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X-ARA
Cross-asset risk assessment

Desk study

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CEDR Call 2013: Ageing Infrastructure Management

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Executive summary

This document is the first technical report delivered in the course of the X-ARA project. The main purpose of the report is to document the current status of risk assessment in the field or asset management – both the available literature and the current practice of road administration.

The work that led to this report was twofold:

A comprehensive literature review has been carried out on the topic of risk assessment with focus on the integration of risk assessment into asset management systems.

This task was complemented by a workshop and a series of interviews where road operators have been asked about three topics: (a) what external factors are currently considered in their asset management work, (b) to what extent risk assessment is currently implemented in their systems and (c) what developments do they expect for the future. The outcomes of the interviews and the workshop have been edited to a series of case studies to allow a comparison of the different approaches.

The report concludes with a discussion of the findings of the literature review and the current practice of road operators. The results are the basis for the development of the risk framework (covered in WP2 of X-ARA) and the tool that is derived from the framework (to be developed in WP3 of X-ARA).

The literature review has brought up many definitions of the term “risk”, all with slight deviations, but many of them referring to risk as the product of probability of occurrence multiplied with the consequences.

Regarding risk management frameworks, many sources suggest a five-step procedure that starts with (1) *defining the context*, then (2) *risk identification*, (3) *risk analysis*, (4) *risk evaluation* and ends with (5) *risk treatment*. Other approaches use a four-step approach where the steps (2) and (3) or (3) and (4) are treated together in some way.

In the first step, the context is specified, in a spatial and/or organisational manner. The time period under observation is defined as well.

For the second step, risk identification, several lists of risks are presented that may be considered. Risk types include natural hazards, organisational and economic risks.

The risk analysis covers all activities that lead to the determination of the frequency of occurrence and the magnitude of the consequences. Several methods exist, e.g. failure mode and effect analysis and fault tree analysis, however, they were currently found not implemented at road operators.

The risk evaluation step is then used to determine the acceptability of a risk by comparing the level of risk to predetermined standards or target risk levels. In the next step, risk treatment, measures to modify risk are implemented. Usually, four strategies can be followed: risk avoidance, risk reduction, retention/acceptance and transfer/sharing.

This straight-forward methodology has not been found fully implemented in any of the road operators that have been interviewed. Parts of the risk-assessment framework are implemented at each road operator, although sometimes they are not labelled as such. While for construction projects dedicated risk management procedures are commonly used, in asset management risk assessment is only partly implemented, e.g. for structures or tunnels. In maintenance systems, routine monitoring is often considered sufficient as some form of risk treatment.

External factors are considered to a varying degree. Climate change is considered by some road operators in the form of scenarios that allow a forecast of maintenance and operation cost. Funding is tightly linked to macroeconomic factors, even more if the maintenance budget comes from toll revenues. There is a common feeling that the maintenance budgets are not in danger of a sudden dramatic cut. Regarding demand, a constant conservative growth is largely anticipated with no sudden deviations. Social factors and politics are considered to have a certain influence, however difficult to anticipate.

The availability of data upon which maintenance decisions are taken is considered sufficient for pavements and structures. For these assets, routine monitoring is in place for several years at each interviewed road operator. For street lighting, gullies and drainage there is still some work to do to reach the level of completeness and quality of pavement data, although there are data collection strategies in place to catch up in these areas. What needs improvement is the trust and understanding in the collected data and their central availability.

1 Introduction

1.1 Introduction into the project

The main objective of the project **"X-ARA – Cross-Asset-Risk-Assessment"** is the development of a comprehensive risk assessment framework including a set of guidelines and a practical software tool (**X-ARA risk tool**) for the network level assessment of asset risks and impacts. Our approach will take into account the requirements and needs of different stakeholders, considered in an initial desk study, and will be focused on delivering a working model fit for use by National Road Administrations around Europe. The project builds on earlier European projects, including aspects of the ERA-NET 2010 Asset Management Programme, as well as drawing on the direct experience of operational asset-managing organisations. Our Team comprises a unique blend of experience from research, academia, and private sector experts and asset operators.
The resulting model will take into account high-level external variable factors affecting the different assets in an ageing road infrastructure, such as;

Climate Change	Asset performance
Funding/politics	Demand (traffic)
Macro-economic factors	Social factors

It will include the framework for the necessary input parameters (indicators), the definition of sub-risks and cumulated risks (in form of risk factors) and the procedures to implement the solution on a road infrastructure network. We will relate all our research to the 'real world' by the use of a Reference Project drawn upon NRA data, but the output methodology and model will be generic and adaptable by different NRAs, under the auspices of CEDR, using their own local data and parameters. The assets themselves as well the economic, geographic and social factors differ in each country so it will always be necessary for each country to calibrate the risk model to its own environment, using guidelines which we will provide.
X-ARA will enable an NRA to execute a risk-based assessment and comparison of different maintenance strategies at a network level, and then 'overlay' the effects of broad influencing factors to asses 'what if' outcomes, in the medium to longer term. To produce a reliable high-level model, we believe it is necessary to consider a bottom-up approach (using real data) that can be used to measure sub-risks, as well the high-level top-down influences. The **X-ARA risk tool** needs to be based on real, available and affordable data, and the software will be independent of any proprietary database or software platform. We will consider the risk-specific effects on safety, operation, and traffic, of high- to low- or non-coordinated maintenance activities but will exclude new construction programmes (schemes). An NRA will be able to examine a worst case/best case set of scenarios for their own environment and socio/political situation, and consider the implications on funding as well as economic and social outcomes for stakeholders, while meeting the requirements of environmental and other legislation.
X-ARA has the potential to aid an NRA to provide better prognosis of risk against different funding scenarios, and thus will be a powerful tool when juggling ever-reduced budgets against ever-increased demand and uncertainty. It adds real value to existing asset data, is capable of further exploitation across CEDR member countries and gives transnational

benefits by providing a common framework for assessing risk which can be configured for each country location.

