RIMAROCC

Risk Management for Roads in a Changing Climate

Case Study - *Network Scale*
The French Northern Motorway Network

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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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Risk Management for Roads in a Changing Climate

Case Study on Network Scale – The French Northern Motorway Network

Author(s) this deliverable:

Yves Ennesser, EGIS, France

Jean-Jacques Fadeuilhe, EGIS, France

Estelle Morcello, EGIS, France

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1 Foreword

"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.

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. Additional funding to the RIMAROCC project has been provided by all participating partners. We would like to thank KNMI, Météo France and SMHI for their input on climate change and critical climate factors.

The Project Steering Group from the ERA-NET Board, Åsa Lindgren (Project Manager), SRA, Sweden; Alberto Compte and Eva Ruiz-Ayucar CEDEX, Spain and Geoff Richards and Dean Kerwick-Chrisp, 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.

This case study was conducted to implement the RIMAROCC framework for risk analysis. The RIMAROCC method is developed to fit different geographical scales including structure, section, network and territorial level.

2 Comments on Network Scale Analysis

In the RIMAROCC method, as defined by the project steering committee, scales of analysis are independent from each other. Network can be the compilation of "sections". However, it is considered here as a specific analysis, which can be carried out by operators even if the whole information for a comprehensive analysis - such as the one required at the section scale - is not available or does not exist.

So, network level analysis is a "strategic" analysis with an objective of determining what elements of the network are critical and what the priority of action (ranking) is to mitigate risks related to these elements.

This kind of strategic analysis needs the active collaboration of the network level decision makers for capital investment, the corresponding operational managers, meteorologists involved in climate change and familiar with the study area, pertinent experts on infrastructure vulnerability, as well as a consultant to facilitate the technical approach implementation.

Regarding the economic approach, we assume that in case of occurrence of a major meteorological event, the whole concerned section(s) is/are closed and traffic is diverted on other sections of the network.

3 Overall Presentation of the Network Case Study

3.1 Framework and Problematic

The present case study deals with the **French Northern Motorway Network**, mostly operated by the SANEF company. This case study is at the network scale, considered as a specific network under the responsibility of only one operator, with alternative routes operated by other operators (State, Regional Council, General Council).

The Northern Motorway Network irrigates the geographical triangle Paris-Calais-Valenciennes (Belgium border). It is approx. 1000 km long, and is structured according to the following motorways (see the map below): A1 between Paris and Lille, A16 between Paris and Boulogne, A26 between Saint Quentin and Calais, A29 between Saint Quentin and Amiens, A2 between the A1 and Valenciennes. This network is made of 14 main motorway sections (started and/or ended by interchanges) and 26 sub-sections (delimited by nodes, i.e. motorway entrance/exit points).

The objective is to implement and monitor the RIMAROCC method in order to identify what meteorological risks (in connection with climate change) could emerge, what parts of the network could be vulnerable, what could be the possible consequences, and what action plan could be elaborated.

3.2 Short information about the case study.

The present case study is under the full responsibility of EGIS. Owing to the scientific interest of the approach, SANEF has accepted to collaborate with EGIS on this study, but this collaboration is limited to data provision. SANEF is not responsible for any interpretation of these data by EGIS and is not liable to implement the RIMAROCC method.

The northern motorway network connects the two most densely populated regions in France: Ile de France (Paris region) and Nord – Pas de Calais (the northern region, at the Belgian border). These are respectively the 1st and 4th French regions in GDP, showing major industrial concentrations. Between these two economic cores, the network crosses the Picardie region (transit zone of rural type). At international scale, this network is the road link between the Paris capital region and Great Britain - Benelux. With more than 60 000 veh./day in its southern part, the A1 motorway is the main axis of that 1000 km long network.

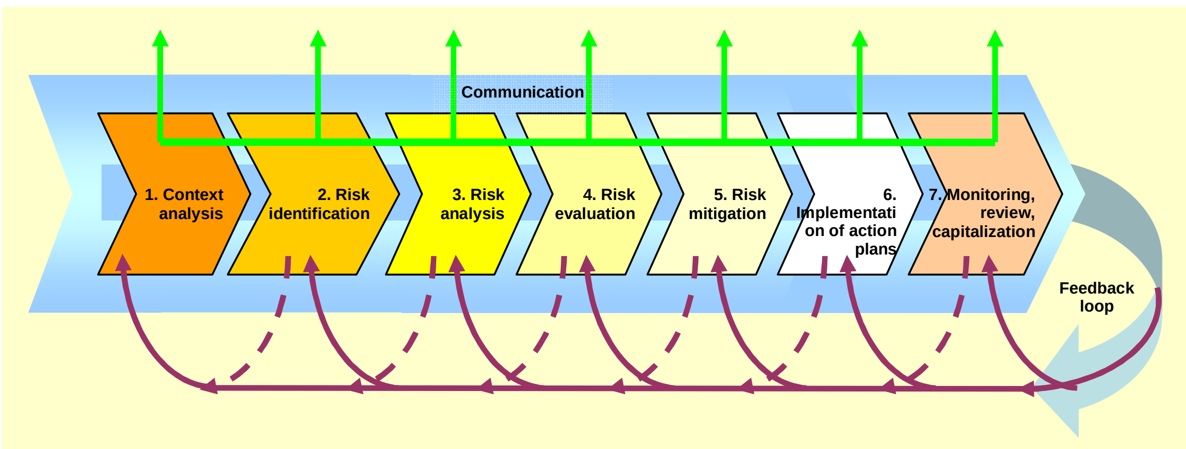
The climatic context is oceanic, with continental influence eastwards. Summer is relatively cool (18°C on average in Paris) and winter mild (6° C on average in Paris), with frequent rainfalls all over the year. However annual precipitation is relatively low (641 mm on average in Paris, 687 mm on average in Lille). On the whole, due to maritime influence, the coastal area is milder, while extreme temperature and precipitation values increase in the country side. Winds are stronger on the sea side. The study area is rather flat, with highest topographical points reaching only 200-250 m. Though this smooth relief is not significant regarding the main climate characteristics, it creates microclimatic conditions.

Climate change projections show significant increase in temperatures and decrease in summer rainfall as well as winter frost/snow. There is no clear trend with extreme rainfall events.

3.3 Short Description of the RIMAROCC Method

The proposed method is a cyclic process to continuously improve the performance and capitalise on the experiences. It starts with an analysis of the general context where risk criteria are established and ends up with a reflective step where the experiences and results are documented and made available for the organisation. In practice the steps are not always totally separated. There can be work going on in several steps at the same time – but it is very important that the logic structure is kept. There are feedback loops from each step to the previous ones and also a marked loop from the last step as a reflection and as part of the cyclic process.

The continuous communication with stakeholders, external experts and others is very important and marked as (green) arrows throughout the whole process.



Scope of steps and sub-steps

Key steps	Sub-steps
1. Context analysis	1.1 Establish general context 1.2 Establish specific context for particular scale of analysis 1.3 Establish risk criteria and indicators adapted for each particular scale of analysis
2. Risk identification	2.1 Identify risk sources 2.2 Identify vulnerabilities 2.3 Identify possible consequences
3. Risk analysis	3.1 Establish risk chronology and scenarios 3.2 Determine impact of risk 3.3 Evaluate occurrences 3.4 Provide a risk overview
4. Risk evaluation	4.1 Evaluate quantitative aspects with appropriate analysis (CBA or others) 4.2 Compare climate risk to other kinds of risk 4.3 Determine which risks are acceptable
5. Risk mitigation	5.1 Identify options 5.2 Appraise options 5.3 Negotiation with funding agencies 5.4 Elaborate action plan
6. Implementation of action plans	6.1 Develop action plan at each level of responsibility 6.2 implement adaptation action plans
7. Monitor, re-plan and capitalize	7.1 Regular monitoring and review 7.2 Re-plan in case of new data or delay in implementation 7.3 Capitalization of return of experience on both climatic events and progress of implementation
Communication and gathering of information	

4 Lessons Learned

1. Because of the size of a network (e.g. 2.000 Km with alternative routes) such study is "light", focusing on identification of critical sections, nodes or structure, which will be studied at the appropriate scale in a second phase (see other RIMAROCC cases studies for lessons learned). So, one of the key lessons of this case study concerns the actual needs of network managers:
   a. they need a first (short, strategic) analysis for their own information/appropriation about the key issues leading to:
      - the identification of critical climate events for their network,
      - the identification of critical sections or nodes with respect to climate change adaptation, to be validated by further investigations on some sections or nodes (chosen through a random sampling),
      - the identification of key possible economic consequences (orders of magnitude),
      - general orientations for the next steps of the analysis and main orientations for the adaptation policy or strategy.
   b. a more "analytical" review, developed on the network sections and nodes. This second study phase will give a more quantitative (more accurate) approximation of risks and is required to set up a detailed action plan.
2. Clearly define the study objectives and the horizon of analysis (2030/2050/2100?)
3. Establish the "point zero" (reference situation) before starting the analysis, if specific and appropriate databases are not available,
4. Identify and characterize, with the assistance of meteorological authorities, new specific meteorological events at the horizon of analysis (do not forget that the key initial risk is climate, not the road condition),
5. Establish a "frame of reference" of network vulnerabilities for the specific network under study, in connection with meteorological events (keep in mind that risk management for road in a changing climate is a new approach, and engineers or operators do not know all related phenomena and their consequences),
6. Use interviews to collect or confirm information (at the network scale, the required data are mostly gathered through the knowledge and expertise of the operator's team),
7. Adapt risk criteria indicators and their rating to the actual data availability at the appropriate scale.
8. When dealing with consequences, it is necessary to differentiate immediate consequences (e.g. traffic interruption) and progressive consequences (e.g. bridge scour); action plans will be based on this differentiation.

These lessons learned from the study case feedback lead to some small amendments in the basic RIMAROCC method. That is why case studies are really important in such a methodological elaboration.

