CLIMATE CHANGE AND INVESTMENT STRATEGIES FOR EXISTING ROAD NETWORKS: PRELIMINARY CONSIDERATIONS

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ABSTRACT

Climate change, whatever its sources, will affect all countries and impact all economic and human activity, notably the road infrastructure sector.
The first section addresses the need for a systemic and systematic approach to climate events and their consequences by presenting several interactions between climate, the road network and climate-related risks, and indicates the relevant terminology with reference to the ISO 31000 Risk Management standard.
The second part deals with the risk management process developed in Europe (RIMA-ROCC project), including its aims, in particular anticipation, and the limitations due to the multiplicity of stakeholders and uncertainties about how exactly climate change will manifest itself.
The third part deals with the various actions that may be considered to ensure the network's operational continuity in the face of climate change.
Finally, the last part proposes various investment strategies that may be considered while reiterating that the demand for investment due to the consequences of climate change will be considerable. The often unfortunate consequences of inter-sectorial decisions taken under the pressure of events make anticipation essential, requiring the implementation of investment plans spanning several decades.

Key words: infrastructure, climate change, risks, strategies, investment, anticipation, transport network

> "It is not the strongest of the species
> that survive or the most intelligent,
> but the ones that are most
> responsive to change."
> Charles Darwin

Climate change, as predicted by scientists, will have an impact on the transport system and notably the road infrastructure network.

The French road network now totals around 1 million kilometres. In the absence of any particular events (natural and climatic risks in particular), it is likely that 95% to 98% of the network that will be in operation at the end of the 21st century will be comprised of infrastructure already defined in 2010. This involves a real challenge: as new infrastructure will already take the problems of climate change into account, it is the existing network that will require the heaviest investments to future-proof it against the potential consequences of climate change.

1. CLIMATE, CLIMATE EVENT AND CLIMATE-RELATED RISKS

1.1. Climate change and its implications

Whatever the causes of climate change, there would seem that there is:

- an underlying trend towards a new climate with different characteristics from the current one; this new climate may be durably stable, but it must be remembered that current projections do not go beyond the end of the century;
- the existence of an intermediate period with extreme climate events that at times run counter to the long-term trend, which may cloud the message received by decision-makers.

An event is a change in a particular set of circumstances. An event may be a one-off or may reoccur and have several causes. An event may consist in something that does not reoccur. An event may sometimes be referred to as an “incident” or “accident”. An event without any consequences may also be called a “quasi-accident” or “incident” or “near success”. (According to ISO Guide 73:2009 [1] and ISO 31000:2009 Risk Management [2].)

This situation may be illustrated in the following manner: the road network in northern France, between Paris and the Belgian border, was subject to only infrequent freeze-thaw cycles up until the end of the 20th century. The change in temperatures throughout the 21st century shows that, by the end of the century, the network will only be subject to this phenomenon exceptionally but that it is highly likely between now and then (until 2050?) that there will be a very marked increase in the number of freeze-thaw cycles in some winters with all the attendant and well-known effects on pavements.

It should also be noted that some events are slow-onset events. This is, for example, the case with periods of drought, which can damage roads, but which are not considered “events” as generally perceived by non-specialists.

A consequence is that an event can affect objectives. An event may trigger a series of consequences. A consequence may be certain or uncertain and may have positive or negative effects on achieving objectives. The consequences may be expressed in qualitative or quantitative terms. Initial consequences may trigger a chain reaction. [According to ISO Guide 73:2009 and ISO 31000:2009 Risk Management]

The analysis of these climatic events and their consequences on road infrastructure therefore demands a specific approach. Studies carried out in recent years (in the UK and France within EGIS in particular) have demonstrated the advantage of an approach based on risk-analysis methods.

A risk is the effect of uncertainty on achieving objectives. An effect is a positive and/or negative discrepancy in relation to an expectation. Objectives can have different aspects (for example, financial, health, safety or environmental goals), and may involve various levels (strategic level; project, product, process or entire organisation levels). A risk is often defined in reference to events and/or potential consequences or a combination of both. A risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and its likelihood. Uncertainty is a state, even partial, of lack of information for the understanding or knowledge of an event, its consequences or likelihood. [According to ISO Guide 73:2009 and ISO 31000:2009 Risk Management]

1.2. The notion of climate-related risks in the road sector

Climate-related risks derive from the possibility that future climate events may differ widely from those taken into consideration when dimensioning road structures[1]. The dimensioning, which is undertaken during either a structure's design or upgrade, takes into account the climate data known at that time. The climatology/dimensioning pairing forms what we refer to as the reference technical-climatic "bubble" and the dimensioning factors are defined with reference to the recommendations.