1.2 The Scope of the report

This report is the first one delivered in the course of the X-ARA project. The main purpose of the report is to document the current status of risk assessment in the field or asset management – both the available literature and the current practice of road administration.

1.3 The structure of the report

The report starts with the findings of the literature study in chapter 2. First, a list of the various definitions of risks is given. After that, procedures for risk assessment found in the literature are described.

Sources of literature that have been used:

- Reports of PIARC Technical Committee 3.2., Risk management for roads, 2010
- Reports of the FHWA
- Reports from EraNet Road/CEDR projects of the last asset management call
- A literature search at the following scientific databases: *IEEE/IEL Electronic Library*, *Thomson Reuters Web of Science* and *Science Direct*. These three libraries cover the vast majority of journals and conference proceedings in the technical field. Various search terms and combinations of them have been used: risk assessment, asset management, pavement management etc.
- Documents from governmental and other organisations members of the project team were aware of.

Beside the literature survey, the second task was to collect information about the current practice of risk assessment in asset management from different road operators.

To cover the current practice, a workshop and a series of interviews with asset management experts from road administrations have been carried out. The main idea of the workshop and interviews was to discuss the view of road operators on the topic of risk assessment and the effect of external influencing factors on their work. Road operators from Austria, Slovenia Denmark, Hungary, The Netherlands and UK have been consulted. The results of these discussions are presented as case studies in chapter 3in order to make the different approaches comparable.

In chapter 4, the findings of the literature review and the current practice of road administrations are discussed. These results are the basis for the development of the risk framework (covered in WP2 of X-ARA) and the tool that is derived from the framework (to be developed in WP3 of X-ARA).

2 Literature Survey

2.1 Definition of risk

Risk can be considered as the uncertainty of the system (e.g. increase/decrease in traffic volume, variation in predicted bearing capacity of road foundations, etc.). Or, it can be considered as the probability of occurrence of an external event that could lead to the overall or partial system failure or loss in certain aspect of the network performance (e.g. safety, asset value, etc.). Risk is mostly defined as a threat (has negative connotation), but can be perceived as an opportunity, as well (positive connotation).

Terms 'risk', 'hazard', 'threat' and 'event' are sometimes used interchangeable through the literature. However, these terms usually have slightly different meanings. Before reviewing the definitions of risks from the literature, definitions of terms 'hazard', 'threat' and 'event' found in the literature are provided:

> *Event* – "An incident or situation which occurs in a particular place during a particular interval of time." [1] or "Occurrence of a particular situation or set of circumstances leading to a consequence; including both threats and opportunities." [2]
>
> *Hazard* – "Likelihood of occurrence of an event that calls for immediate measures to minimize its adverse consequences." [1] or "a condition, event, object or circumstance that could lead to or contribute to an unplanned or undesired event." [3]
>
> *Threat* – "An event that has the potential to move the outcome of an activity to a more unfavourable position." [2]

The International Organization for Standardization (ISO) defines risk as [4]:

> "The effect of uncertainty on objectives. An effect is a deviation from the expected—positive and/or negative. Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).Risk is often characterized by reference to potential events and consequences, or a combination of these."

Following the ISO guidance, the Risk Management Process Manual of the New Zealand Transportation Agency defines risk in the similar manner, as [2]:

> "The chance of something happening that will have an impact on objectives. It is measured in terms of a combination of the likelihood of an event and its consequence."

The World Road Association (PIARC) defines risk in line with the ISO definition as well:

> "The combination of the probability of a hazard and its consequences." [5] or as "Quantitative expression of uncertainties and of harmful consequences associated with a hazard." [1]

Similarly, the Institute of Risk Management defines risk as [6]:

> "The combination of the probability of an event and its consequence. Consequences can range from positive to negative. All organizations have objectives at strategic, tactical and operational levels - anything that makes achieving these objectives uncertain is a risk."

American Association of State Highway and Transportation Officials (AASHTO) in their Transportation Asset Management Guide associates risk with the uncertainty [7]. Here, risk in the asset management is assessed as vulnerability to a variety of natural and man-made hazards:

> “Risk is the threat to transportation operations caused by extreme events, other external hazards, and from asset failure arising from any cause”.

The US Federal Aviation Administration (FAA) links ‘hazard’ and ‘risk’, by defining the risk as [3]:

> “…the future impact of a hazard that is not controlled or eliminated. It can be viewed as future uncertainty created by the hazard.”

Within the US Federal Highway Administration (FHWA) reports No. 1-5, risk has been broadly defined as risk of failure, including: (i) catastrophic failure of an asset, (ii) the failure to achieve desired condition levels, (iii) failure to preserve asset value, and (iv) failure to ensure desired levels of service [8][9][10][11][12]

Amekudzi and Meyer, in their report for the Georgia Department of Transportation and in the context of transportation infrastructure management, define risk as the risk of catastrophic or non-catastrophic failure [13]. Non-catastrophic failure was explained as performance failure. Catastrophic risks have been related to occurrence of a negative event and the severity of the consequences of this negative event. This report notes that risk is actually uncertainty, related to: (i) data errors, (ii) modelling errors, and (iii) forecasting errors.

Highway Infrastructure Asset Management Guidance Document defines risk in the following manner [14]:

> “An uncertain event, which, should it occur, will have an effect on the desired performance on an asset or series of assets. It consists of a combination of the likelihood of a perceived threat or opportunity occurring, and the magnitude of its impact on the objectives, where: Threat is used to describe an uncertain event that could have a negative impact on the levels of service; and opportunity is used to describe an uncertain event that could have a favourable impact on the levels of service.”