Network Case Study - The Seven RIMAROCC Steps

Step 0 - Quality Plan

- The Consultant in charge of the study is EGIS, with collaboration of Météo France for climate aspects. The EGIS companies involved in the present study are certified ISO 9001, or have initiated a similar quality approach.
- The objective at the network scale is to identify, analyze and evaluate risks due to climate change in order to establish a general policy of investment and maintenance (see also section 3.1).
- All climatic risks have to be considered.
- This study is an experimental exercise. It is a reflection and investigation approach on a sensitive subject. No communication outside the actors is allowed.
- The study is performed in a six months period after data collection by EGIS.
- For this pilot study, there is no implication of national authorities to define acceptable risks.
- Quality control was performed by all the team members. Quality controller for this project is the Technical Director of EGIS.

Step 1 - Context Analysis

By establishing the context, the authority responsible of the climate risk management study (subsequently referred to as the *risk manager*) articulates its objectives, defines the external and internal parameters to be taken into account when managing risk, and sets the scope and risk criteria for the remaining process.

Main chapter	Sub-chapter
1. Context analysis	1.1 Establish general context 1.2 Establish appropriate context for particular level 1.3 Establish risk criteria and indicators adapted for each particular level

Step 1.1 - Establish General Context

In the framework of the present case study, only the main features of the general context are presented. This overview could be completed in compliance with the RIMAROCC method.

External Context

The French road network is more than 1 million kilometers length. The motorway and highway network is about 20.000 km, in which 8.000 km are private motorways (concessions).

The external context is the external environment in which SANEF seeks to achieve its corporate objectives. It focuses on general aspects and steering documents:

- The legal framework is the one currently enforced in France, with the State (Ministry of Ecology, Sustainable Development, Energy and Sea) as the "owner" and SANEF as a concessionary company.
- At the present time, no policy in the field of climate change has been approved yet. The National Plan for Climate Change Adaptation is currently being prepared.
- Construction or repair activities are performed according to French construction standards. These standards are progressively replaced by Eurocodes.
- European and French provisions for traffic regulation apply to the network under study. Critical infrastructures are operated according to specific rules.
- SANEF keeps tight relationships with external stakeholders, through a permanent dialogue on the following issues: noise, nature and landscape protection (with motorway neighbours and NGOs); interchanges, public transport, traffic velocity regulation, modulation of toll pricing, parking areas (with local communities, chambers of commerce); service quality procedures, toll, resting and parking areas, internet web site (with customers); operational procedures, contract management (with state authorities). Local stakeholders and the public are informed about the network operational conditions through radio broadcasting (Radio Trafic), internet SANEF web site, and brochures distributed at the toll barriers.

Internal and Risk Management Context

SANEF is a former semi-public concessionary company, privatized in 2006 and belonging to the ABERTIS group, which operates a three parts motorway network in North of France:

- the northern network from Paris to the Belgium border and the Channel,
- the eastern network from Paris to German and Luxembourg borders,
- the western network from Paris to Normandy and the Channel.

SANEF northern network is approx. 1.000 km of motorways structured in 4 major axes with a triple function:

- transit of international traffic from northern European countries to south of Europe and northern Africa,
- national transit from harbors along North Sea and Channel to Paris region,
- regional transit.

This network is a very strategic one and an interruption of one or more sections could create an important prejudice to the regional and national economy as well as to the SANEF company. Concession contract ends in year 2029.

The national authority in charge of concession contract control is "Direction des Infrastructures de Transport" within the French administration.

SANEF has an efficient organization with competent employees, proofed procedures, operational equipment and adequate databases.

The internal organisation for risk management within the SANEF organisation takes place in the overall operation and maintenance organisation for road operation.

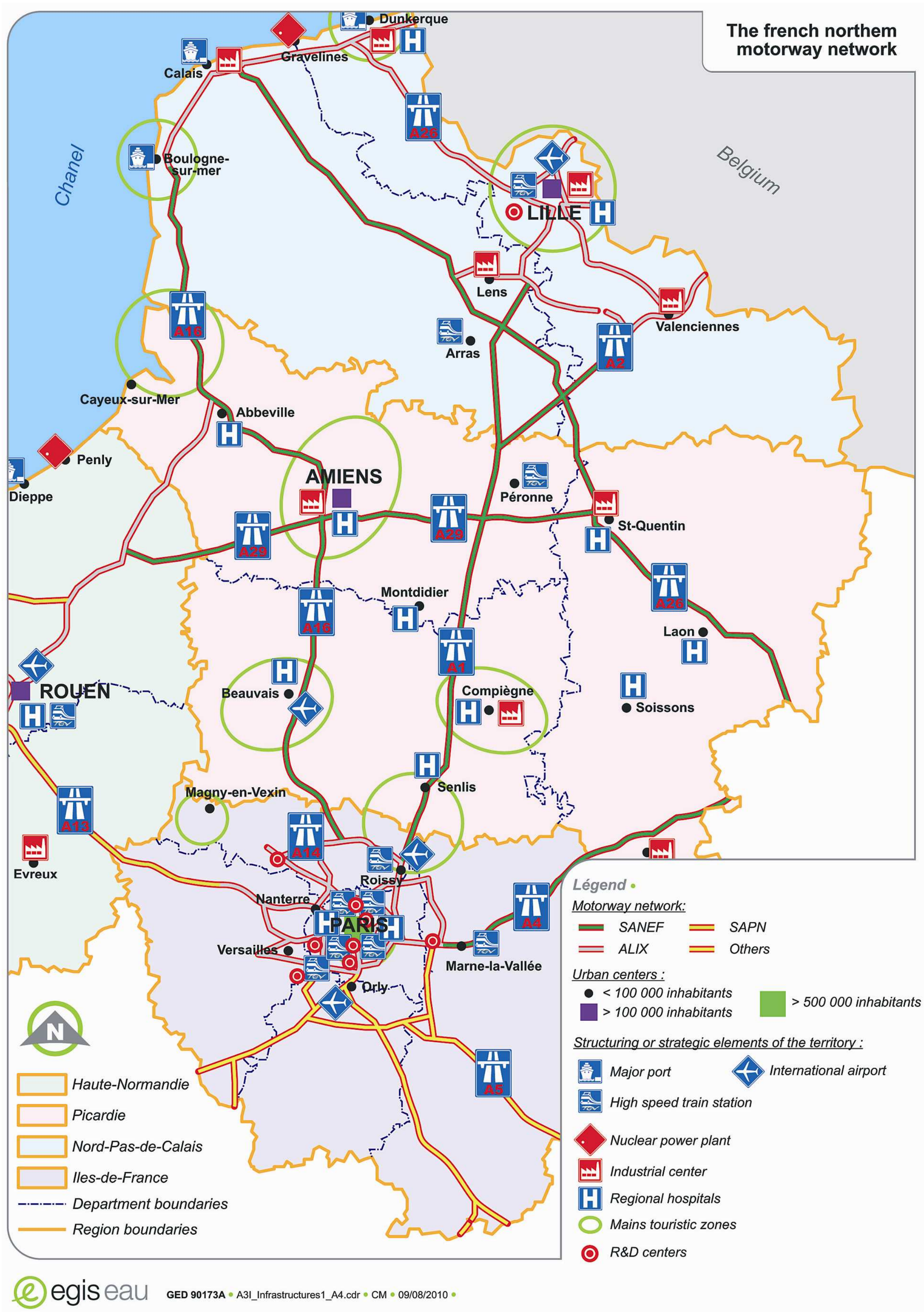
Organisation level	**Persons in charge**	**Tasks**	**Comments**
Holding Company	ABERTIS risk committee	General framework for risk management	Defines the main guidelines for risk management within the ABERTIS group
General Directorate	SANEF Board	General management policy	Defines SANEF objectives, together with tasks and responsibilities of Directorates. Applies the risk management policy for infrastructures
Technical and Operational Directorate	Edouard Fischer	Operational policy	Defines operational procedures and the technical framework of the network management
Construction Directorate		Construction policy	Defines and supervises investments required to meet SANEF objectives
Directorate for Risks and Audits	Henri-Pierre Chavaz	SANEF Risk management policy	Animation of the risk identification and mitigation process; coordination with the operational and construction directorates
Northern Network Directorate		Northern network management	Applies the risk management policy for operations
Local Technical Centres	Local technical managers	Local operation and maintenance	Implement safety procedures; carry out maintenance and repair works

There is no specific frame of reference for network vulnerabilities within SANEF.

Step 1.2 - Establish Specific Context for Sanef Northern Network

The purpose is to refine and clarify the context according to the specific scale of analysis: the SANEF northern network. The table and maps presented hereafter show its main characteristics.

The perimeter of the northern network is shown on the following map, together with the main strategic components of the study area.