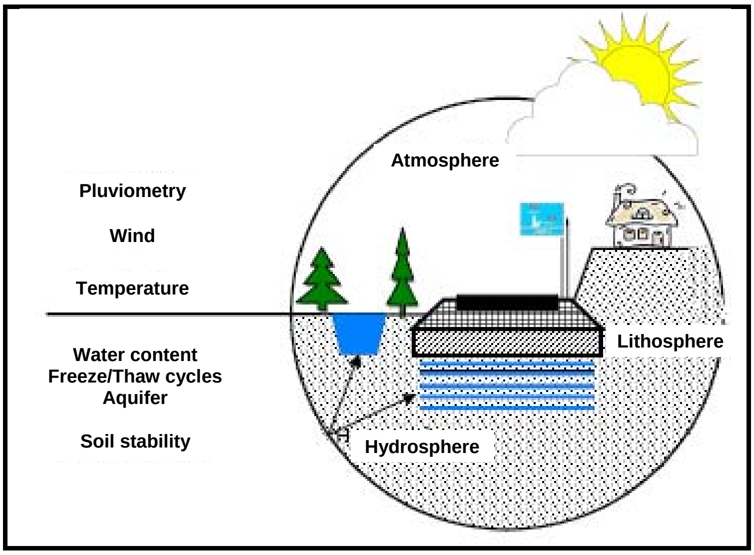

Figure 1 – The climate bubble

As a structure, a road (and in fact all infrastructure) is designed and dimensioned taking into account the climate "bubble" relevant to its location: temperatures, hygrometry, pluviometry, etc., expressed as minimums or maximums or a minimum-maximum range. The changes forecast for these parameters have only recently started to be taken into account.

1.3. Representation of a climate-related risk process

The risk takes the form of a process that can be represented as follows:

[1] As this refers to the study of existing networks, there is no corresponding opportunity. On the other hand, when studying climate-related risks liable to affect new infrastructure, or in the case of certain major repairs, we find ourselves in the classic case in which we seek to identify the risks and opportunities.

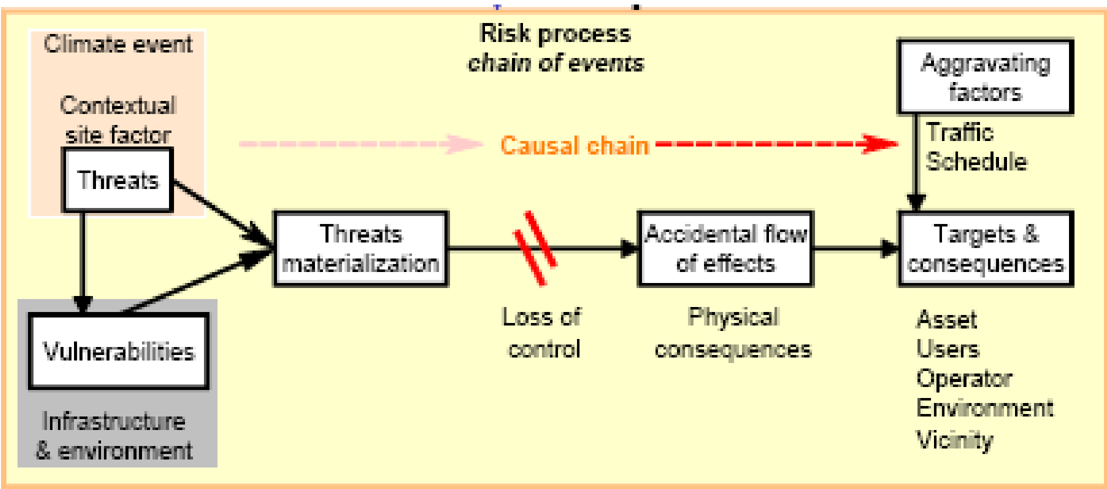

Figure 2 – Chain of events in a climate-related risk

1.4. Characterisation of climate-related risks[2]

Climate-related risks can be characterised by three components: threats, vulnerabilities and consequences [3]: Risk = f [Threats, Vulnerabilities, Consequences]

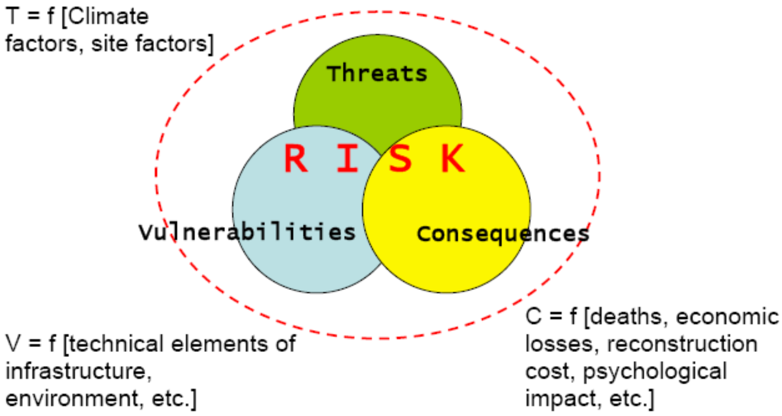

Figure 3 - Representation of risk characterisation

Threats are comprised, on the one hand, by climate events outside the reference climate “bubble” and, on the other hand, by the road’s context. This contextual site risk factor can be, for example, land sealing or deforestation in part of the upstream watershed, or changes to cultivation methods. The contextual site risk factor can be considered an aggravating factor.