National Cooperative Highway Research Program (NCHRP), in their report on the topic of climate change, recognizes the importance of the magnitude of the consequences and costs in risk definition [15]:

> “The climate related risk (…) relates not only to the failure of the asset but also to the consequences or magnitudes of costs associated with that failure [16].”

2.2 General risk management framework

In general, a risk management process includes five steps as shown in Figure 1 [1][4][5]. The first step is usually named ‘context definition’, but ‘decision scope’ and ‘definition of the system’ terms are also in use in the literature [17][18].The next step is the risk/hazard identification followed by the risk analysis step, i.e. the risk estimation. Risk evaluation and risk treatment are final two steps closing this risk management process.

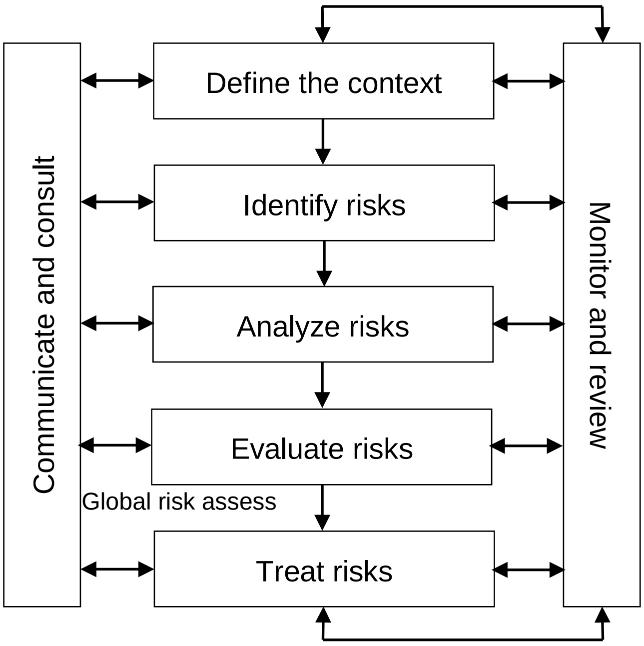

Figure 1: General risk management process [1] [4] [5]

A similar approach was adopted in the National Cooperative Highway Research Program (NCHRP) Report 632, which defines the fundamental tasks in risk management as follows: (i) defining risk tolerances, (ii) identification of threats/hazards, (iii) assessing impact or consequences, (iv) development of counter measures, and (v) implementation of those measures [19].

Some authors use four steps in the risk management process. For example, in the Highway Infrastructure Asset Management Guidance Document procedure, it is recommended to use the following steps [14]:

- Establish risk content by defining objectives and appetite for managing risk, and by setting risk criteria, approach and process;
- Identify risks by identification of risk groups, risk events and critical assets;
- Evaluate risks through likelihood, consequence and performance of overall risk assessment;
- Manage risks, i.e. reduction, mitigation, elimination, by developing Risk action plan, and Risk register.

The National Cooperative Highway Research Program in their report No. 706 also recommends a four-step process for the risk management [20]:

- First is the establishment of risk tolerances (e.g. little risk for high-volume, substantial risk for low-volume assets);
- Second, threats and hazards are identified and ranked either qualitatively, or quantitatively. The consequences of the risks are assessed, again either qualitatively or quantitatively;
- Third, potential strategies or counter measures are identified; and
- Fourth risk management efforts are monitored for effectiveness.

It is noted that the term ‘risk assessment’ is used often in the literature and may confuse readers where this ‘step’ fits in the risk management process and what exactly it represents. Depending on the authors, risk assessment can be defined as “the overall process of risk identification, risk analysis, and risk evaluation” [2] or “the overall process of risk analysis and risk evaluation” [1].

In this report, the five step risk management process is adopted and all information gathered from the literature review was sorted to fit these five main steps.

2.2.1 Risk–based asset management

If risk management principles are implemented in the asset management processes, then the new generic risk-based asset management framework could be defined as shown in Figure 2 [18]. Here, there should be noted the difference between two terms: asset management risks and asset risks. Asset management risks are related to the management process itself, while the asset risks are related to the asset and its performance. The risk-based asset management process includes several additional steps in comparison with the traditional risk management framework. Also, inputs should include information such as cross asset interactions, asset criticality, asset vulnerability, proximity of other assets and the importance of the asset’s location or route.

While developing risk-based asset management processes, agencies could adopt the so-called “Three Rs” strategies for managing risks from external threats [10]:

- Redundancy - duplicative or excess capacity that can be used in times of emergency. For example, solid management of the assets on detour and emergency evacuation routes increases a highway system’s redundancy.
- Robustness - the capacity to cope with stress or uncertainty. For example, well maintained assets better cope with the stresses of storm events.
- Resilience - the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