The french northern motorway network
Dunkerque
Gravelines
Calais
Boulogne-sur-mer
Chanel
Belgium
LILLE
Lens
Arras
Valenciennes
Cayeux-sur-Mer
Abbeville
Penly
Dieppe
AMIENS
Péronne
St-Quentin
Montdidier
Laon
Soissons
ROUEN
Beauvais
Compiègne
Senlis
Magny-en-Vexin
Evreux
Roissy
Nanterre
PARIS
Versailles
Marne-la-Vallée
Orly
A26
A16
A2
A29
A1
A13
A14
A4
A5
N
Haute-Normandie
Picardie
Nord-Pas-de-Calais
Iles-de-France
Department boundaries
Region boundaries
Légend
Motorway network:
SANEF
SAPN
ALIX
Others
Urban centers :
< 100 000 inhabitants
> 100 000 inhabitants
> 500 000 inhabitants
Structuring or strategic elements of the territory :
Major port
International airport
High speed train station
Nuclear power plant
Industrial center
Regional hospitals
Mains touristic zones
R&D centers
egis eau
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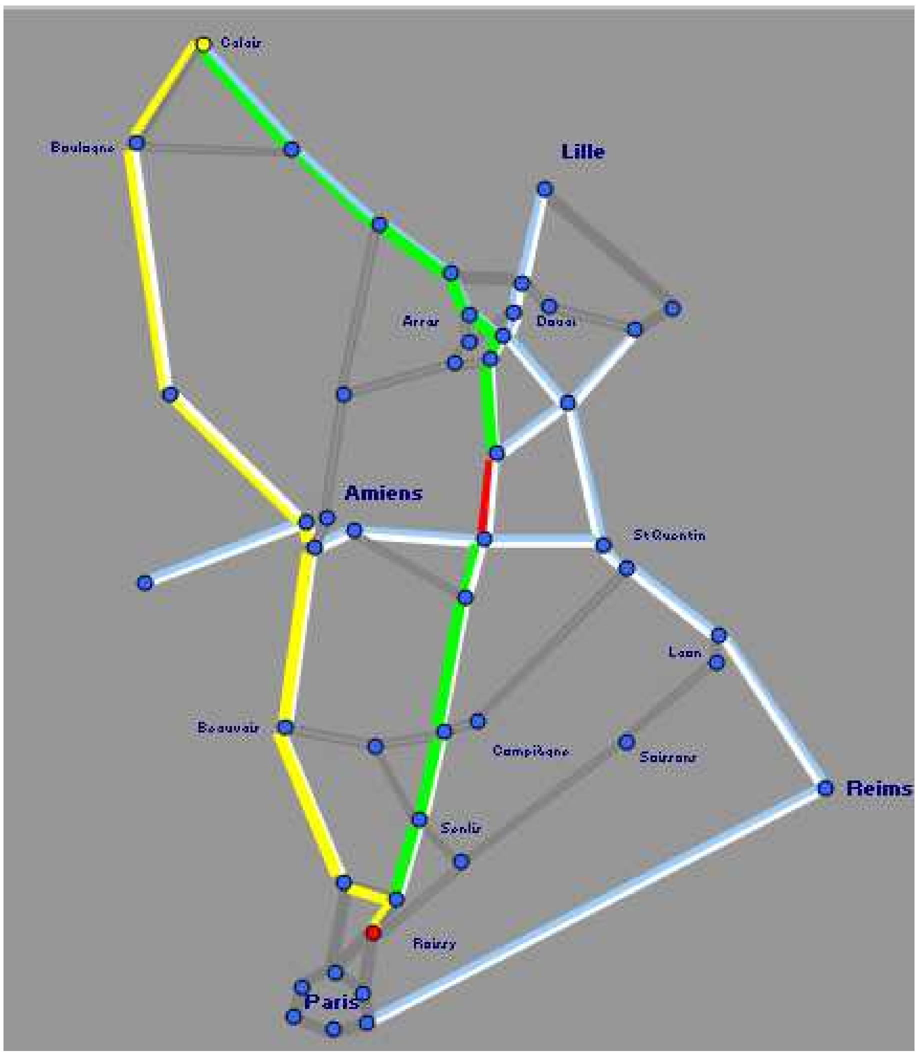
The table and synoptic below shows all sections and nodes, as well as alternative routes for the international traffic (in grey).

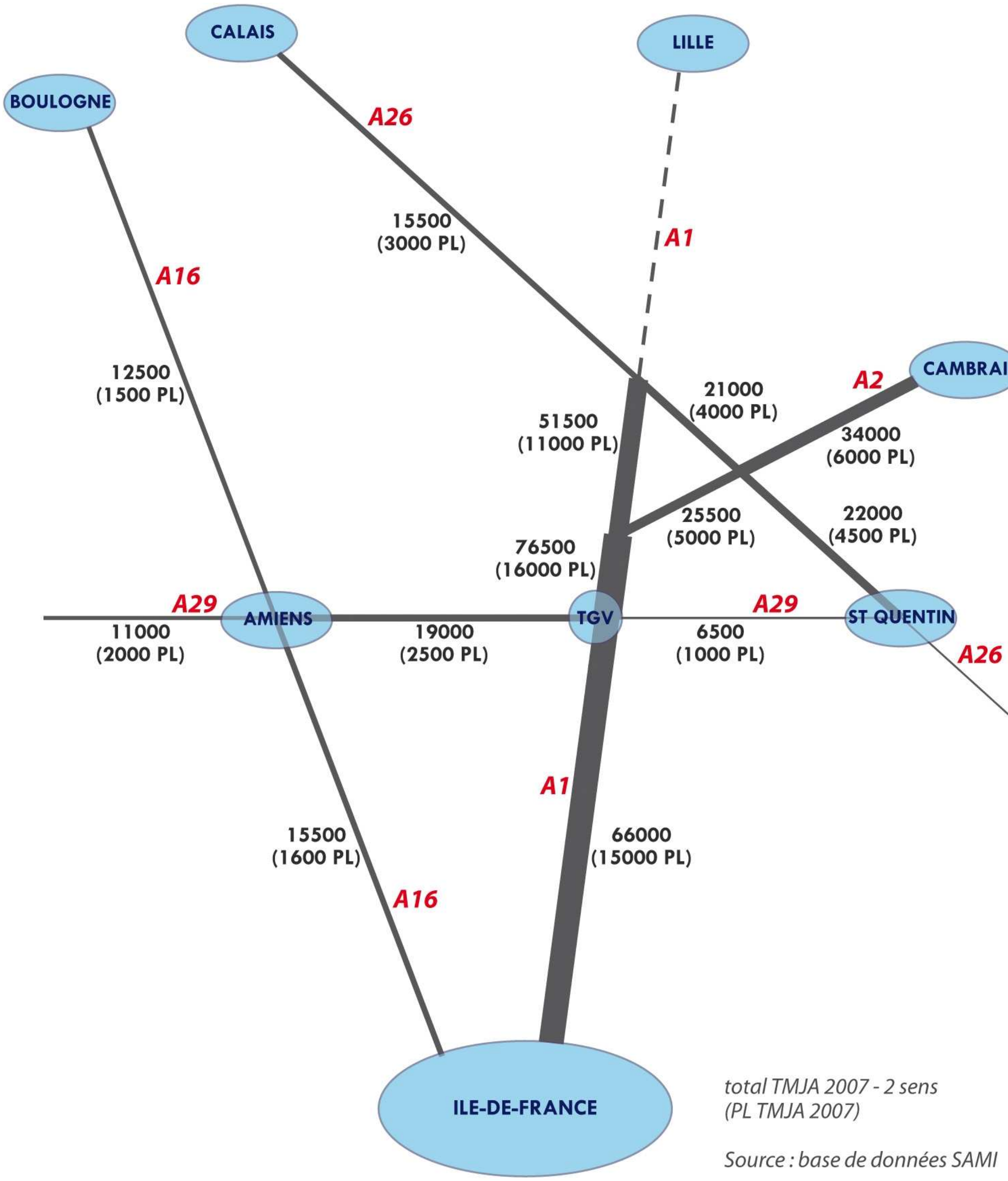
SANEF northern network and alternatives

Motorway/Road	Number of sections	Number of nodes	Singular points
A 16	6	7	Boulogne viaducts
A 1	7	8	Roissy and Neufchatel tunnels
A 26	8	8	
A 29	3	4	
A 2	2	2	
Total Sanef	**26**	**29**	
Paris motorways	2	2	
Alternative public network	12	5	
Total	**40**	**36**	



Synoptic representation of the network

As shown on the following traffic chart, the A1 motorway – linking Paris to the main regional metropolis (Lille) and further Bruxelles – is a highly trafficked motorway, with an average of 64 000 veh./day in its first part.



Traffic Chart of the SANEF Northern Network

The general context presented above is still valid at the network scale. Among the specificities of the present network case study, it is worth noting that:

- Climate scenarios are provided by Météo France, using available meteorological observations in the study area, and results of downscaling exercises.
- Climate risk factors are those defined in the RIMAROCC method, with some adaptations with respect to the local climatic context and data availability.

Step 1.3 - Establish Risk Criteria and Adapted Indicators for Network scale

The definition of risk criteria is an important step. This may be seen as a “one-time” job, since the criteria may be used in many different studies at the same geographical scale (network). It must be noted that defining risk criteria is an iterative process requiring feedback from steps 2 and 3. It is indeed difficult, if not impossible, to set risk criteria without verifying that the required data are relevant and available at the appropriate scale.

The criteria for Exposure, Vulnerability (sensitivity) and Consequences are listed below, together with evaluation classes (from low to critical). It must be pointed out that these criteria, indicators and threshold values are EGIS’ proposals and do not commit SANEF by no mean.

Exposure indicators

With respect to climate risk factors, the main exposure indicators are duration, intensity, extent and probability (likelihood).

Climate indicator	Indicator unit			
	low (1)	**medium (2)**	**high (3)**	**critical (4)**
E1 - Duration of event	Hours	Days	Weeks	Months
E2 - Intensity	See Step 2.1.			
E3 - Scale of event	Very local (e.g. 100 km²)	Local (e.g. 1000 km²)	Regional (> 10.000 km²)	National (> 100.000 km²)

Likelihood	Indicators	
Event may occur once in 10 years	4	Very likely
Event may occur once in 20 years	3	Likely
Event may occur once in 50 years	2	Unlikely
Event may occur once in 100 years or in the XXIst century	1	Very unlikely

Comments:

- Specific intensity thresholds must be defined for each climate factor, taking climate change into consideration.
- It is better if the likelihood scale fits with design standards already in use in the country of the road operator.
- Likelihood may significantly differ with climate change (e.g. a climate event occuring today only once in 20 years may happen every 10 years in 2050)

Threat and Vulnerability indicators

These indicators refer to aggravating factors regarding climate risks (e.g. site factors likely to worsen floods) and vulnerable (sensitive) components of the infrastructure (undersized drainage system, cracks in the pavement surface layer, clogged up culverts, etc.).

	low (1)	medium (2)	high (3)	critical (4)
V1 - Age of the infrastructure	< 10 years	10 – 30 years	30 – 100 years	> 100 years
V2 - Design standards	Recent design standards (< 5 years)	5 – 25 years	25 – 50 years	> 50 years or unknown standards
V3 - Control and maintenance procedures	Systematic inspection after each unusual climate event + high maintenance means	Periodical inspection (at least 1/year) + average maintenance means	Occasional inspection (only after occurrence of damages) + low maintenance means	Nearly no inspection nor maintenance means
V4 - Traffic level	< 2.000 veh./ day	2.000 - 10.000 veh./ day	10.000 – 50.000 veh./ day	> 50.000 veh./ day
V5 - Site factors likely to worsen climate risks	Optimal situation regarding land cover, topography, erosion and flood control	Acceptable situation regarding land cover, topography, erosion and flood control	Degraded situation regarding at least one site factor	Degraded situation regarding all site factors, or situation highly degraded for one site factor

Comments:

- o Vulnerability indicators can be associated with risk factors (V5) or with infrastructure design or operation (V1 to V4).
- o In the present case study, at the network scale, indicators V1 to V4 are considered more important and reliable than indicator V5, which is less discriminating (same situation for most of the road sections) and/or more difficult to assess at a large geographical scale.