The vulnerabilities can be defined as faults or weak points liable to cause damage in the event of exposure to an extreme climate event. These faults or weak points must be assessed within their context (and therefore in relation to their level of exposure): a given element will be a weak point in a zone exposed to increased precipitation but will not be a weak point in a zone exposed to increased winds. The vulnerability of the transport system therefore depends on its sensitivity or the sensitivity of its components to climate event exposure. This vulnerability may be decreased if the system has the capacity to adapt (floodable roads, rarely used on the French road network, are a good example). The vulnerability is principally linked to two elements: technical (design, construction, ageing and maintenance quality), and location of the road section or structure (site and its context).

[2] A distinction must be made between risk characterisation and level of risk (extent of a risk expressed as the combination of consequences and their likelihood) and the notion of criticality.

The interaction between threats and vulnerabilities gives rise to a chain reaction that will, beyond a certain threshold determined by the structure's dimensions, cause an undesirable event leading to a loss of control over the structure, generally triggering a flow of effects resulting in consequences. In the case of flooding, for example, the flow of effects may be a rise in water levels, a landslide, mudflow, or debris of all kinds blocking drainage and other hydraulic structures.

The consequences will be more or less extensive damage to the network that will in turn have consequences on the transport system (users, operator and transport companies), local inhabitants, the economic and social system, environment, etc. These consequences may be immediate (road pavement destroyed by flooding) or medium to long term (effects of soaking on an embankment, or deep seepage). In addition, some of these consequences may be amplified by aggravating factors (for example, the season and timing of the event). They can be classified into six main areas:

- Personal safety and injury (or death);
- Cost for repair or reconstruction of the damaged infrastructure;
- Loss of operating revenue for the operator as a result of the infrastructure's unavailability;
- Economic and social cost of the impact at the local, regional, national and possibly international levels;
- Damage to image, loss of confidence or prestige, and political consequences;
- Impact on the environment.

The first studies carried out in France, under the GERICI project [4] [5] since 2004, then on SANEF's northern network (by EGIS) and on the coastal road between Sète and Agde, demonstrate the extent of the consequences of climate-related risks and the need to protect the network to ensure the operational continuity of the transport system.

The issue of protecting the road network must be clearly defined and a policy to mitigate climate change risks developed accordingly. In protecting the road network, the aim is to limit the impact that climate events may have on the transport system and the environment.

1.5. Likelihood of the occurrence of climate events

Even if we are not certain as to the occurrence of these climate events or their frequency, climatologists state they are likely to happen and may occur at any time. It is worth considering that these predictions are based on projections made using models which, while increasingly precise, still do not incorporate all the factors that are liable to affect climate, and that the main uncertainty relates to the IPCC (SRES) scenarios. For this reason, indices that provide a general indication but which are not derived from a probability law are used in risk analysis calculations.

The "likelihood" is the possibility of something happening. In risk management terminology, the word "likelihood" is used to indicate the possibility of something happening, whether this possibility is defined, measured or determined in an objective or subjective, qualitative or quantitative way, and whether described using general or mathematical terms (such as a probability or frequency over a given period). The English word "likelihood" has no direct equivalent in some languages and it is often the equivalent of the word "probability" that is used in its stead. However, in English, the word "probability" is often limited to its mathematical interpretation. Consequently, in risk management terminology, the word "likelihood" is used with the intention of its having as broad an interpretation as that of the word "probability" in many languages other than English. [According to ISO Guide 73:2009]

2. RISK MANAGEMENT: AN ANTICIPATION TOOL

Defining a protection and operation strategy for road infrastructure and preparing the corresponding investment policy, with the end of the century in view, requires access to data that risk management can provide due to its comprehensive approach and regular reviews.

2.1. Objectives and specifics of climate-related risk management

Risk management involves performing a set of coordinated activities in order to manage and steer an entity with regard to risk. Climate-related risks are not managed in a general manner; rather an operator (Department of Roads at the national or local level, motorway concession company, etc.) manages climate-related risks liable to impact the infrastructure for which they are responsible. One of the specifics of the management of this type of risk is that the relevant entity is not the sole owner[3] of the risks liable to affect the infrastructure.

