evaluation must be performed – similar to a quantitative safety evaluation. However, in the impact of the deviation on the resulting risks need only be considered on a qualitative base.

2.4.3 Guidelines in Norway

The Norwegian Public Roads Administration (Statens vegvesen) has developed guidelines for risk analyses of road tunnels (Statens vegvesen, 2007b) to describe when a risk analysis is necessary, witch analysis to be utilized at different levels and an introduction to how they can be done. The guidelines focus on tunnel safety and the risk for accidents. Three methods are mentioned; preliminary risk analysis, detailed risk analysis and statistical risk calculation. The risk analysis is based on the general risk analysis process described in the guidelines for risk assessments in road traffic (Statens vegvesen, 2007a), see section 2.2.4.

There is a demand for a risk analysis for all road tunnels longer than 500 m in Norway. The risk analysis is conducted as to be able to make certain decisions with regard to safety and should be a positive contribution for making the tunnels as safe as possible. The risk analysis should highlight the risk picture, i.e. identify unwanted actions/accidents, causes, and possible consequences with adherent probability.

Before the start of a risk analysis a TUSI calculation should have been conducted. TUSI stands for Tunnel Safety (TUnnel SIkkerhet) and is a computer program for calculation of frequency of fire- and of road accidents in road tunnels. The following analysis process will often be appropriate:

1. Statistical analysis using TUSI for creating a simple risk picture.
2. Rough risk assessment to identify and prioritize safety problems and propose actions.
3. Detailed risk analysis to study special problems, if required.

Rough risk assessment

The rough risk assessment is a process oriented method involving a group with interdisciplinary competence. Safety problems are identified both for the whole tunnel and different elements, and the risk is assessed, i.e. how often the unexpected event may occur and what the impact could be.

In step 1, description and demarcation of the analysis object is made in a “Hazard identification meeting” (HAZID-meeting). Special conditions at the road tunnel which may give particularly high risk level are identified. An assessment is made if the risk level lies within the framework of what is technically and economically feasible.

In step 2 the safety problems are identified either openly or by going through a list of unwanted events. The risk is assessed for example by using a scheme (worked out in MS Excel) assessing the impact of identified safety problems and accompanying probabilities in step 3. If the rough risk assessment is made as a first phase in a following detailed analysis the analysis of measures can be made as a part of the detailed analysis.

The risk reducing measures in step 4 can be for accident prevention or damage reduction. The effect of different measures are compared with each other either through assess how muck the probability for an unwanted event will be reduced or how much the impact of the damage can be reduced. The documentation in step 5 can for example be made in an analysis table or a text document. A risk matrix is used to illustrate the risk.

Detailed risk analysis

A detailed risk analysis is always preceded by a rough risk assessment. The identification of safety problems is already carried out in the rough risk assessment and does not have to be remade. The results from the rough risk assessment form the basis for the detailed risk analysis. Fault Tree Analysis and Event Tree Analysis are proposed in the guidelines, even though other methods can be used.

The guidelines stress the importance of the planning of the analysis (in step 1). The rough risk assessment gives important information that can be used in the planning of the detailed analysis. Relevant issues in this context are proposed. On the basis of the results of the rough risk assessment, an eventual updating of the identification of safety problems are made (step 2). A more detailed analysis of causes of unwanted events may be desired. Then a fault tree analysis may be used. The analysis of impact (in step 3) can be conducted using an event tree analysis. There are both qualitative and quantitative event tree analyses. The probability for an unwanted event to occur comes from an understanding of causal connections gained in an analysis of causes (for example Fault Tree Analysis) or from a statistical analysis. In step 4, where Fault Tree Analyses or/and Event Tree Analyses have been carried out, sensitivity studies could be conducted analysing how big importance an error of the different barriers have for the probability of an unwanted event and for different impacts. The format of the documentation in step 5 ought to be adapted to the goal and the purpose of the analysis.

3. Risk management and risk analysis methods suitable for climate change adaptation

3.1 *General methods including traffic and transport*

3.1.1 The Deltares approach for spatial planning, the Netherlands

The Deltares approach is used for spatial planning and to design water management systems. The approach starts from the perspective of the decision maker. The climate change scenarios are not the starting points, but the requirements of key water management issues (or any other sector, e.g. road) on the climate state. The approach starts with an assessment of how much climate changes can be accommodated by the sector's management strategy and what magnitude of change would cause difficulties. This can be considered a sensitivity analysis of the sector. It provides an overview of the vulnerability of the sector's management strategy to climate change.