Consequence indicators

The main consequence indicators of climate risks refer to traffic accidents (deaths), traffic interruption or disturbance, directy related to climate events or to damages caused by climate events.

	Low (1)	Medium (2)	High (3)	Critical (4)
C1 – Deaths	1 to 3	3 to 10	10 to 50	> 50
C2a - Downtime on 1 section	1-3 days	3 days to1 week	1 week to 3 months	More than 3 months
C2b - Downtime on 1 route	< 1 day	1-3 days	3 days to 1 month	More than 1 month
C2c - Downtime on 2 parallel routes	< 1 day	1-3 days	3 days to 2 weeks	More than 2 weeks
C2d - Downtime on all the network		0.5 to 3 days	3 days to 1 week	More than 1 week
C3 – Degraded operational conditions	< 1 month	1 to 3 months	3 months to 1 year	> 1 year
C4 - Damages *	< 1 million €	1-10 millions €	10 to 100 millions €	> 100 millions €

* Total repair costs for the whole network

Comments:

- o Traffic interruption (down time) being the most usual consequence of climate events, it seems relevant to split this indicator in several sub-indicators.
- o Degraded operational conditions may happen after traffic interruption or not.
- o It is relevant to consider socio-economic consequences (indirect costs) of traffic interruption or disturbance as well. However, this indicator requires specific investigations to be carried out by specialists.
- o It must be pointed out that, given the cumulative effect of assumptions on exposure and vulnerability factors (leading to high uncertainties), consequences are not easily predictable. Therefore, the consequence assessment will have to rely on "scenarios" based on previous events for which the consequences are already known.

Step 2 - Risk Identification

The risk manager should identify sources of risk, areas of impacts, unwanted events (including changes in circumstances) and their causes and potential consequences. The aim of this step is to generate a comprehensive list of risks based on events that might stop, degrade or delay the normal operation of the road system, or create troubles or damages in the exposed area.

Main chapter	Minor chapter
2. Risk identification	2.1 Identify risk sources 2.2 Identify vulnerabilities 2.3 Identify possible consequences

Step 2.1 - Identify Risk Sources

Climate is the source of risks considered within the RIMAROCC method. So, climate factors are the primary risk factors to be addressed in the present case study. As site factors (environmental context of the infrastructure) are likely to moderate or worsen climate factors in some extent (e.g. heavy shower will turn into flood only in case of specific topographic and land cover configurations), they can be defined as secondary risk factors. The current condition of the road infrastructure (pavement wear, embankment erosion, clogged up culverts, etc.) can also affect the infrastructure resistance capacity regarding climate factors and, as such, be considered as a secondary risk factor. In the RIMAROCC method, it is however more considered as a vulnerability factor and is analysed in section 2.2.

A – Climate Factors

Climate factors were identified with Météo France's collaboration. This collaboration with climate specialists allowed: 1) to refine the table on present knowledge regarding critical climate parameters and to adapt it to the local context (see table below); 2) to obtain detailed maps of some critical climate data over the whole study area.

Climate change projections were provided, using the available results of the Météo France ARPEGE-Climat model, with the IPCC A2 scenario and for the 2050 horizon. The A2 scenario has been chosen because it is the current “worst case” scenario, but likely to become the medium scenario in the next IPCC report. The 2050 horizon is deemed far enough to show significant impact of climate change, but also close enough to be considered as relevant for the current network operator.

In addition to climate change projections, detailed data on the current situation regarding extreme climate events were used to refine the analysis. These data being more accurate than the results of climate change projections, they were used to locate the network sections the most exposed to critical climate events.

It must be stressed that mapping climate factors also allows analysing the situation of the whole area under influence of the climate event and thus enables to establish correlations between possible impacts on the road network and possible impacts on adjacent transport infrastructure or territories.

SUMMARY OF PRESENT KNOWLEDGE REGARDING CRITICAL CLIMATE PARAMETERS FOR CLIMATE CHANGE ANALYSIS IN THE STUDY AREA

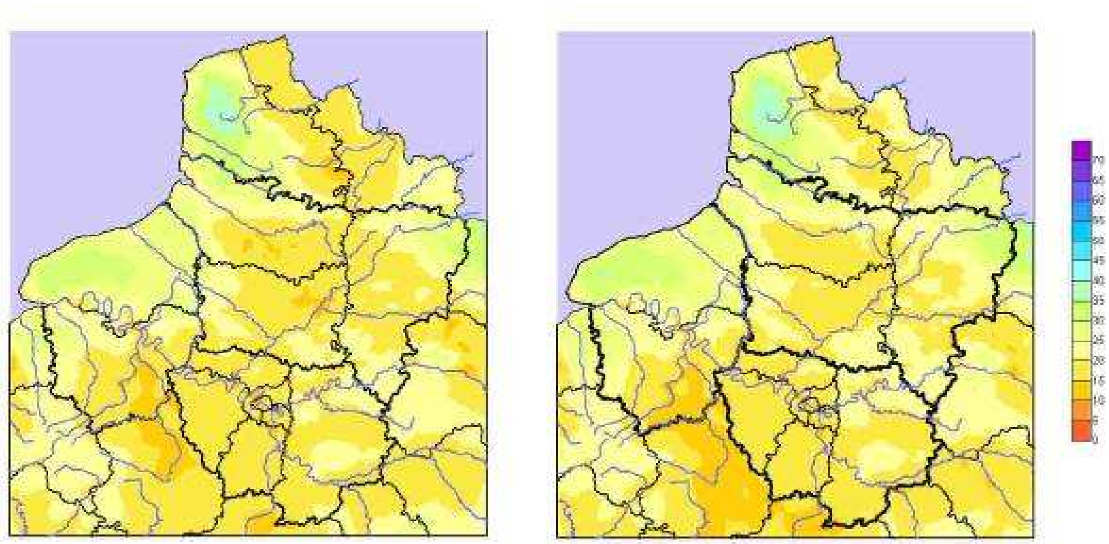
Weight *	**Climate event affecting roads**	**Critical climate parameter**	**Amount of change for 2100 compared to 1961-1990 (++, +, +/-, -, --) **: overall situation for Europe**	**Availability of predictions: qualitative, quantitative, or impossible**	**Certainty of predictions (IPCC legend)**	**Amount of change for 2100 compared to 1961-1990 (++, +, +/-, -, --) **: downscaling on North of France– ARPEGE-Climat (50km resolution)**
4	Extreme rainfall events (heavy showers and long rain periods)	➢ Max. intensity in [mm/h] and [mm/24h]	Intensity: + Frequency: ➢ North + ➢ South ?	Qualitative	Likely	+/-: no significant trend
4	Seasonal and annual average rainfall	➢ Average amount [mm/ 3 months]	Sum. / Wint. North Eu: +/- / ++ South Eu: --* / -	Quantitative	Sum. / Wint. North Eu: L / VL South Eu: VL / L	-: annual average rainfall (10 %) --: summer (25-30 %)
4	Sea level rise (long term effect) + waves and storm surges (short term effect; see specific row in table)	➢ Rise [m]	++ XXI Cent.: 0,2 to 0,6m IPCC assumption: no accelerated ice cap melting	Quantitative Qualitative if considering accelerated ice cap melting	> 0.2m is virtually certain in 2100	+/-: Pas de Calais region +: Picardie region (+0.4 m for 50 years storm surges)
3	Maximum temperature and number of consecutive hot days (heat waves)	➢ Average max. [T°C on 24h]	South: ++21th Cent T°C aver. Global: 1,8 to 4,0 °C (best estim. /scen.).	Quantitative	V. Certain in Europe	++: max. temperatures (1 to 4.5°C) +: min. temperatures (0.5 to 3.5°C)
		➢ Maximum [T°C]	+: North/continent ++: for extremes	Quantitative	V. Certain	++: number of hot days (> 25°C): + 57 %
		➢ Heat wave duration [number of consecutive days], [hw/year]	++ 5 to 30 days	Quantitative	Very likely	++: number of extremely hot days (> 35°C)

* Weighting performed by the RIMAROCC steering committee (growing importance from 1 to 4)
** ++: strong increase, +: increase, +/-: variable; -: decrease; --: strong decrease; ?: unknown