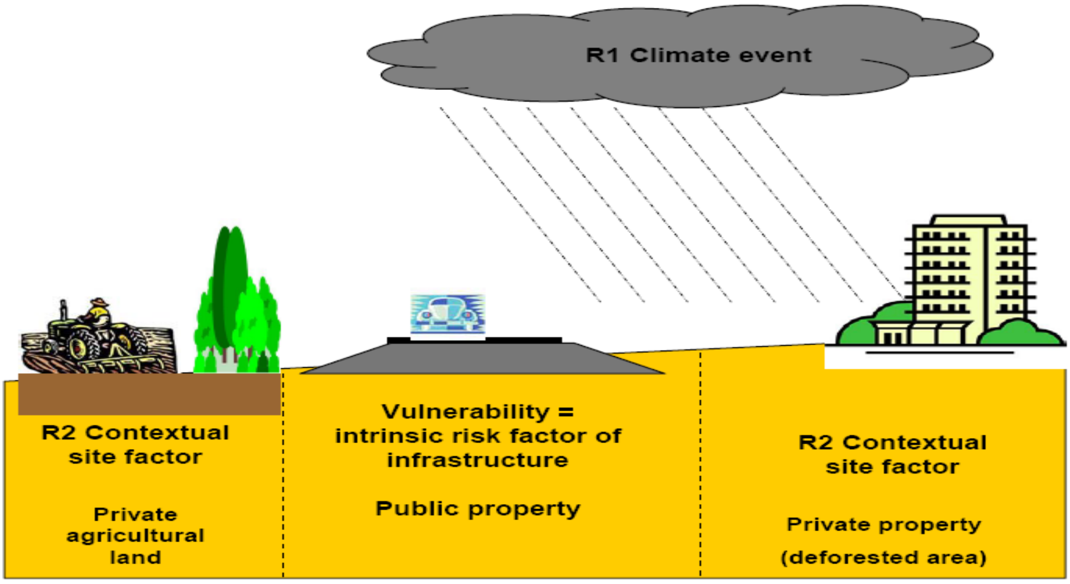

Figure 4 - Identification of risk owners

Domaniality issues arise, as can be seen from the above diagram (downstream, changes in cultivation methods can result in the reduced capacity of natural outfalls, whereas upstream, deforestation and urbanisation subsequent to the road's construction significantly increase the flow of rainwater runoff), and other entities own what we refer to as contextual site risks. These issues will lead to the involvement of other stakeholders in the management of climate-related risks. Hence, a systemic and systematic analysis is required.

Another element compounding the complexity of the approach is the fact that the exact evolution of climate change is an unknown, although it is known that change will be gradual and uncertain in how it manifests itself and that it will occur over a long period (this century and more) during which all technological, political, economic and social systems will also change.

[3] The risk owner is the entity responsible for the risk and having the authority to manage it.

2.2. A climate-related risk management process: RIMAROCC[4]

The risk management process and method developed under the RIMAROCC project are based on the ISO 31000 Risk Management standard.

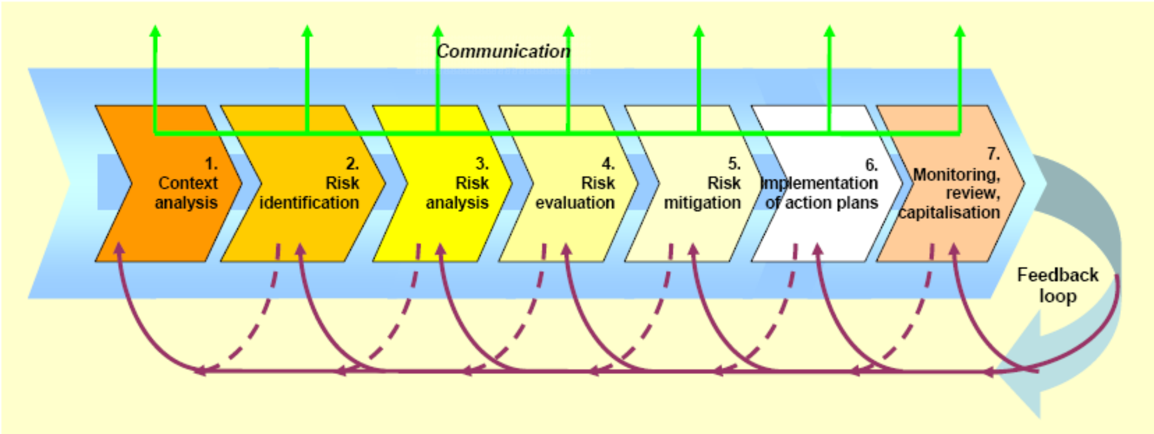

Figure 5 – The climate-related risk management process proposed by RIMAROCC

It is a seven-step iterative process detailed in a guidebook available on the web [6].