The analysis reveals the so called "tipping points" in the sector management, as shown in Figure 3-1. These are defined as the extension of change beyond which the current strategy should be re-considered. Such tipping points can be associated with many different issues such as technical (e.g. the strategy should be abandoned because of limitations of known technology), physical, financial or society issues.

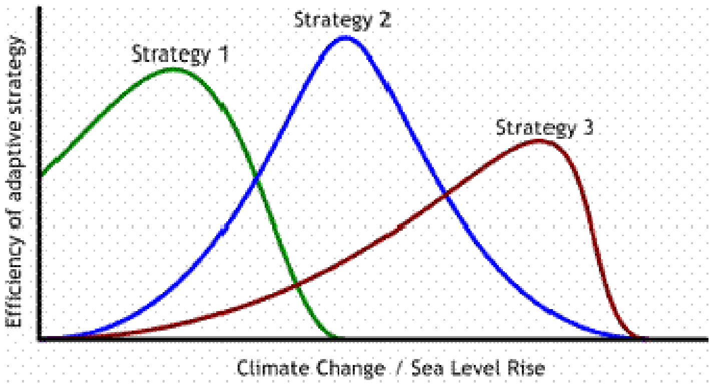

Figure 3-1: The efficiency of an adaptive strategy changes with the amount of climate change. The tipping point of strategy 1 is when the green line intersects with the horizontal axis. From this point on this strategy will not be efficient anymore. However, from the intersection between the green and blue lines it is more efficient to change strategy to strategy number 2.

Main steps in the approach

1. **Identification of risk factors:** Define a long list of all possible effects of climate changes and their impacts. These are presented in a scoreboard matrix with scores for likelihood and for level of importance of the different impacts.

2. **Risk analysis using urgency matrix:** By summing up the scores from the risk identification scoreboard and placing them in an urgency matrix, the risks can be ranked to find the most relevant risks to include in the analysis, see Figure 3-2.

	Impact						
Likelyhood	Major		Moderate		Minor		Insignificant
very likely							
likely							
fifty/fifty							
unlikely							
very unlikely							

Figure 3-2: An urgency matrix is used to identify the relevant risk factors to include in the analysis.

3. **Strategy analysis:** The different steps in the strategy analysis are shown in Figure 3-3**.**

   3.1. **Finding tipping points**: Using a bottom-up approach an assessment is made of how severe climate changes can be accommodated by the selected infrastructure and what magnitude of change would cause difficulties. Determine under what changes of boundary conditions the strategy it is no longer effective by comparison with design criteria, consulting experts/representatives from different sectors or assessing historical variation of boundary conditions. The time for the tipping point can be calculated using existing climate scenarios, interpolation and expressing uncertainties.

   3.2. **Identification of strategies**: Determine alternative strategies and score on criteria (based on objectives). Important strategic questions are: For how long will the strategy be efficient (i.e. time horizon)? (robustness), How easy is it to change in time to an alternative strategy? (adaptability). Examples of strategies for roads are: more frequent maintenance (a resistance strategy), monitoring in combination with evacuation plans (a resilience strategy).

   3.3. **Strategy analysis**: The strategies are summarized in a table where their effectiveness in time is expressed on a time (or climate change) scale and the possibilities to change strategy is illustrated. This is complemented by criteria evaluation of multiple criterions such as economy, safety and social climate, in order to rank the strategies.