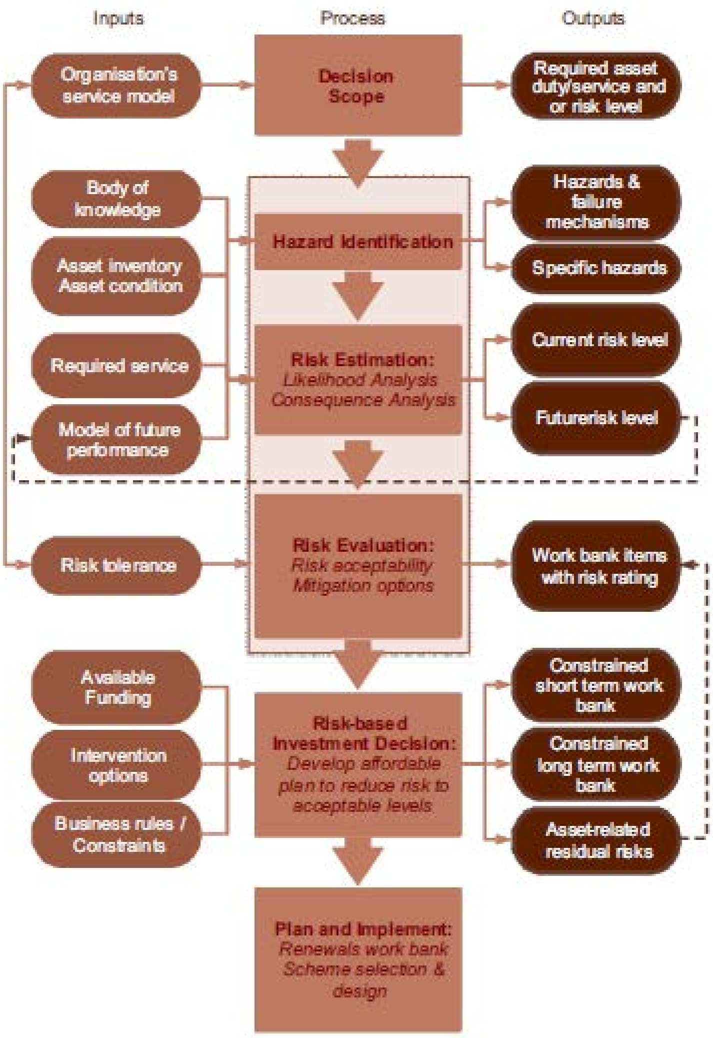

Figure 2: Risk-based asset management process [18]

2.2.2 Defining the context

A number of stakeholders are involved in the road operations and they all have different needs and expectations. These stakeholders can be divided into two groups: stakeholders expecting some service from the road network, and road authorities [21]. The first group consist of users, neighbours, financial institutions, and society. In the second group are the network owners and the road operators. Perception of risk and its definition depend on the party who is evaluating it. Thus, the risk management process, especially for the road operations, is a complex process [5].

There are several aspects of risk management implementation regarding the road operations and maintenance which provide different context of the system: organizational risk management, risk management for road networks, risk management for road projects and crisis management [23]. Additional context is the risk management for the road assets [18][22].

Organizational risk management represents the concept of managing the number of risks related to the organization or business thus maintaining the corporate values [23]. Although these risks were traditionally in the financial area or dealing with the unexpected disasters, recent trends show that the economy and society are also areas with the need for proper risk management techniques. There are several techniques for enterprise risk management: COSO-ERM framework, INTOSAI Framework, the Orange Book: Management of Risk and ISO 31000:2009 [4].

The quality of a road network can be defined as a transport system's ability to manage and resist major interruption such as major accidents and natural disasters [23]. The goal of road authorities is to provide a network's minimum operational function with the acceptable safety margin in cases of hazard occurrence. Risk management in the context of a road project represents the sensibility of a project not to reach planned cost, time and function. Common risks in road projects are considered to be engineering risks which are assessed and addressed at the planning and design stages. Due to their size, complexity, costs and importance, mega-projects usually involve a number of different stakeholders [5]. Generally, they all have different objectives and perceptions of risks. For all stakeholders, risks are considered both ways: interaction of the project with its environment and surroundings and risks induced by the context on the project.

Crisis management represents the set of actions planned to be executed in the case of severe events, i.e. management of emergencies after the event has occurred [23]. Important steps in the development of the crisis management, beside traditional risk management steps, are contingency plan developments to cope with the consequences of adverse events. Most highway agencies have contingency plans.

Another context is the risk management for road assets. It follows the general principles of risk management frameworks. The first step is essentially the choice between two approaches: pro-active and reactive management [18][22].
Pro-active maintenance management reduces the likelihood of unplanned events or repairs and increases the likelihood of reliable service [18]. Reactive maintenance management reduces short term costs but increases the likelihood of major unplanned repairs and service disruption. Advantages of the pro-active management compared to the reactive management in terms of the better value for money can be defined as the former is more sustainable, safer and enables more controlled maintenance strategies [22].

In general, the context of the risk management for road assets should be defined in a way to address both the observed problem and possible solutions [18]. For example, the scope should include information about which service aspects and level is observed (safety, revenue, etc.), the time line (5 or 30 years horizon), and the extent (network, area, or single route). Or, risk assessment can be considered at two levels: the network level (Strategic Level Risk Assessment – SLRA) and at the local, road section, level (Tactical Level Risk Assessment – TLRA) [22]. For those assets for which the SLRA showed that there is a need for the further risk investigation and assessment, the TLRA methodology is applied. Essentially, both risk analysis procedures are similar; the main difference is that at the TLRA level, each risk is analysed in detail.

Agencies may apply risk-based asset management practices to key networks, corridors and facilities, particularly ones moving freight [11]. Risks to the achievement of agency goals, reaching performance targets, meeting public expectations, satisfying customers or achieving acceptable condition and performance on key highway networks, corridors or individual assets could also be managed. A risk-based asset management approach to moving people and goods focuses on evaluating the networks, corridors and facilities that create the greatest threats and opportunities for achieving goals of mobility and safety. A set of examples is given within the FHWA report [11] for North Carolina, Utah, Washington, Minnesota, VicRoads, Michigan and Florida.

Another context is related to the security concerns. The elements of transportation infrastructure such as roads, tunnels, bridges, administration buildings and traffic control centres are vulnerable to terrorist and criminal activities [5]. Also, the question of internal security which considers security of personnel, facilities and information technology (IT) as crucial elements for the operation of the road system is a subject for the risk management application. Personnel are considered as the first priority. Although the generic risk management process can be applied here as well, countermeasures have to be carefully planned in order to ensure protection of lives and operation of the organization and systems. Countermeasures can be divided into two groups: prevention and emergency plans. For these reasons, there is a clear need to integrate security concerns in the risk management process.