A risk management process is the systematic application of management policies, procedures and practices to activities in communication, consultation and context identification as well as to activities in risk identification, analysis, assessing, processing, monitoring and reviewing.

2.3. Risk management and mitigation

The main aim of risk management is to implement appropriate treatment to reduce (mitigate) the consequences of this risk either by adopting measures regarding the source of the risk, or by implementing measures aimed at limiting the consequences.

It should be remembered that risk processing may create new risks and/or modify the characteristics of other risks. Also, in most cases, there will still be a residual risk which should not be overlooked.

3. IN THE FACE OF CLIMATE-RELATED RISKS, ONE OBJECTIVE: PROVIDE APPROPRIATE PROTECTION TO ENSURE OPERATIONAL CONTINUITY OF THE ROAD NETWORK

Network protection involves defining and implementing a set of appropriate and planned measures to overcome or limit the consequences of the impact of a climate event on the transport system (network/assets, users, economic system, etc.) in order to ensure its operational continuity.

The aim of protection programmes [7] will therefore be to propose measures that:

- Reduce the threats: by taking action not against the climate event itself (we cannot stop the rain from falling) but on the contextual site factors, several examples of which are given below;

[4] The RIMAROCC (RIsk MAnagement for ROads in a Changing Climate) method was developed by a European grouping led by the Swedish Geotechnical Institute and including French engineering firm EGIS, the Norwegian Geotechnical Institute and Deltares (Netherlands). The project's sponsors were the National Road Administrations of 11 European countries.

- Mitigate the vulnerabilities: reduce the susceptibility of the infrastructure or its components to destruction, loss of capacity or operability, by replacing certain materials or strengthening certain structures, by installing protection or modifying the position or location of the road or structure, etc. For this, we need a consolidated trend analysis of climate change or occurrence of exceptional events measured against the structure or network's sensitivity, which justifies the establishment of a "zero" point (what a given structure, in its current design or configuration, can resist today without undergoing any modifications);
- Minimise the consequences: reduce possible losses from damage caused by a climate event by instituting warning plans and alternative transport plans, for example.

These protection programmes must be designed as part of a comprehensive and systemic analysis integrating the possible impact of climate-related risks on other elements of the economic and social system throughout the period running from the risk's materialisation through to the complete restitution of the functions provided by the infrastructure.

The protection strategy to be implemented will, conventionally, include four components (prevention, protection, response and recovery) defined in accordance with the particular road section:

- Preventive action is taken to predict, detect or reduce the threats, notably to protect life and property;
- Protective actions are carried out to reduce vulnerabilities and/or minimise the consequences of an extreme climate event. They can range from strengthening a specific section through to the reconstruction of a section or structure along a more appropriate alignment;
- Response actions are activities planned to enable, if required, an immediate reaction and emergency response to the immediate consequences of an extreme climate event. These include compiling response plans, training and exercises, purchase of appropriate emergency equipment, etc.;
- Recovery actions are implemented after the event. Their aim is to bring the transport system back into service. These actions also include repair or reconstruction work and the analysis of past events, as well as updating prevention, protection and response measures for other sections of the road network. They may be based on the definition of a sensitivity "zero" point.

Table 1 – Objectives of the actions to be implemented

	Act on the threats	Reduce the vulnerabilities	Minimise the consequences
Prevention	Yes	Yes	Yes
Protection	No	Yes	Yes
Response	No	No	Yes
Recovery	No	No	Yes