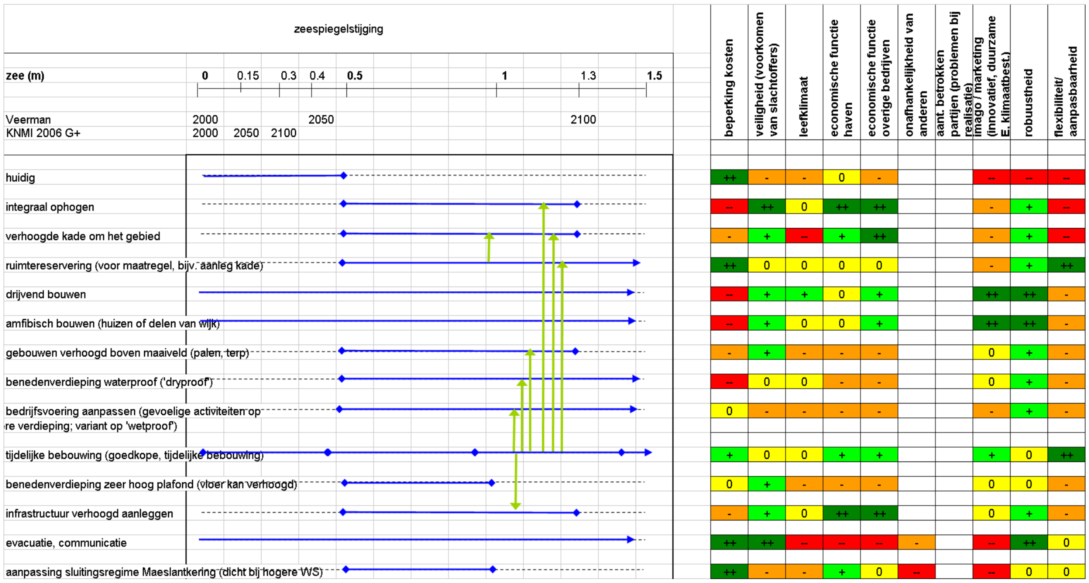

Figure 3-3: Strategy analysis in the Deltares approach.

4. **Feasibility check:** The most pertinent strategies from step 3 are investigated further with cost benefit analyses and by assessing effectiveness and possible cooperation with other sectors and projects.

3.1.2 The GERICI project for infrastructures, France

Egis has developed GERICI: a Climate Risk Analysis and Management Approach and Model for Infrastructures. GERICI is a GIS model for measuring the vulnerability of all sensitive components of an infrastructure. Initially the study was conducted on a motorway. On the basis of a socio-economic analysis, GERICI provides assistance to the authorities concerned in regard to structuring and establishing priorities for the investments to be made, and in the case of the forecast or announcement of an exceptional event, definition of the scenario to be initiated to take the most relevant emergency measures in collaboration with the other partners, including the emergency services.

A meteorological risk analysis method

The risk analysis method used in GERICI is based on several existing approaches as those described in PIARC publications, or the FMECA (Failure Modes, Effects and Criticality Analysis) method. The method is also based on the normative corpus, especially the French FD X50-252 guideline for risk assessment and management issued in February 2006. It has applied lessons learnt from risk management in highly sensitive domains such as the nuclear industry. The systematic approach implemented in GERICI highlights the various links between the elements structuring danger and risk issues. It has made it possible to model the danger in more general terms, as a process chain leading a source of danger to trigger disastrous effects on infrastructures, users, residents, the environment, etc.

Main steps in the approach

The following summary describes the different steps in the approach. A synthesis of the GERICI approach is shown in Figure 3-5.

1. **Establish context:** As a basis for the research work involved it is necessary to measure and define requirements, introduce a common vocabulary comprehensible by all, and

determine the component elements to be integrated in the GIS tool.

2. **Identification of risk factors:** The risk factors are divided into three groups: climatic factors, infrastructure intrinsic factors and site factors. The climatic factors included in GERICI are rain, floods, wind, snow, low and high temperatures. They are regarded as long-term sources of danger for the infrastructure and its components, continuity of service and residents. Examples of intrinsic factors are: mistake in design, lack of maintenance on hydraulic pipes, etc. Examples of site factors are: development of urbanization, waterproofing of soils, etc.

3. **Risk analysis:** Risk estimation is done qualitative or quantitative depending on possibilities and requirements. In order to characterize the vulnerability the infrastructure (motorway) is divided into seven domains: major hydraulics, minor hydraulics and drainage, engineering structures, equipment, geotechnical, environment and pavement. In each domain, the components of the infrastructure are classified in families according to their degree of sensitivity to the unwanted events. Three typical thresholds are established for each element: dimensioning level, critical level and breaking level. The infrastructure analysis is conducted in cooperation with road operators and experts.

4. **Risk evaluation and risk map:** The infrastructure is digitalised into a number of geo-referenced objects in the form of a table which also contains technical and vulnerability characteristics for each object. The information is then displayed in a GIS. When applying a meteorological event of defined type and intensity to a chosen infrastructure section, each object sensitive to the selected event is displayed in graphic form, using a colour code according to sensitivity level which it is likely to reach during the event. Results are analysed in light of their foreseeable consequences on: costs, infrastructure's durability, continuity of service to users, users' safety and environmental effects. Critical scenarios are identified and displayed in a frequency/severity risk matrix. The risk evaluation process is described in Figure 3-4.