2.2.3 Risk identification

In the process of risk identification, one should look for the answers to two basic questions: what can happen, and how and why it can happen? [1] There are number of techniques to accomplish this process: checklists, expert judgment, experience, records, flow charts, brainstorming, systems analysis and scenario analysis, and systems engineering techniques. Or, the risk identification can be defined as "… the process of determining what can happen when carrying out an activity; where, when, why and how". [2]

Another definition of the risk identification process is that it represents the step in which one seeks for the potential hazards that can jeopardize which ever interest he has [5]. In that sense, a road transport authority has to deal with the number of risks covering various aspects, such as physical and natural risks, accidents, engineering failures, public policy issues concerning safety, spending, licensing, monitoring, vehicle design, environment etc.

The following risks can be highlighted as potential threats for the achievement of the agency's asset management strategic objectives [10]:

- Operational risk (can be a consequence of information systems that do not provide the necessary analysis, insight or reliability; maintenance failures caused by a lack of timely treatment and/or inadequate asset inventories, lack of management support, or weak program management and/or loss of experienced asset management staff);
- Financial risk(related to budget shortfalls that prevent adequate investment, price increases that influence purchasing power and/or rising interest rates that increase the agency's costs to finance major reconstructions);

- Strategic risk(triggered by changing legislation e.g. in terms of environmental standards; public opinion and/or stakeholder demands);
- Hazard risk(e.g. floods; seismic events; barge strikes).

Regarding the risk situations, there are two possible scenarios: possibility of both gain and loss (dynamic risk) and possibility of loss only (static risk). Table 1 provides examples for both static and dynamic risks.

Table 1: Examples of static and dynamic risks [5]

Static risks (attitude preserving) – examples	Dynamic risks (attitude developing) - examples
• Nature (flooding, heavy snowfall, landslides, etc.) • Diseases • War • Accidents • etc.	• Idea • Market • Development • Achieving project goals • Organizational performance • etc.

Regarding the types of risk, there is a number of aspects that can be taken into account, thus there are no uniform risk categories [5]. For example, risks can be classified into two categories: natural and man-made (see Table 2). Natural risks are easier to identify and to codify, while man-made risks can be difficult for the identification [1]. Another example of risk classification is in four categories: natural risks, technological risks, biological risks, and civil or political risks. Events, i.e. hazards, can be categorized, for example, by their consequences: personal injury, property damage, environmental damage, other socio-economic damage and intangible injury [23].

Table 2: Examples of risks categorized in two risk categories [5]

Natural risks– examples	Man-made risks – examples
• Landslides • Earthquakes • Floods • Avalanches • Bushfires / Forest fires • Rock fall • Snow storm / Ice storm / Heavy snowfall • Wind storm / Rainstorm / Heavy rain • Fog • Volcanic eruption • Drought	• IT security risks • Work accidents • Transport of dangerous goods • Overloading (height, weight) • Aeroplane, ship, or train crash • Fire • Industrial accidents • Wartime explosives / Mines • Strikes • Terrorism / Vandalism • Traffic congestion • Dam collapse

If the risk is defined as a system failure, then the risk can be divided into two groups [19]:

- "internal programmatic risks" such as failure to adequately perform planning, design, construction or maintenance (inaccurate forecasts of asset deterioration and/or revenues, inaccurate project cost estimates, and unforeseen ground conditions on construction projects). Usually those risks have great probability of occurrence but it is rare that they will cause the closure of a link in the network.

- "external non-programmatic risks" over which an agency has little or no control, such as earthquakes, terrorism or vehicle/infrastructure crashes. Those events have low probability of occurrence, and are highly unpredictable, but can affect the network performance.

Another possible classification of risks is according to the level of organization at which it is considered. For example, risk can be identified at three different levels [24]:

- Strategic risk which includes: risk of a lack of or deferred funding; risk of unanticipated occurrence of a natural event, e.g. flood, earthquake, landslip, avalanche, bush fire, adverse weather;
- Risk at portfolio and network level includes: risk of catastrophic failure of a network structure; risk of pollution and/or negative impacts on flora and fauna; risk of damage to the asset; Risk of premature deterioration or obsolescence of the asset; Risk of overspend;
- Risk at project and operational level, such as risk of schedule slippage; risk of suboptimal design and/or construction practices or materials; risk of failure of integration of new projects with existing asset; risk of failure to gain property access; risk of poor contract execution and ensuring outcomes.
- Other significant risks, which are workforce planning, climate change, volatility in fuel prices, and other economic factors, emergency management and response planning.

Furthermore, at the strategic level, risks can be grouped in four groups [14]:

- Planning risks (strategic planning; asset management strategy; performance and level of service and performance; asset management planning; funding and investment; climate change / natural events and environmental);
- Management Risks (leadership and organization; stakeholder and communication; information and data; people, including competency; financial; IT including asset management system);
- Delivery Risks (procurement; cost; works programming; scheme identification and design; contract and project management);
- Asset Risks (Risks common to all assets including investment, performance and loss of service; severe consequence of failure, accessibility and construction).

Since mega-projects usually last for decades, managers have to consider both known risks and those that cannot be anticipated in advance, like catastrophic events or future budget cuts [5]. Management of those risks requires a mitigation or risk response plan. It is crucial to be consistent in the management of mega-projects in all project phases: planning, design, construction and operation. Although there are numbers of risks which can be identified for mega-projects, some are highlighted as most critical: workers security, schedule delays, juridical risks, scope and performance creep, political and public expectations and perceptions, financial, architectural and financial risks.