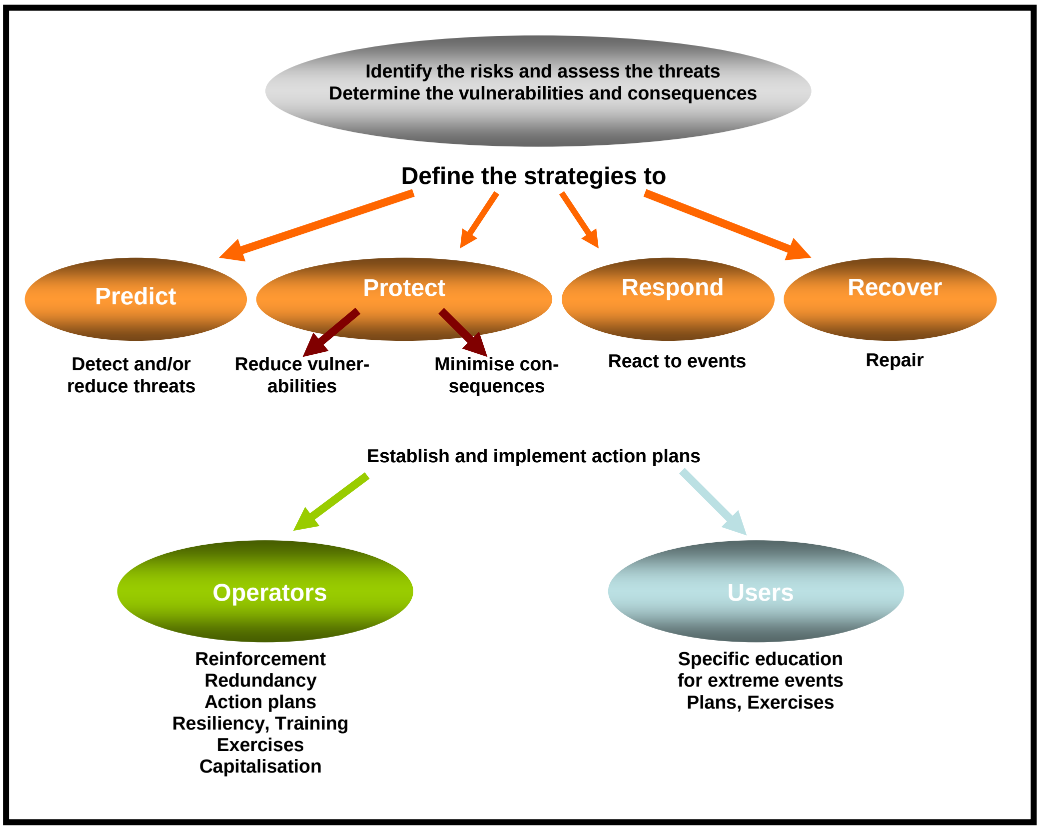

Figure 6 – The potential responses

Whatever the nature and seriousness of the impact of climate events, we are currently not sure that the entire road network can be returned to useable condition, even over a long period. As a result, we will have to determine an order of priority that may change over time. Right from the start of the discussions, it is therefore necessary to analyse and categorise the structures and networks according to their function and the types of response that we are able to provide in the event of a climate event. Depending on the nature of the traffic carried, the role played by each highway and the definition of acceptable risk adopted, we might, for example, adopt the following categories (to be consistent with the European “key infrastructure” approach):

A. The infrastructure can be used in all circumstances (except during the event and, for safety reasons, during the three hours[5] following the event: for example, in the event of winds exceeding 120 km/h); if such is the case, the infrastructure is of the “hardened” type[6];
B. The infrastructure will be available three days after the start of the event (three days’ autonomy for households, industry and services: element of resilience);
C. The infrastructure will be useable in degraded condition after three days and for a period to be determined on a case-by-case basis (possibly indeterminate if low traffic);
D. The infrastructure will be out of service and will require work to make it useable or it may even have to be abandoned.

[5] Indicative period needed to ensure the trafficableness of an itinerary and proceed with road coning if needed.
[6] There will always be events that destroy hardened infrastructure: it is not possible to “infinitely” harden key infrastructure. It is therefore necessary to accept a probability (0.1% per year?) of an event resulting in hardened infrastructure becoming inoperable.

The choice of classification in these various categories will depend on the consequences of traffic closures. Cost-benefit analyses may be used to identify in which category a given piece of infrastructure falls. However, certain highways have strategic importance and need to be hardened whatever the results of socio-economic studies, because of the strategic nature of the facilities (hospital, industrial estates, airports, etc.) or the size of the population they serve.

The strategy to adopt, based on a combination of these components, must be tied into an investment programme spanning several decades based on the knowledge of and evolution of climate change, on the various potential technical options to ensure operational continuity of the network, and on socio-economic analyses to justify the required investments.

4. INVESTMENT STRATEGIES

4.1. Cost drivers in state investment strategy

4.1.1. An overarching problem

Climate change will not only impact transport infrastructure but the entire socio-economic system across the entire country. The following figure, adapted from MacCracken [8], shows the main potential impacts.

Figure 7 - Impact of climate events on the socio-economic system

4.1.2. Significant financial needs that are difficult to schedule

A very high level of investment funding will be required to adapt to climate change (cf. The Stern Review [9]), even if spread over time; this implies scheduling risks given the uncertainty still surrounding the "calendar" for the appearance of climate events.

4.1.3. A very specific timescale

Climate change will occur over a very long period of time relative to human life and the conventional notions of short, medium and long term. Additionally, the uncertainty persisting around the sequencing of these various events and their potential consequences relative to the various climate horizons adopted by climatologists are clouding the message received by decision-makers.

Taking into consideration three climate horizons – 2050, 2070 and 2100 – it is not certain, all else being equal, that the consequences will continue to worsen. It is quite possible that we may be faced with a period of extreme but infrequent climate events with serious consequences, followed by periods of average events at a far more regular frequency. Rather than adapting to climate change, it may be more appropriate to adapt to future climate variations.