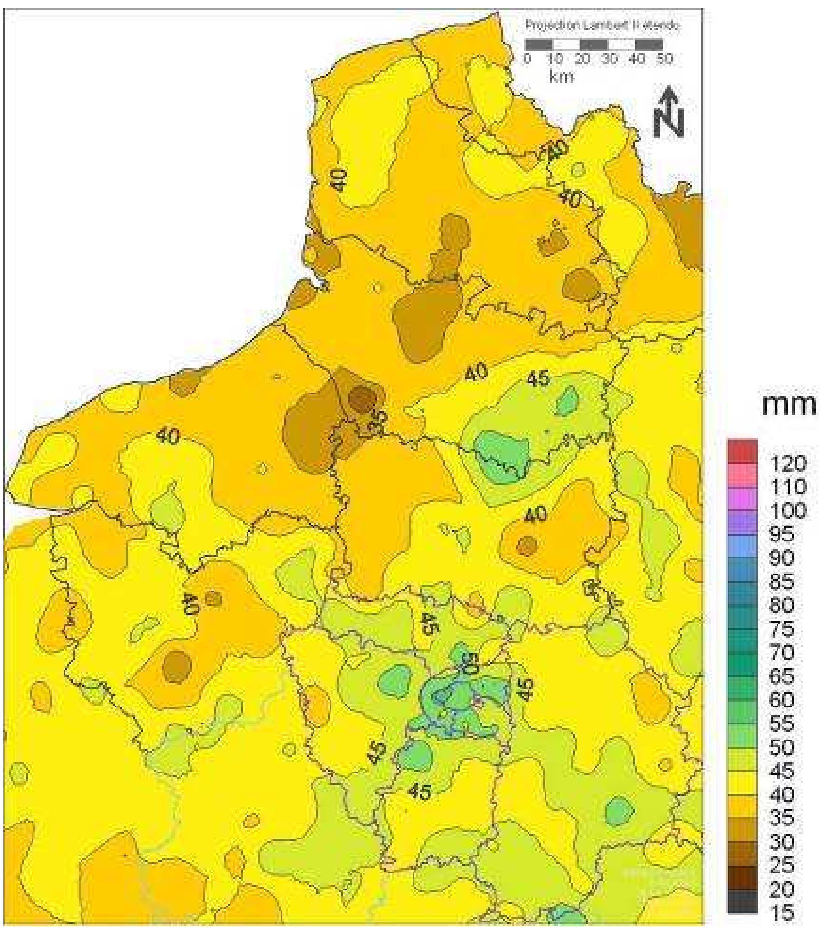
Weight *	Climate event affecting road	Critical climate parameter	Amount of change for 2100 compared to 1961-1990 (++, +, +/-, -, --) **: overall situation for Europe	Availability of predictions: qualitative, quantitative or impossible	Certainty of predictions (IPCC legend)	Amount of change for 2100 compared to 1961-1990 (++, +, +/-, -, --) **: downscaling on North of France – ARPEGE-Climat (50km resolution)
2	Drought (consecutive dry days)	➢ Drought duration [number of consecutive days], [d/year]	++ over South. Eur. ++ centr. & West Eur.	Quantitative Qualitative	Very Likely More likely than not	++: 5 to 25 additional days of drought per year
2	Snowfall	➢ Max. snowfall in 24h [m/day] ➢ Snow duration at the ground [nb of days]	Int: + Far North Eur. ? Rest of Eur. Freq: - N/W/cent Eur. Duration: -- whole Eur.	Qualitative Qualitative Quantitative	Likely Likely V. Certain	--: twice less compared to the present average situation, but strong interannual variability
2	Frost (number of icy days)	➢ Minimum [T℃] ➢ Average [min. T℃ on 24h] ➢ Frost duration [number of days/year] ➢ Frost index [frost penetration into the soil, Hellmann number]	+ (small possibility that minimum temp. increases more than average minimum) ++ 1,8 to 4,0 ℃ -- -- Same changes over whole Eur.	Quantitative Quantitative Quantitative Quantitative	Likely V. Certain V. Certain V. Certain	-: 5 to 10 % decrease of frost days --: strong decrease of cold days during the present period, which continues in the 21st century (above all during the second half) --: ditto for extreme cold days --: decrease of "cold warning" procedures
2	Thaw (number of days with temperature zero-crossings)	➢ Thaw days [number of days with 0℃ crossings]	+ North. and Cont. Eur. - South (research going on)	Qualitative	V. Certain in North. Eur.	-- : reduction of number of days without thaw
2	Extreme wind speed (worst gales) : extra tropical or convective systems induced	➢ Max. speed [km/h]	+ in North-West Europe ? elsewhere North shift of the storm tracks (500 – 1000 km)	Qualitative	Likely in North Poor (unknown) in South and West.	+: rise in strong winter winds (9 to 18 %) -: slight reduction in summer (5.5 to 11 %)
1	Fog days	➢ Fog days [number of days with fog]	?	Not yet possible (local effects)	Unknown	?

* Weighting performed by the RIMAROCC steering committee (growing importance from 1 to 4)
** ++: strong increase, +: increase, +/-: variable; -: decrease; --: strong decrease; ?: unknown

Example of climate change projection map used for the network case study: number of days with rainfall > 10 mm (present situation on the left and future situation on the right)



Example of map of extreme climate event used for the network case study: maximum rainfall intensity in 1 hour for a 100 year return period (current situation).



Given the present knowledge on climate change, the climate features of the study area, and the meteorological data availability, the network case study focused on the following climate factors:

- Extreme rainfalls
- Seasonal and annual average rainfall
- Maximum temperature and number of consecutive hot days (heat waves)
- Extreme winds
- Frost / snowfall

Combinations between climate factors are possible but not considered as determining.

B – Contextual Site Factors

In the framework of the case study it quickly appeared obvious that a comprehensive analysis of site factors along the whole network was not cost effective. Indeed, beyond several tens of kilometres (i.e. a "section" scale), it is very time consuming to collect this kind of data at the appropriate level of detail.

According to general information provided by SANEF staff, the study area shows:

- Some new urbanized areas but well controlled regarding surface water drainage.
- No specific problem with deforestation.
- Possible consequences of changes in agricultural exploitation mode, due to suppression of hedges and cultivation of surface water discharge areas.

Let us note that it seems possible to identify some physical features of the network environment through specific data sources, e.g. Corine Land Cover maps to identify changes in land use, or geological maps to identify possible geotechnical issues, but this kind of data cannot be taken into account without further investigations. For example, changes in land use can change the run-off conditions, but the actual impact on water flows can be estimated only if knowing the concerned watershed limits, together with the flood or erosion management actions already implemented to mitigate this impact.

In this context, it is deemed very difficult to incorporate site factors in the RIMAROCC process at the network scale. It shows the importance of getting the "reference situation" (point zero) before starting the RIMAROCC approach.

Step 2.2 - Identify Vulnerabilities

Establish a Vulnerabilities Frame of Reference is not in the scope of the RIMAROCC project, but the RIMAROCC consortium considers that the handbook users would experience many difficulties with the RIMAROCC method if there is not any available frame of reference in their country. So, it is necessary to define a specific approach at the beginning of the risk management process.

Vulnerability can be defined as the potential of the road network to be harmed by climate events. Vulnerabilities are physical features or activities/functions of the road network that can be affected.

In theory, vulnerabilities should be identified for each section (40) and nodes (36) of the network, in relation with a maximum of 5 possible climate events. Within each section or node, it would be necessary to clarify what the vulnerable components are: embankment, pavement, equipments, etc.

At the network scale, it is not possible (not cost effective) to investigate each section, node or singular point. So, the methodological approach is based on interviews of a pool of technical experts in SANEF company. Indeed, it is assumed that none knows the network issues better than the company experts. A specific guide has been developed to interview the operator's employees (see annex 1). For the present case study, 10 specialists from SANEF in various technical field and operation system were involved.

Based on these interviews, and according to risk criteria defined in Step 1.3., the following vulnerability factors have been identified:

- The infrastructure age (some of the northern network sections are the oldest motorway sections in France);
- The high traffic level of some sections, considered as critical in terms of traffic safety as well as economical activity;
- Design standards (e.g. when some parts of the network were upgraded from 2x2 to 2x3 lanes, the drainage network was not resized);
- Specific issues (sensitive elements) related to design, operation or maintenance. For example, in some sections, concrete security barriers prevent fast drainage in case of heavy rainfall, and this device could be the cause of flooding (e.g. Roye incident in 2003)

This information is summarized in the next tables (N.B.: for confidentiality reasons, the network sections are coded). The first one shows, for each section, the connection between climate risk factors and sensitive elements of the infrastructure. The second one presents the main vulnerability factors and the related climate risks.

Section	**Climate factors**					**Sensitive elements of the infrastructure (potential impact on infrastructure/operation)** N.B.: all structural damages can lead to traffic interruption
	Extreme rainfall	**Seasonal and annual rainfall**	**Extreme winds**	**Frost**	**Snowfall**	
AX-1	X					Undersized drainage system (traffic interruption)
AX-2	X	X				Undersized bridge (bridge structure damages)
AX-3	X					Undersized culverts (road structure damages)
AX-4	X		X			Bridge showing structural defects (bridge structure damages)
…						
AY-1		X				Hydromorphic grounds (road structure damages)
AY-2		X		X		Pavement cracks (road structure damages)
…						
AZ-1				X	X	Steep roadway slope (traffic interruption)
AZ-2			X			Viaducts (traffic interruption)
…						
Node A	X					Poor underpass drainage (traffic interruption)
…						

Section	Length in km	Age / design standards	Traffic (veh./ day)	Exposure to climate events		Sensitive elements of the infrastructure
				Current situation	With CC (estimates) *	
AX-1	10-15	< 1960	60000 - 70000	Overflow for Q10	+ 10 % additional flow	Undersized drainage system
AX-2	25-30	< 1960	60000 - 70000	Overflow for Q100	+ 5 %	Undersized bridge
AX-3	45-50	1960-1970	40000 - 50000	Overflow for Q100	No change	Undersized culverts
AX-4	25-30	1960-1970	40000 - 50000	Extreme wind speed > 120 km/h	+ 5 %	Bridge showing structural defects
…						
AY-1	20-25	1980-1990	20000 - 30000	Average seasonal rainfall: 500 mm	+ 5 %	Hydromorphic grounds
AY-2	20-25	1980-1990	20000 - 30000	Average number of frost days: 20	- 5 %	Pavement cracks
…						
AZ-1	30-35	1990-2000	10000 - 20000	Average number of snow days: 15	- 20 %	Steep roadway slope
AZ-2	15-20	1990-2000	10000 - 20000	Extreme wind speed > 140 km/h	+ 10 %	Viaducts
…						
Node A		1960-1970	40000 - 50000	Flood for Q10	No change	Poor underpass drainage
…						

* A2 IPCC scenario for 2050

Step 2.3 - Identify Possible Consequences

It is assumed that the primary consequences of extreme climate events on road network are (see Step 1.3.):

- Deaths, i.e. number of people killed on the road network because of accidents generated by climate factors;
- Down time, i.e. traffic interruption during a variable time period and affecting a variable portion of the network;
- Disruption, i.e. traffic disturbance because of climate events or after climate events (restart of the traffic after total interruption);
- Damages caused by climate events on the infrastructure and its equipment (N.B.: damages are often the main causes of mortality, down time and disruption)

At the network scale, three different geographical perimeters can be considered to identify possible consequences: network, territory, economic system. At the network level, only the four consequence categories above quoted will be addressed. At the territorial level, i.e. the regional perimeter directly serviced by the network, the analysis can be completed with the socio-economic consequences of the traffic interruption or disturbance. Finally, addressing the consequences at the level of the economic system, i.e. from the regional to the European scale, would consist in analysing the impact of major or recurrent traffic interruptions on the organisational and operational aspects of the economic system.