AASHTO Transportation Asset Management Guide identifies many potential sources of risk to a transportation agency, which can be grouped into four major areas [7]:

- Natural events and hazards: These include floods, snow storms, extreme wind, wildfire, landslide, tsunami, and earthquake. Probabilities and return periods of these events may be calculated, it is not possible to predict the exact time of the occurrence of the next event.
- External impacts on the agency: These include the failure of other parties or organizations to provide a service or product upon which the transportation agency depends. These can include power supply or the supply of materials which are deficient in some way.
- Physical asset failures: These events are caused by poor or deteriorating condition or performance of an asset or asset component, leading to disruption to users or effects on the environment and require remedial work. Certain types of failures may be sudden (e.g. fracture of structural steel) or can be predicted through the use of predictive modelling tools.
- Operational risk events: These events include vehicle operator errors (e.g. impact of a vehicle with a structure); vehicle equipment failures that cause fires or collisions; failure of safety features of the transportation system; or intentional damage. It may also include errors made within an organization, such as management decisions or design errors.

Some examples of hazards which are used in one of the existing risk management tools - CAPTool- are presented in Table 3 below. Heavy rainfalls, earthquakes, and forest fires can also be considered as natural hazards [25]. Useful techniques for managing rainfalls and earthquakes were developed in Japan, while Canada's strategies for managing forest are a good example too.

Table 3: Example of list of hazards [25]

Type	Hazard / threats
Unintentional hazard	Fire Structural failure HAZMAT (Hazardous materials and items)
Natural hazard	Flood Earthquake Extreme weather Mud/landslide
Intentional hazard	Small explosive (hand carried) Large explosive (vehicle borne) Chemical/Biological/Radiological Criminal acts

In addition to the presented three groups of hazards in Table 3, performance risks can be considered as the fourth type [19]. This group considers: underperformance of an asset due to design, materials, and construction defects coupled with lack of accurate condition inspection or forecasting capabilities.

Climate change related negative impacts could lead to unfavourable temperature changes, increase/decrease in precipitation, increase in storm surges, and changes in sea-levels, as the US DOT identified in their research [25]. Each of these impacts can be further divided into climate change effects which are then related to the road network risks (Table 4).

Another possible risk's categorization is into two groups: individual risks and societal risks [17]. Individual risk is the likelihood that a person exposed to the hazard might experience some specified level of harm (the risk per person-kilometre). Societal risk is the risk expressed as the relationship between the frequency that some specified accident (hazard) will occur and the number of the people affected and the level of harm [26]. Societal risk is usually expressed as "FN curve" which is a plot with the frequency of hazards causing a specified level of harm to N people on Y axis, and N as number of people on X axis.

Traditionally, road authorities have considered risks regarding the infrastructure, personnel and finance such as physical and natural risks, accidents and engineering failures [23]. However, recent developments in modern society bring attention to other issues of public policy such as safety, spending, licensing, monitoring, vehicle design, environment etc. These issues are part of the risk environment and, as such, need further education, awareness, claims understanding and media attention.

Topic of social acceptance of risks and their perception with focus on road operations should be considered [27]. In general, there is a difference between the risk assessment of experts which conduct technical assessment, and general population which bring additional qualitative assessment of risks based on their perception (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Not all risks affect or interest people and their interest in specific risks can be changed by specific events or public campaigns. It is difficult to define which risks are acceptable or not. Commonly, social standardization tries to establish which risks are acceptable. In other words, risk identification should take into account social and political surroundings.

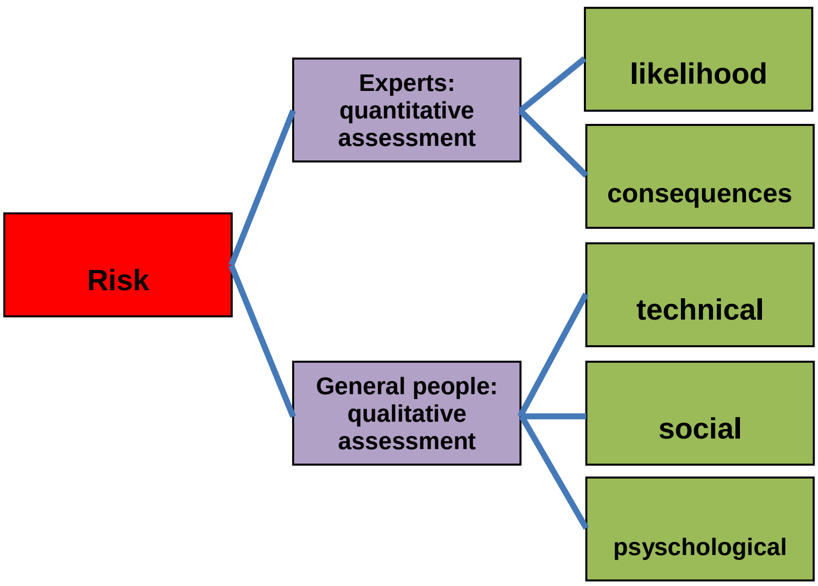

Figure 3: Different assessments of risks – experts vs. general population [27][25]

Table 4: Climate change effects and associated risks for road infrastructure [25]

Critical climate variables	Major risks to road infrastructure
Extreme rainfall events (heavy showers and long rain periods)	• Flooding of roadways • Road erosion, landslides and mudslides that damage roads • Overloading of drainage systems, causing erosion and flooding • Traffic hindrance and safety
Seasonal and annual average precipitation	• Impact on soil moisture levels, affecting structural integrity of roads, bridges, and tunnels • Adverse impacts of standing water on the road base • Risk of floods from runoff, landslides, slope failures, and damage to roads if changes in precipitation pattern (e.g. changes from snow to rain in winter and spring thaws)
Sea level rise	• Inundation of roads in coastal areas • Erosion of road base and bridge supports • Bridge scour • Reduced clearance under bridges • Extra demands on infrastructure when used as emergency/evacuation roads
Maximum temperature and number of consecutive hot days (heat wave)	• Concerns regarding pavement integrity, e.g. softening, traffic related rutting, embrittlement (cracking), migration of liquid asphalt • Thermal expansion on bridge expansion joints and paved surfaces • Impacts on landscaping
Drought (consecutive dry days)	• Susceptibility to wildfires that threaten transportation infrastructure directly • Susceptibility to mudslides in areas deforested by wildfires • Consolidation of substructure with (unequal) settlement as a consequence • More generation of smog
Snowfall	• Traffic hindrance and safety • Snow removal costs • Snow avalanches closing roads or striking vehicles
Frost (number of icy days)	• Traffic hindrance and safety • Ice removal cost
Thaw (number of days with temperature zero-crossings)	• Thawing of permafrost, causing subsidence of roads and bridge supports (cave-in) • Decreased utility of unimproved roads that rely on frozen ground for passage
Extreme wind speed (worst gales)	• Threat to stability of bridge decks • Damage to signs, lighting fixtures and supports
Fog days	• Traffic hindrance and safety • More generation of smog