4.1.4. Budgetary arbitration difficult to produce

At the level of each country, once the choice of technically feasible solutions has been determined, it will be necessary to take the relevant financial decisions. Figure 8 below, based on the work of Rasmunssen and Svedung [10], provides a simplified representation of the role and responsibilities of each of the stakeholders involved in the investment to be made.

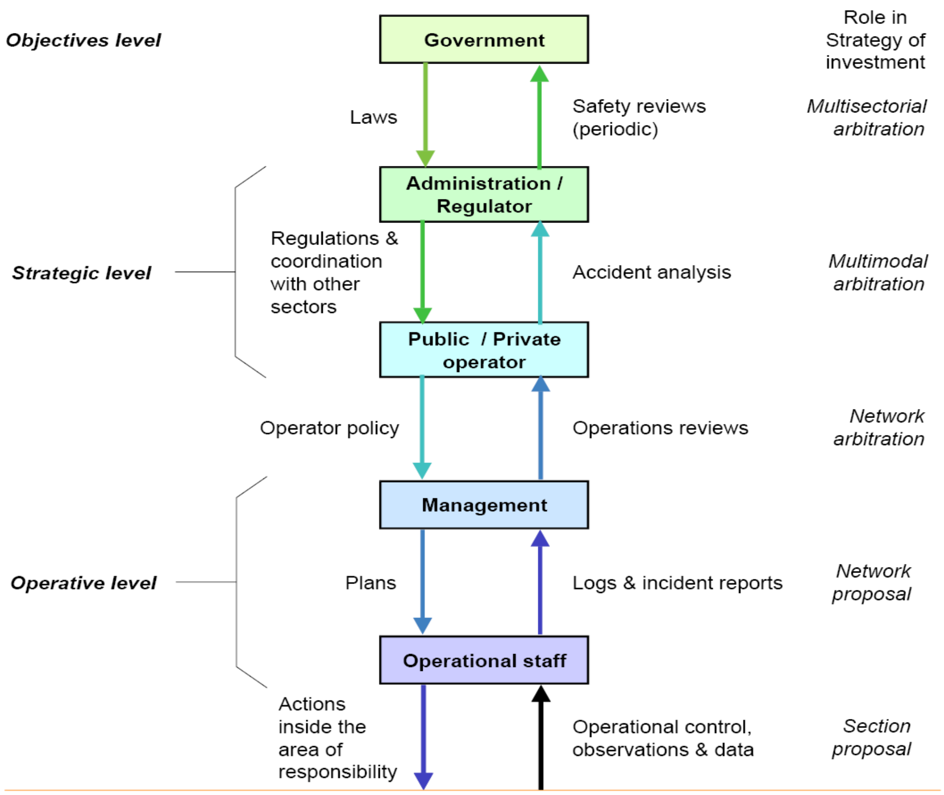

Figure 8 – Stakeholder's roles and responsibilities

4.1.5. Investment in new infrastructure and investment in network upgrades

While strategies for investment in new infrastructure now fully factor in climate change (Hallegatte [11], Groves [12]), few strategies have so far been defined in the area of existing networks (UK Highways Agency [13] [14]), even though there is now an emerging awareness of this issue [15].

For an investment in new infrastructure, several variants can be considered and clear criteria can be defined for making choices. For investment in the existing network renewal or upgrades, the criteria involved are very different and include a sizeable element of policy, sociology and the weight of history. Additionally, while investment in new infrastructure is easy and inexpensive, it becomes very difficult and costly for existing networks, and there is no free option (interview with S. Hallegatte 2010).

4.2. Elements for an appropriate investment strategy

4.2.1. A new approach

Investment strategy studies for existing networks must now systematically form part of a systemic approach: the concern is for the operation of the entire transport system and not just the road network on its own. These studies must also include an analysis of modal and multimodal redundancy. Such studies can be time-consuming and costly, and their level of precision remains relatively uncertain. For simple cases, solid work by experts may make it possible to pinpoint more rapidly the expected level of service from each component in the road network.

The actions adopted must systematically be assessed and compared against the potential consequences, and must take into account the national policy, or that of the structure in charge, in terms of risk acceptability (in economic, social, legal, political and moral terms) as well as the principle of precaution. Residual risk should also be factored into the calculations.

The potential solutions should be examined at various scales in order to integrate both local service issues and long-distance transit problems (including the provision of alternative itineraries). At the regional level, the focus of this approach should preferably be on multimodal transport. Consideration may be given to compiling a “hardened” transport master plan.

Continuous anticipation, through regular risk reviews, should be implemented to take into account potential new risks resulting from progress in climate studies.

4.2.2. Potential strategies

Strategy development must be based on thorough knowledge of the networks meshing the territory, their traffic and economic and social roles.

The indications presented below are in random order, and do not point to any particular prioritisation.