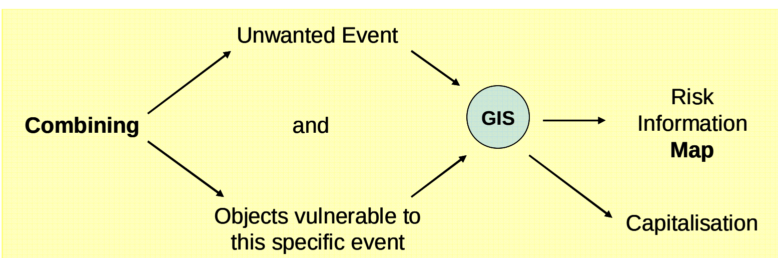

Figure 3-4: Risk evaluation in GERICI.

5. **Take preventive/palliative measures and develop action plans:** The GIS tool can be used in two ways. In simulation mode the tool can be used to identify vulnerable sections and objects thereby making possible to take preventive actions on a priority basis. When an extreme weather alert is issued by a meteorological institute the GIS tool can be used to measure the probable consequences for the infrastructure and to provide instructions and decision scenarios for operators.

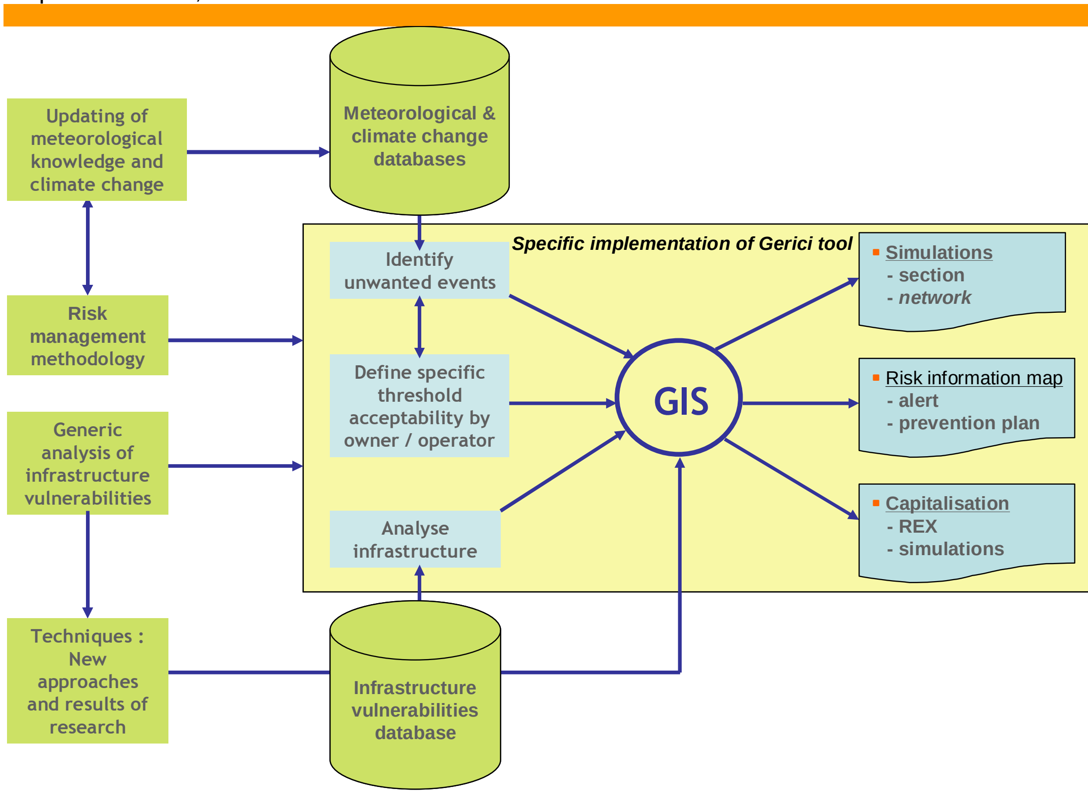

Figure 3-5: Synthesis of Gerici approach and methodology bricks. The green boxes are general aspects. The blue boxes are specific for the road owner.

3.2 *Methods for roads*

3.2.1 Guidelines in the United Kingdom

The Highways Agency has recognised the need to ensure that it can continue to provide an effective strategic road network in the context of a changing climate. Therefore a Climate Change Adaptation Strategy has been developed, and in support of this strategy the Highways Agency Adaptation Strategy Model (HAASM) (Highways Agency, 2008). The HAASM provides a systematic process to:

- identify the activities of the Highways Agency that will be affected by a changing climate;
- determine associated risks and opportunities; and
- identify preferred options to systematically address them.