In the framework of the present case study, only the first level of consequences (network) has been studied. It would be relevant to complete this analysis with considerations to the territory and the economic system, but such investigations require data not available at the network operator level, and therefore should involve other stake holders such as regional councils or road administration.

It is difficult to forecast the consequences of climate events on the road network. For example, the number of deaths is highly unpredictable. For the present case study, assumptions were based on the network operator incident database (record of all incidents caused by climate factors and leading to complaints from users or nearby residents), and on interviews of operator experts.

One of the most recent example of climate related incident on the SANEF network is presented below.

Inundation of the A1 motorway in 2001: the Roye episode

On 7 July 2001, in the Roye district, an exceptional rainfall event led to the A1 motorway closure, from km 102.2 to km 103.6, during two days hours.

The precipitation amount has been estimated at 200 mm in 12 hours, meaning that it rained the equivalent of one third of the average annual precipitation in only half a day. Knowing that, the hundred years rainfall was previously estimated at 68 mm in 24 hours, the "Roye episode" clearly appears as a multicentennal event. Moreover, this episode happened after a rainy period, inducing strong reduction in the ground infiltration capacity.

The event chronology was as follows:
- Saturday 07 AM: the ∅800 culvert on km 102.2 exceeds its discharge capacity and starts overflowing on the carriageway. The traffic is diverted.
- 01:30 PM: the whole carriageway in the Lille-Paris direction is flooded;
- 06 PM: the water level reaches the top of the guard rail, that is to say approx. 70 cm;
- Monday 10 AM: the inundation is finished; the motorway is reopened.

The A1 motorway, near Roye, the 7th of July, 2001

Lessons learned:
- the concrete safety fences formed obstacles to proper drainage of excess water on the carriageway. It has been necessary to make openings in the fences to facilitate drop in the water level.
- The meteorological event leading to the flood is characterised by its exceptional intensity together with a very local extent. Knowing that:
  . it is very unlikely that such event would happen again at the same place,
  . no significant damage to the infrastructure occurred,
  . an exceptional traffic interruption no longer than 3 days is deemed acceptable,
  . the drainage and hydraulic system is estimated fully operational for a 100 years flood,

  no particular mitigation measure has been implemented by SANEF.

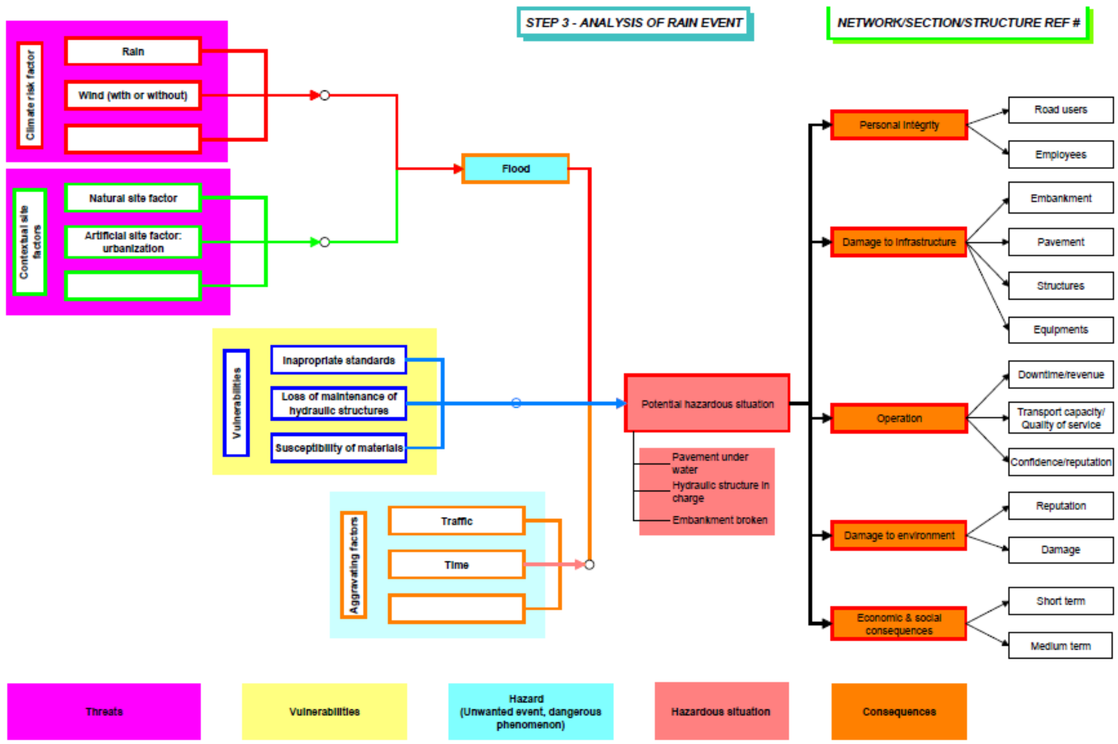
Step 3 - Risk Analysis

Risk analysis involves developing an understanding of the risk. Risk analysis provides an input to risk evaluation and to decisions on whether risks need to be treated, and on the most appropriate risk treatment strategies and methods. Risk analysis can also provide an input into making decisions where choices must be made and the options involved by different types and levels of risk.

Main chapter	**Minor chapter**
3. Risk analysis	3.1 Establish risk chronology and scenarios 3.2 Determine impact of risk 3.3 Evaluate occurrences 3.4 Provide a risk overview 3.5 Define sections or nodes for which detailed approach is required 3.6 Carry out a detailed analysis of critical sections, nodes or singular points

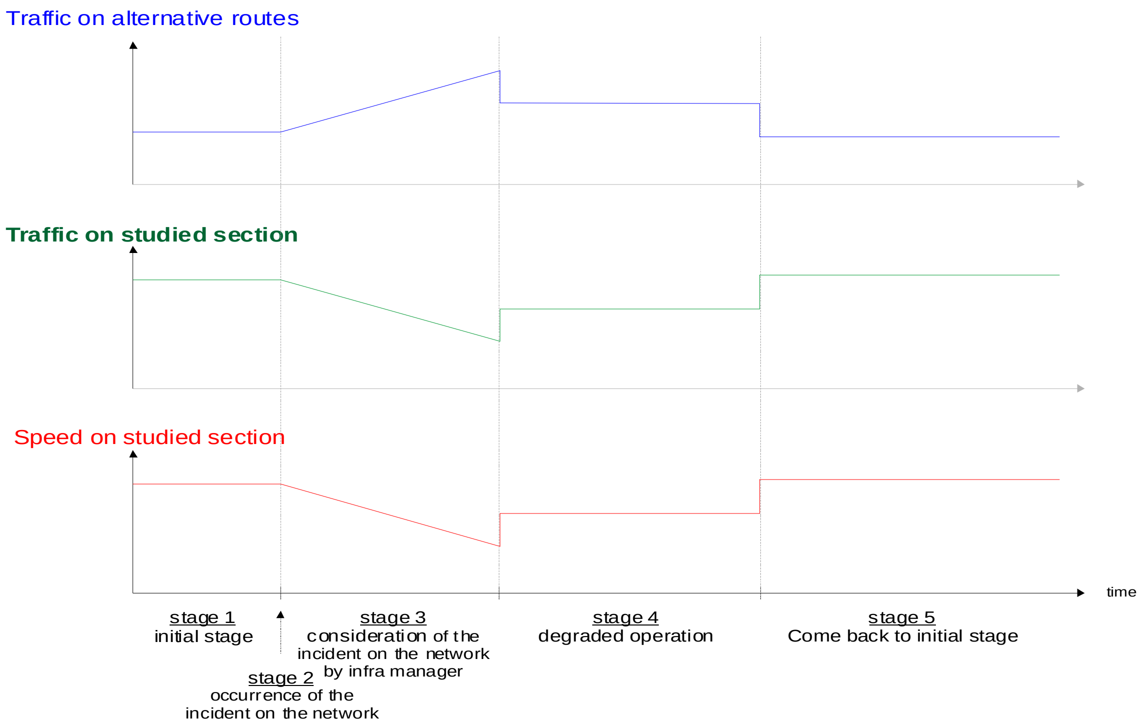
Step 3.1 - Establish Risk Chronology and Scenarios

Specific diagrams to define scenarios for the main climatic event were created as a tool to facilitate dialogue with the interviewed experts. An example of such a diagram is given below, regarding flood related risks:



The interest of such work is to break down risk scenarios in their elementary components, allowing identifying what the possible defence means are: monitoring, early warning, reaction … These issues were discussed with SANEF experts.