1. ***Strengthening the preventive maintenance strategy***

The initial effects of climate change, already felt over the past few years, show that standard maintenance expenditure will probably increase and that additional heavy maintenance programmes will have to be rolled out, although we are as yet unable to define their extent or content. This expenditure does not target hardening but merely maintaining certain technical specifications.

2. ***“Wait-and-see” strategy: towards abandoning certain roads***

Damaged roads are generally repaired to their original condition (without any specification changes) and are closed temporarily as work progresses.
However, once a certain point is reached, maintenance costs can become prohibitive in comparison to the advantages offered by the road’s use. It may be necessary to stop try-

ing to save the road. The functions it provided will then be transferred to alternative itineraries.
It is also possible to wait until a structure or section is “close” to ruin before rebuilding in order to comply fully with the new conditions: there is an “optimum” moment when to abandon a piece of infrastructure, depending on its current condition, future use and maintenance or renovation cost.

3. ***Modal and intermodal redundancy development strategy***

When two highways serve the same point (even if one route is longer than the other), it may be advisable to concentrate investment on one of the two in order to guarantee operational continuity. Similarly, if other modes of transport are possible, consideration might be given to hardening one if the other can be restored within an acceptable timeframe.

4. ***Preventive hardening strategy***

Depending on a highway’s strategic importance, the following options may be considered:

a. **Hardening**: the infrastructure must be useable in all circumstances (except during the event and for the three hours following it, for safety reasons: for example, in the event of wind exceeding 120 km/h);
b. **Semi-hardening**: make the infrastructure fully useable within three days after the start of the event (three days’ autonomy for households, industry and services: element of resilience); emergency services may be equipped with specific vehicles if the related events have a certain level of recurrence (for example once every five years), or resort to a fleet of regional, national or military vehicles.

5. **Post-hardening strategy**

Wait until the climate event occurs to proceed with hardening or semi-hardening including closure for a period to be defined. Temporary closure is acceptable and there may in some cases be a level of degraded service after the work is completed.

6. **Strict selection and scheduling of new investment strategy**

Some highways will have to be created beforehand (preventively) or restored after the occurrence of a climate event; all provisions incorporating climate change should be included in the design for these investments, notably initial mapping and projections reflecting the extent of the potential phenomena, along with an “action” roadmap that sets out warning thresholds and measures designed to anticipate the critical condition. This strategy may eventually lead to the implementation of a strategic hardened or semi-hardened structural network.

4.2.3. Support measures

Whatever the strategy or strategies adopted, a certain number of support measures must be studied and implemented:

- Mapping of the current network basing the approach on an analysis of the type: nature of the event / type of road or structure / potential impacts by thresholds (temperature, wind, etc.) / acceptability;
- Develop anticipation and information;
- Availability of fleets of emergency vehicles suited to the conditions resulting from potential damage to the infrastructure;
- Acquisition of maintenance equipment and products (for example, snowploughs, etc.).

4.2.4. A regional-scale strategy

It should not be forgotten that the investment strategy to be defined concerns an entire region. This strategy should include redundancy of some routes as well as a multimodal approach; some routes can be provided by rail, or even by navigable waterways for heavy traffic.
The issue of having access to a category of useable infrastructure during the events (for emergency vehicles, for example) may be raised. But it is perhaps more judicious to have access to suitable vehicles rather than investing in overly-hardened roads.
The way in which civil society responds – long used to service levels to which it may no longer aspire – will also have to change.
In short, the proposed investment strategy will be a combination of the various elements cited above (or others). It must be sufficiently flexible to adapt over time; the reconsideration of certain technical choices should not result in a complete revision, and the investments made must not be "lost" in the event a different direction from that currently envisaged is adopted.

CONCLUSION, AT THIS STAGE

There will not be one but several strategies to be implemented in the coming decades, and they will in all likelihood be reviewed on a fairly regular basis as we acquire more knowledge about climate change, and in light of the political, economic, social, ethical, etc. choices that decision-makers will face. These uncertainties are not a reason for doing nothing; on the contrary, they are a reason to extend the scope of our knowledge about climate change so that we are better able to anticipate and retain access to operational infrastructure at the various stages in our planet's change.

The proposed solution is for appropriate anticipation to climate change and its consequences, based on two elements:

- a systemic and systematic approach to climate events and their consequences;
- the definition of investment plans spanning several decades and incorporating a short-term plan (to face already extant threats to be identified from a diagnosis of the reference situation or "zero" point) along with medium and long-term plans.

This may ensure that the infrastructure remains operational within the understanding that we currently have of climate change, while enabling the authorities in charge to keep a capacity to react to respond to unforeseen situations in the future.

The use of methods, such as RIMAROCC, and the use of tools, like GERICI®, should provide us in the years ahead with extensive feedback to drive progress in this area.

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