To this aim, one should be aware that there are two types of indicators which reflect different stakeholder's perception of road operations: functional indicators, and technical indicators [21]. A functional indicator reflects a functional performance of the asset as expected by stakeholders not directly involved in the operation of the road network. A technical indicator either reflects a physical property of the asset or the relationship between road physical characteristics and a specific property. This indicator is more in use by road operators. All indicators can have four levels, from the basic level (physical property or condition of the asset) to the High Level Management Indicators – HLMIs (at the network level).

The basic approach in the risk assessment is "risk analysis by scenario" – RAS [5]. A scenario can be described as the assumed path between the present situation and the future situation. The focus of scenario analysis is the specific interest which can be a target, a budget, a plan or an asset. What can potentially jeopardize an interest is called a hazard or event or peril. Risk factors cause hazard and their appearance can be reduced by preventive measures. These three elements (risk factors, hazard and interest) are part of the chain of events which represents a cause and effect theory (see Figure 4). For each specific interest, risk factors and one hazard create one scenario. A scenario could include estimates and their variations in order to create a set of possible outcomes. RAS can be expanded to include several additional steps such as a risk matrix with prioritization of risks which have to be calibrated by the stakeholders.

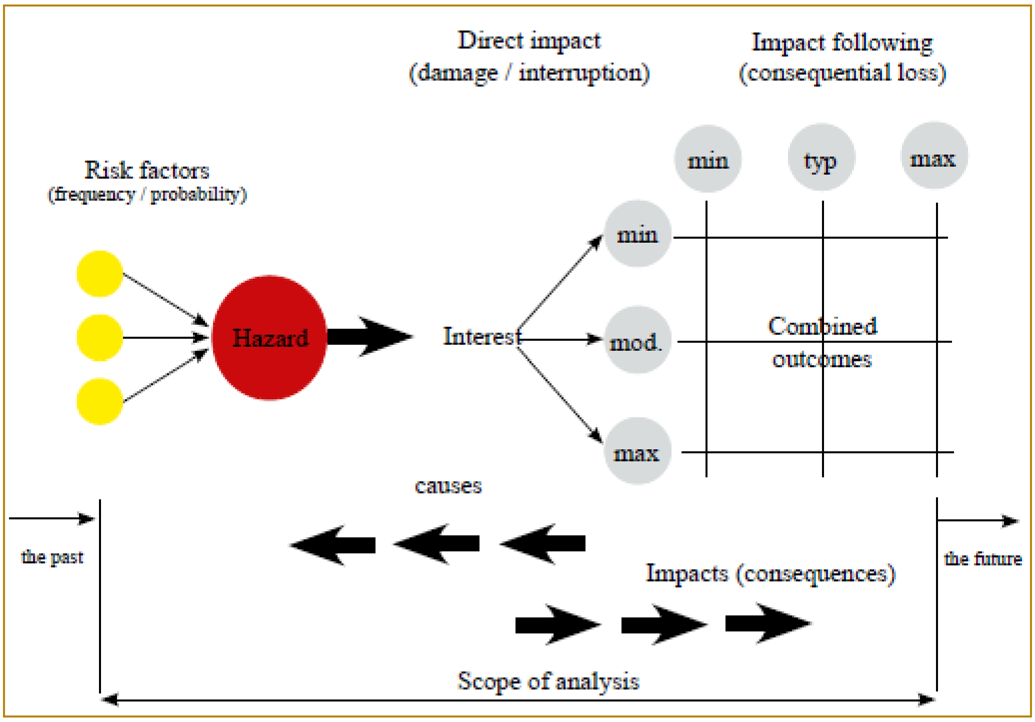

Figure 4: Risk assessment by scenario [5]

Consequence can be defined as the outcome of an event, e.g. increased journey times, isolation of local communities or a drop in public perception of the service provided [14][22].It can have positive or negative effects and can be expressed qualitatively or quantitatively.

The consequences associated with an event leading to failure or service reduction may include:

- Public health / Safety – including fatalities and personal injuries;
- Functionality – impact of a loss or reduction in service at route, asset or component level, such as weight restrictions on a bridge;
- Cost – increased costs due to bringing forward or delaying work, repair costs, fines or litigation costs and loss of income or income potential;
- Sustainability – any impact on future use of highway infrastructure assets.
- Environment – environmental impacts, such as pollution caused through traffic delay or contamination from spillages, the sensitivity of the route/area, etc;
- Reputation / Public image – public confidence in organizational integrity; and
- Stakeholder's interest / Community costs – damage to property or other third party losses, which may include business impacts, traffic delays, etc.

In addition to the scenario-based approach for the analysis of potential impacts, there is also a system based approach [17]. For a scenario based approach, the set of identified possible scenarios, probabilities and possible consequences are estimated for the each scenario separately. In the system based approach, risks are estimated for an overall system taking into account all influencing factors and usually using the logical tree for the development of the potential system behaviour.