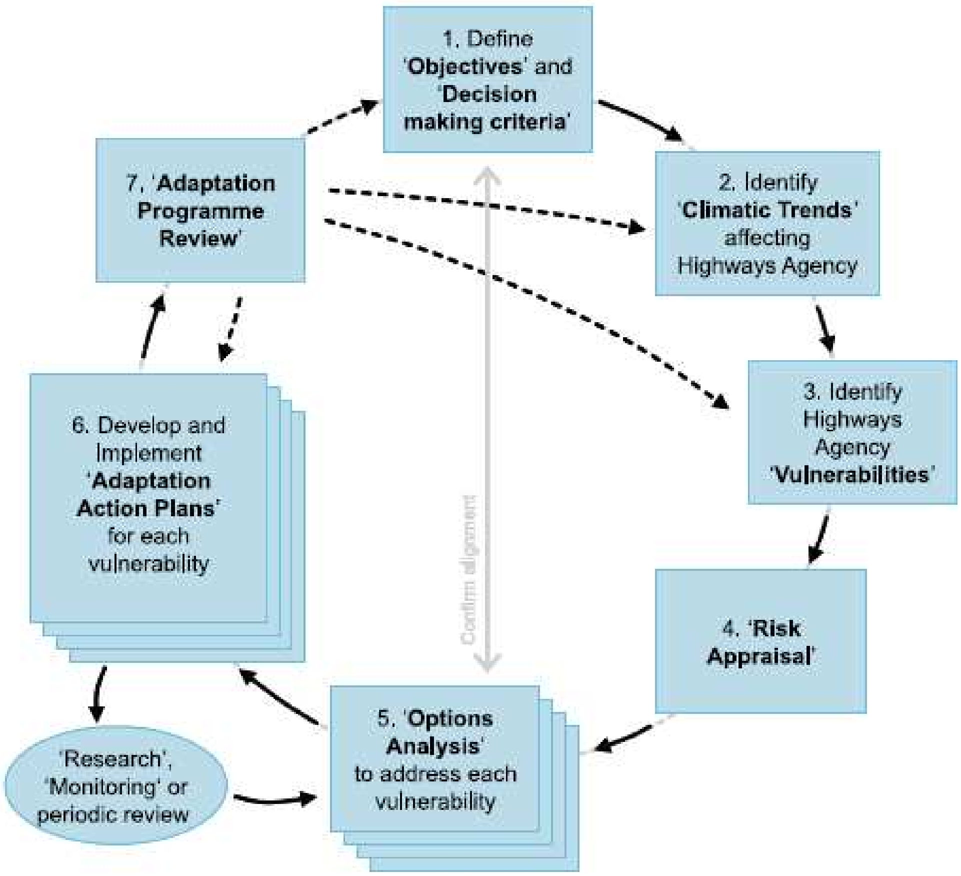

Figure 3-6: Highways Agency Adaptation Strategy Model (Highways Agency, 2008).

The HAASM illustrated in Figure 3-6, comprises of seven stages which are described briefly below.

Stage 1: Define Objectives and Decision-making Criteria

The definition of the objective is to enable the Highways Agency to systematically develop and implement its responses to the challenges of climate change in support of the delivery of its corporate objectives. The criteria are defined as follows: Preferred adaptation options shall accord with the Highways Agency's sustainability requirements and provide the optimum balance between minimum whole-life-cost, certainty of outcome and residual risk.

Stage 2: Identify climate trends that affect the Highways Agency

Stage 3: Identify Highways Agency vulnerabilities

Highways Agency activities that could be affected by climate changes are identified. These are termed vulnerabilities and a vulnerability schedule in form of a matrix has been produced. The matrix lists the Highways Agency activities that could be affected by projected climatic changes. It establishes their relationship to climate change hazards and to associated risks to the Highways Agency corporate objectives.

Stage 4: Risk appraisal

This stage utilises risk appraisal to categorise the nature of the risk associated with each of the vulnerabilities identified in stage 3. It provides a mean of "scoring" the climate change induced risks so that vulnerabilities can be ranked. The primary criteria used to assess vulnerabilities are: uncertainty; rate of climate change; extent of disruption; and severity of disruption.

Stage 5: Options analysis to address vulnerabilities

This stage identifies and assesses the options available to the Highways Agency to respond to the risks associated with each of the vulnerabilities identified in Stage 3. Options for the treatment of risks include: future-proof designs; retro-fit solutions; developing contingency plans; updating operating procedures; monitoring; and research.