Taking the example of partial closure of a section (traffic disturbance), the risk chronology can be represented as follows:

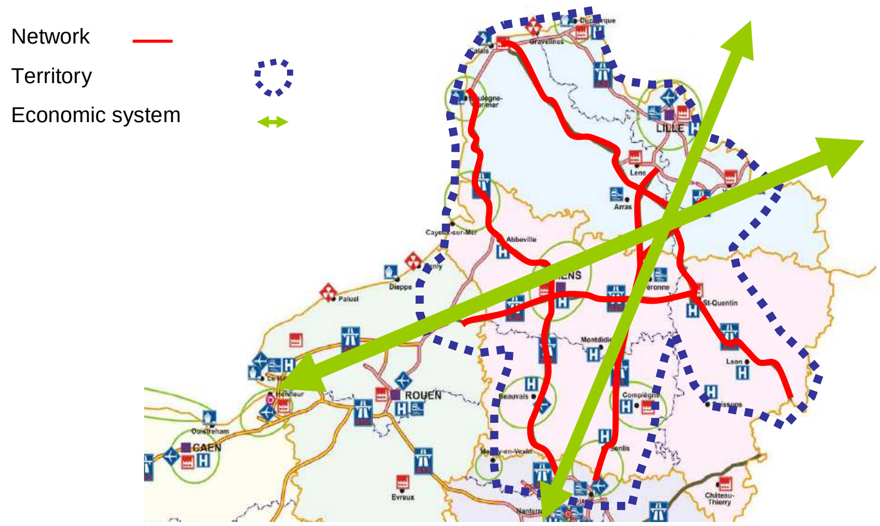


Step 3.2 - Determine Impact of Risk

In compliance with Step 2.3., the climate risk impact assessment (studied through a partial or global break down of traffic flows on a network) should be implemented according to 3 geographical perimeters:

- First perimeter: road network, in order to take into account the impact of climatic risks on traffic flows observed on this network,
- Second perimeter: territory, in order to take into account the impact on socio-economic organisation of these territories,
- Third perimeter: large economic approach (at European scale), in order to take into account the impact on road network use, of a decrease in transport service quality, by logistics managers.

Three overlapping perimeters



Road network approach

The first scale is micro-economic and only concerns flows directly affected by incidents resulting from a climatic risk. We need to address, for these flows, the economic value of the consequences: deaths, damages, loss of time, traffic jam, etc. These consequences are highly dependant on the importance of flows.

Territorial approach

The socio-economic organisation of territories served by the road network is based on the network characteristics (location of entrance points, length, travel time to main agglomerations, etc.). Some companies are organised (choice of economic partners) according to possibilities supplied by the network. What will happen if the connection between territories and their economic partners is not operating any longer (how warehouses which supply retail shops are supplied? How do manufacturers send their products to their customers?)

Macro-economic approach

The last and third scale concerns industrial and economic system at European level. At present, our production system is organised with just-in-time flows. The main industries are European (it is the case for example of the automobile industry, with European manufactures dedicated to 2 or 3 automobile models, sold in all Europe). There are few spatial constraints, because transport cost is very low and efficient. What may happen if the transport link is significantly less efficient? Should we consider a decrease in the sphere of influence of European plants and warehouses? Will "space" be integrated again in the economic activity?

As already specified in Step 2.3., the two last levels of assessment require data that are not available among the road network operators. So, the present case study was restricted to the network approach.

Step 3.3 - Evaluate Occurrences

Extreme climate events, likely to have impacts on the road system, are – by definition – exceptional. Climate events to be considered in the present analysis are those exceeding the design standards of the network. Regarding drainage and hydraulic issues, the main occurrences to be taken into account will therefore be 10 or 25 years for the drainage system, 100 years for culverts and bridges.

In the climate change context, occurrence is changing. It is still difficult to forecast in the present case study area what these changes will be (see table in Step 2.1.). For example, change in extreme rainfall events is still uncertain. And even for climate risk factors with better prediction certainty (e.g. heat wave or snowfall), it is still hazardous to quantify the possible changes, because the projections strongly rely on what IPCC scenario is considered and what climate model is used.

In the present case study we decided to consider the A2 scenario (worst case scenario) together with the ARPEGE-Climat model run by Météo France. When comparing for a same geographical place and the same climate model, the current and future situation (2050), it is possible to quantify some changes (e.g. max. temperature will increase by 1.5℃, and the occurrence of heat waves will increase by 30%). However, it must be kept in mind that these figures result from a cascade (or pyramid) of assumptions and uncertainties.

Step 3.4 - Risk Analysis: Overview Using a semi-Quantitative Approach

Implementing a semi-quantitative approach, means to fulfil a "risk table" for each of the network sections (or nodes). Such risk table describes for each climate risk factor the corresponding probability (likelihood), the section exposure, the section vulnerable elements, and the related consequences. This information is scored (e.g. 1 for low exposure, 4 for high exposure), so as to allow comparing sections with each other and aggregating the scores of all risk criteria in a single mark. After completion of all risk tables, the sections can be ranked according to their overall score, from the lowest to the highest risk level regarding climate factors.

In the present case study, the following risk table was used:

Section AX_1

Risk description	**Exposure**	**Likelihood**	**Vulnerable elements**	**Possible consequences**	**Total score**
Extreme rainfall	>30 mm/h	1/10 years CC+	Age + traffic + undersized drainage	Down time: 1-3 days	
score	2	4	4	1	11
High seasonal rainfall	>300 mm/ 3months	Annual CC-	Age + traffic	None	
score	2	0	2	0	4
Heat waves	10 days > 35℃	Annual CC++	Age + traffic + design standards	None	
score	3	4	2	0	9
Extreme wind	>120 km/h	1 / year CC+	Age + traffic + design standards	None	
score	2	2	3	0	7
Snowfall	20 days/y	Annual CC--	Age + traffic + design standards	Down time: 1-3 days	
score	3	0	3	1	7
Total score	12	10	14	2	38

It is recalled that:

- risk description, likelihood and exposure are given by climate experts
- vulnerable elements are defined through interviews of the network operator experts
- possible consequences are determined through similar events already experienced on the network (expert interview + incident database).

Score assessment:

- Exposure: refer to Step 1.3. indicators. Specific intensity values for each climate factor are given by Météo France (see Step 2.1.). These values vary according to the geographical location of the motorway section. The score results from the combination: intensity x duration x scale of the event. For example: on Section AX1, rainfall intensity is the highest of all the northern network study area (score 4), extreme rainfalls last only a few hours (score 1), and their scale is often very local (score 1). The resulting global score for exposure is: (4+1+1)/3= 2. Global scores are rounded (e.g. 2.33 = 2).

- Likelihood: theoretically, the same assessment grid as the one proposed in Step 1.3. should be used. However, likelihood mainly depends on the intensity thresholds considered for exposure, and these threshold values mainly depend on local available meteorological data, making the score arbitrary. In addition, the event likelihood appears relevant only if a comparison with the infrastructure design standards is possible. For Section AX_1, it is the case for extreme rainfall exceeding the 10 years return period design standard for the drainage system, but no such return period can be considered for high seasonal rainfall or snowfall (there is no related design standard). If no objective criteria of likelihood can be used, it is recommended to base the scoring on climate change trends. As climate change may induce beneficial effects (e.g. drop in seasonal rainfall and snowfall), likelihood may be scored + or -. However, to simplify the scoring, it is recommended to give a “0” value for climate factors showing improvements in the future situation.
- Vulnerable elements: refer to Step 1.3. indicators. According to the assessment grid, for extreme rainfall, Section AX_1 can be scored 3 for “age of the infrastructure”, 4 for “traffic level”, and 4 for “design standards” (all the more because of the undersized drainage system). The final score is rounded to 4. Scoring of “design standards” for other climate factors: without information on site factors (hydromorphic grounds, unstable slopes…) “design standards” is not considered as relevant regarding “high seasonal rainfall” (score 0); according to its design standards, Section AX_1 is not supposed to be vulnerable to heat wave effects (score 0); Section AX_1 has been built before enforcement of the “snow and wind” design standards (score 2).
- Possible consequences: refer to Step 1.3. indicators. Score 0 is given when no significant consequence is expected regarding climate factors.

Scores of all section risk tables are gathered in a single synthesis risk table as follows:

Section	Exposure	Likelihood	Vulnerable elements	Possible consequences	Total score
AX-1	12	10	14	2	38
AX-2					
AX-3					
AX-4					
…					
AY-1					
AY-2					
…					
AZ-1					
AZ-2					
…					

Let us note that this synthesis table can be used to compare the sections for a given climate risk factor (in such a case, only the related score is written down), or to compare the sections all climate risk factors merged.

Step 3.5 - Define Sections or Nodes for which Detailed Approach is Required

This sub-step of the RIMAROCC method is specific to the network scale. It concerns all sections or nodes showing through the Step 3.1. semi-quantitative evaluation significant climate risks.

Example: Section AX_3 constructed during the 60s, operated with high traffic level, showing drainage deficiency, and located in an area of high rainfall intensity (likely to increase with CC) requires further investigations.

Step 3.6 - Carry out a Detailed Analysis of Critical Sections, Nodes or Singular Points

This sub-step corresponds to the implementation of the RIMAROCC method at the section or structure scale (see Handbook, Chapter 4.3 Scale of Analysis). It includes all the methodological RIMAROCC steps, but using more detailed approaches than those used for the network and territorial scales.

In the network study area, the “Roye section” of the A1 motorway has been surveyed with the EGIS GERICI tool for short and intense rain events.

Step 4 - Risk Evaluation

The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. Risk evaluation involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered (N.B. it can also be done through the semi-quantitative approach of the risk analysis stage – see Step 3.4.). Based on this comparison, the need for treatment can be considered.

Main chapter	Minor chapter
4. Risk evaluation	4.1 Risk prioritization 4.2 Compare climate risk to other kinds of risk 4.3 Determine what risks are acceptable

Step 4.1 - Risk Prioritization

At the network scale, the risk evaluation step enables to refine the risk analysis. This can be achieved through two complementary approaches:

- Weighting climate risk consequences, and
- Performing an economic evaluation.

The first approach is a quick method intended to decision makers who do not want or need to implement more thorough investigations.

The main consequences to be weighted at the network scale are: deaths, down time, disruption, damages, socio-economic impacts. They can be weighted as described in the handbook and put in a risk matrix with risk classes:

0 = not important related to the other criterion
1 = of minor importance but still attributes
2 = of major importance
3 = absolutely of major importance related
to the other criterion

This weighting exercise has not been performed in the framework of the present case study. However, it should be mentioned that, at the “strategic” level of the network analysis, it is highly uncertain to forecast any casualty on the road system. So, even if this criterion should be given major importance, it is difficult to integrate it in risk evaluation at the network scale. , As to the weight of the “damages” criterion, it is highly dependant on the respective interest of the network operator towards the impact of climate risks to his own assets (damages to the infrastructure) or to the global economy (down time, traffic disruption and socio-economic impacts).

For road operators requiring more detailed assessments, such as in the present case study, economic evaluation can be performed to determine what is actually at stake and to what extent. Indeed, the economic evaluation is aimed to answer questions such as: how to compare loss of safety (deaths, injuries) with property damages (direct costs for the road operator)? Are property damages more detrimental for the road operator than down time costs (loss of income)? What is the order of magnitude of socio-economic costs (for local communities served by the network) compared to direct costs or income losses for the road operator?

In the present case study, at the network scale, the impacts to be assessed were classified in two categories:

- Effects on users :
  - Deaths and casualties
  - Down time related to traffic congestion
  - In case of traffic diversion:
    - Down time (longer itinerary, congestion on alternative routes)
    - Economic losses (vehicle use additional costs)
- Effects on the network operator:
  - Damages to the infrastructure
  - Means mobilized to restore operational conditions
  - Income losses

"Network incidents" generated by climate events are broken down according to a time sequence presented in the following table.

Risk scenarios under consideration include:

- The climate event (intensity, location), and
- The related operational incident (location, duration, traffic level)

The event duration (traffic interruption) and its geographical perimeter (zone of influence) are the main parameters. Regarding the geographical parameter, have been tested:

- A climate event of local extent, giving only rise to traffic interruption on one motorway section, and
- A wide climate event, leading to traffic interruptions on all roads and motorway sections on a given geographical perimeter.

Because of data privacy, it is not possible to present the economic evaluation outcome.

Sequence and Content of the Economic Evaluation at the Network Scale

Step	Traffic conditions on the SANEF network	Traffic conditions on the alternative routes	Geographical perimeter	Duration	Socio-economic impacts
1 : Initial situation	Normal speed and flow	"Natural" normal flow	-	-	-
2 : Occurrence of a network incident	Slow speed or traffic interruption, accumulation of the flow of vehicles	"Natural" normal flow	-	Depends on the incident severity and the concerned geographical perimeter	➢ Down time (travelers and freight) ➢ Additional heavy vehicle operational costs ➢ Possible damages and casualties caused by the incident
3 : Dealing with the network incident	Slow speed or traffic interruption, the flow accumulation starts decreasing	"Natural" normal flow + growing diverted traffic	Depends on the affected part of the network on the South-North axis	Mainly depends on the concerned geographical perimeter, the accumulated flow and the severity of the network incident	➢ Down time (travelers and freight) ➢ Additional heavy vehicle operational costs ➢ Income losses for the motorway companies ➢ Mobilization cost of resources for solving the problem
4 : Degraded operational conditions			Depends on the affected part of the network on the South-North axis	Required time for coming back to the "normal" situation	➢ Down time (travelers and freight) ➢ Additional heavy vehicle operational costs ➢ Growth of accidents ➢ Income losses for the motorway companies ➢ Mobilization cost of resources for solving the problem ➢ Some flows can be postponed (notably freight), provided reorganization of production and delivery systems to be implemented ➢ Possible economic problems of nearby production sites ➢ Possible access problem to health and safety public services
➢ 4-a : traffic continuation	Slow speed, normal flow? (depends on the incident duration)	"Natural" normal flow + possible diverted traffic (depends on disturbances on the main route and the incident duration)			
➢ 4-b : traffic interruption	No flow	"Natural" normal flow + diverted traffic (partially or totally), slow speed			
5 : Coming back to the initial situation	Normal speed and flow	"Natural" normal flow	-	-	-

Step 4.2 - Compare Climate risks to other Kind of Risks

No specific analysis regarding other kind of risks has been carried out in the framework of the present case study. However, at the network scale, the only comparable risk is the seismic risk. Within the network, at section level, traffic accidents, technological risks (hazardous good transportation, or vicinity of a Seveso type plant), or terrorism acts can be compared to climate risk factors.

Step 4.3 - Determine what Risks are Acceptable

SANEF has not defined thresholds regarding the acceptability of possible failures on its motorway network. However, 1 to 3 days of traffic interruption is deemed acceptable on the North-South axis (A1 or A16), if alternatives routes are available. Usually, in case of disaster involving interruption of the whole supply chain, it is considered that urban areas and the global economy can keep operating during maximum 3 days. Afterwards, some shortages may appear.

In case of large scale climate event, affecting the whole territory serviced by the network, the impact of traffic interruption may be considered as higher (i.e. lower acceptability), insofar as access by other transport means may be more difficult.

At regional scale, risks can be considered as acceptable if it is possible to access cities by at least one major road.

Step 5 - Risk Mitigation (Treatment)

Risk treatment involves selecting one or more options for modifying risks, and implementing these options. The purpose of risk treatment plans is to document how the chosen treatment options will be implemented. Treatment plans should be integrated with the management processes of the organization and discussed with appropriate stakeholders.
Decision makers and other stakeholders should be aware of the nature and extent of the residual risk after risk treatment. The residual risk should be documented and subject to monitoring, review and, where appropriate, further treatment.

Main chapter	Minor chapter
5. Risk mitigation	5.1 Identify options 5.2 Appraise options 5.3 Negotiation with funding agencies 5.4 Elaborate action plan

Step 5.1 - Identify Options

Within the present case study, three options were reviewed:

- **Monitoring and contingency plans**: anticipate meteorological conditions, have reactive organisation (crisis management group) and adapted procedures for traffic diversion, close critical sections or singular points (users' safety), evaluate promptly the consequences after the event and re-open the section (as far as possible). This option is the less expensive and easier to implement, but it is deemed acceptable only if there is no foreseeable damage to persons and environment (apart from the motorway itself).
- **Retro-fitting**: strengthen critical sections or singular points in order to have minimum interruption of traffic, and minimum damages. Decision should be based on detailed analysis at the appropriate scale.
- **Reconstruction**: create new climate-proof sections or structures, in case of unacceptable impacts that cannot be mitigated by the two previous options. This option is especially required when climate or site factors become incompatible with the infrastructure durability (e.g.: sea level rise may involve shifting the infrastructure to areas less exposed to erosion and submersion). In the present case study, this option has not been considered as necessary.

Step 5.2 - Appraise Options

The two possible options were appraised in the economic evaluation, through a cost-benefit analysis. The main outcome of the economic evaluation is that, compared to direct costs to the road operator, retro-fitting is not cost-effective, but taking all socio-economic costs into account, this option is always pertinent.

Step 5.3 - Negotiation with Funding Agencies

This issue is essential for road operators who are not the road owners (i.e.: concessionaire). In such a case, if taking climate risks into account involves additional expenses or investments from the operator, the owner should agree on compensations. Such compensations could include the extension of the concession time period and/or increases in toll fees.

The economic evaluation carried out in the framework of the present case study may be used to open negotiations with the funding agencies. However, it must be pointed out that this kind of negotiation requires more detailed analysis, to be implemented at section or structure scale.

Step 5.4 - Elaborate Action Plans

Based on the network scale analysis, a general action plan can be prepared to define:

- Possible immediate operational decisions (e.g. changes in early warning procedures and enhanced intervention means for identified critical sections),
- Complementary studies at more detailed level for identified critical sections,
- Training of employees (climate risk awareness).

The following table gathers the main categories of actions, according to the incident chronology:

Incident steps	Prevention (action on likelihood)	Protection (action on severity)	Instrumentation and forecast	System maintenance
1. Before warning	Upgrading and retro-fitting vulnerable infrastructure components	Reconstruction	Monitoring implementation + elaboration of procedures for next steps	Control + update
2. During the response time	Check if site access is secured and in conformity	Infrastructure closure and activation of emergency procedures		Warning broadcasting to stake holders + mobilization of means + users information
3. Incident occurrence		Deployment of emergency means		
4. Restoring operational conditions		Repairs		Who? What? How?
5. Crisis exit and capitalization				Final assessment + system improvement

The strategy to be implemented will result from optimisation between risk management needs and funding capacities, requiring defining investment priorities and their planning.

Step 6 - Implementation of Action Plans

Not applicable in the framework of the present case study (needs first action plans to be prepared).

Step 7 - Monitor, re-plan and capitalize

Not applicable in the framework of the present case study (needs first action plans to be implemented).

Annex: Guide for Interviews

GUIDE FOR INTERVIEWS

Motorway …………………… Section or node ………. Pk……… to Pk ……..

Singular point (tunnel, structure, buildings) …………………. Localization ………………

Date of interview../../…. Name and function of the interviewee …………………………

1.Description of significant climate event leading to operation or infrastructure issues

1. Site factors identification (environmental factors likely to worsen climate factors)

3. Vulnerability of road elements to climate event

Climate event	Type	Infrastructure specification or object/component likely to be affected
Rain	1. short / intense	
	2. long time period	
Wind	1. Storm	
	2. Local tornado	
Snow	1. Thickness	
	2. Duration	
Frost	1. Extreme cold	
	2. Frost/thaw cycles	
Heat	1. Extreme heat	
	2. Heat wave duration	
Comments		