Stage 6: Develop and implement Adaptation Action Plans

In this Stage the preferred option is developed into a detailed adaptation action plan, which is then implemented and subject to a process of ongoing review and management.

Stage 7: Adaptation programme review

In this stage key information from the adaptation action plans will be drawn together into an overall adaptation programme. Feedback from Stage 7 goes back to Stages 6, 3 and 2.

3.2.2 Work within the Nordic Road Association

Within the Nordic Road Association (NVF) (www.nvfnorden.org), working group 41, a survey has been carried out regarding what effect climate change would have on the road maintenance. The work was carried out mainly between the years 2004 and 2006 and focused on a risk analysis, i.e. what in the working group's opinion is the probability of a certain event and how big is the consequence. Probability is seen in a national perspective, i.e. the total number of events that occur in the country. Probability can be seen as increased frequency (e.g. storms). Consequences included are costs for road owners and users. The time perspective of the project was from today's climate to expected changes until year 2040. The probabilities and consequences are assessed with the assumption that no preventive actions are taken. A side effect of the national perspective is that some impacts of climate change may not be seen in the results, e.g. the reduced cost for less snow clearance in the south may disappear with the increased cost for snow clearance in the north. (NVF, working group 41. 2008-03-25, working material).

The result of the survey is presented in the form of a matrix where the impact of climate change and extreme weather on risks for unwanted events is measured for each country using colour codes (Figure 3-7 and Figure 3-8).

Prob.	**Description**	**Once in:**
1	Extremely small	100 yr
2	Very small	25 -100 yr
3	Small	10 – 25 yr
4	Some	1 – 10 yr
5	Reliable	yearly
Cons.	**Description**	**Cost**
1	Very small	< 10 M SEK
2	Small	10- 50 M SEK
3	Large	50- 100 M SEK
4	Very large	100- 500 M SEK
5	Catastrophic	>500 M SEK

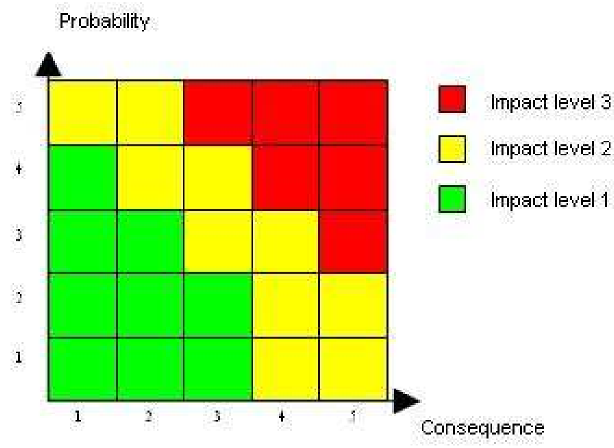

Figure 3-7: A risk matrix is used to sort the climate change-induced events according to their level of impact (NVF, working group 41. 2008-03-25, working material).

Effects of climate changes and extreme weather events	**Sweden**	**Norway**	**Finland**	**Denmark**	**Iceland**	**the Faeroe Islands**
Precipitation and water flow changes						
Larger landslides and rock falls						
Road and bridge carried away by water course						
Flooding						
Temperature changes						
Pavement wear						
Pavement weathering						
Winter transports on frozen unpaved roads						
Frost weathering of concrete structures						
Icing of bridges						
Temperature effects on bridges						
Winter road maintenance						
Congelifraction						
Change of wind speeds						
Large bridges and other exposed areas						
Multiple tree falls over roads						
Closure of roads in mountain areas						
Change of Sea water levels						
Tunnels						
Roads						
Ferry berths						

Figure 3-8: Risk analysis of impacts of climate change and extreme weather in the Nordic countries (NVF, working group 41. 2008-03-25, working material).

4. Conclusions

There is work going on in many ERA-NET countries and others with regard to risk analysis and climate change. From a state of the art research three methods seemed particularly interesting and need to be further examined. These methods are the French GERICI-project, the UK adaptation strategy and the Deltares approach.

During the workshops most discussions were focussing on the best combination of the relevant aspects from different methods to fit with the priority needs identified by the Value Engineering Analysis approach: identification of current strength and future work needed. This forms the basis for future work during summer 2009.

Other questions are discussed as well. What should be in common and what should be specific for different regions and countries. It is important to take into account that the actual risks are significantly varying over Europe and that the end-user tools for risk analysis and management must be “site specific” to a certain degree, but the methods should also have much in common aiming, at being to a large degree independent of geographical location and scale and kind of climate factor in question.

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