Another method in use for the purposes of risk management is a "risk analysis for scorecard targets" [5]. The first step is to identify prerequisites for the scorecard target and then to rank them. Common steps in the risk management process follow where responsibilities are assigned in such way that each risk factor has an officer in charge.

More concepts of risk analysis are: failure modes and effect analysis – FMEA, hazard and operability study – HAZOP, event tree analysis – ETA and fault tree analysis FTA [23]. FMEA is a procedure which enables the identification of a system's potential failure modes, its causes and the severity of the effects. FMEA can be used to identify the probabilities and magnitude of failure modes and to provide an input on measures for risk reduction. It can be extended to include the "criticality", the combination of the probability and severity measures and then it is called "Failure modes, effects and criticality analysis – FMECA".

HAZOP is a technique used for the identification of potential hazards which can lead to operational problems of a system [23]. This technique is based on a theory that risks are caused by the certain deviation of a system from its original design and operations. ETA is a deductive technique and the main idea is to find a combination of events that lead to certain effect. There are two ETA analyses: pre-accidental and post-accidental. FTA is similar to ETA, but it requires the identification and analysis of factors and conditions which can lead or potentially cause or contribute in some way to the occurrence of a defined event.

2.2.4 Risk analysis

Risk analysis can be defined as "…a systematic use of available information to determine how often specified events may occur and the magnitude of their consequences" [10]. In other words, it is a process to establish the level of risk [2].

AASHTO Transportation Asset Management Guide recommends that risk assessment is conducted in three steps, by providing answers to the following questions [7]:

1. What is the likelihood of an extreme event such as a flood or asset failure?
2. What are the consequences of that in terms of damage or loss of function?
3. What is the effect upon the agency's mission, life, property, users and others?

There are quantitative and qualitative methods for risk analysis [17]. Quantitative methods are complex and include various statistical and probability models and analysis. Data availability as an input for developed models may represent the potential problem in the application. For example, there are not many historical data for tunnels. On the other side, qualitative methods are based on expert judgments, but they may be subjective and diverse from case to case. However, in some circumstances they may present valuable information if there are no historical data available. It is usually easier to estimate consequences of a hazard than its frequency. Sometimes, information derived from previous experience is the only estimate of risk frequency. In these cases, these frequencies represent the Bayesian probabilities.

Capturing uncertainties and measuring risks represent the topic in which statistics has significant implementation [5]. One of the basic concepts in use is the estimates of mean and deviation. In other words, for measuring risks, one needs to know not only the frequency and severity, but also the deviation of these parameters. Also, the probability distributions can be used as estimates of parameters of interest. In order to measure the risk, money is usually used as a dimension, but other dimensions can be introduced as well. Risk assessment starts at the early phases of the risk management process when information is still scarce. Through the risk calculations, i.e. determining risk's probability and consequences, risk assessment will reach its final stage.

Example of risk analysis for road assets is for geotechnical assets, e.g. slope instability, where semi-quantitative and qualitative methods are used [22]. In some cases, quantitative methods are not available at all. As for the semi-quantitative methods, the impact and the likelihood for each risk are assessed and presented as score; for example, high impact and low likelihood. The risk is then determined as the RISK = IMPACT x LIKELIHOOD. The qualitative approach is similar to the semi-quantitative. The only difference is in the assessment of the impact and likelihood which is, in this case, more descriptive.

For geotechnical assets, there is limited information on the probability estimates of occurrence of certain event and thus it is difficult to estimate these probabilities [22]. However, looking at other factors, such as the assets general conditions and the record of maintenance activities, the alternative parameter, e.g. the condition grade, can be assigned which can represent the approximation of the probability of the hazard occurrence. Similarly, regarding consequence estimates, one can assign the consequence grade depending on the risks analysed in terms of the potential for the personal injury or fatality, damage to the property, increased maintenance or financial loss etc. Impact for the geotechnical assets is analysed in five categories: cost, time, reputation and business relations, health and safety, and environment. When analysing the assets across the network, it is important in the risk assessment to choose a uniform approach for the estimation of risk probabilities and consequences. **Fehler! Verweisquelle konnte nicht gefunden werden.** provides few examples of risk analysis with estimates of likelihood and consequences [19].

Table 5: Types of risk with examples, according to [19]

Risk Type	Example	Likely impact / Consequence	Relative frequency
Unintentional hazard	Vehicle crashes, hazardous materials spill, oil spill	Short-term road closure, loss of life, potential isolated structural failure	High
Intentional threat	Terrorist attack, crime, war attack	Short or long-term road closure, loss of life, potential isolated structural failure	Very low
Natural hazards	Heavy rain, strong wind, heavy snow and ice, earthquake, hurricanes, flood, mud/landslide	Short or long-term road closure, loss of life, potential structural failure - isolated or corridor wide	Low
Performance	Substandard design, construction defects, material defects, unexpected heavy traffic, incorrect performance models	Increased agency and user costs, increased work zone delay, reduced asset life	High

As highlighted in the PIARC report regarding the risk analysis for road tunnels, accidents in tunnels may have low probability of occurrence but also may have severe consequences in terms of lost lives, damage to structures and impacts on transport economy [17]. Thus, these consequences may have a social impact, impact on an asset performance and impact on macro-economic conditions.

In some cases, it is important to add one more dimension to the risk analysis which reflects the importance of the asset in the overall system. Some assets are more important than others in terms of: (i) the function they play, or (ii) the number of customers they serve [7]. These are the key assets - based on the importance to public safety, network continuity, connectivity, economic activity or social well-being etc. In these cases, risk can be observed as 15]:

Risk = Probability of Event Occurrence x Probability of Asset Failure x Consequence or Costs

2.2.5 Risk evaluation

Risk evaluation is a "…process used to determine the acceptability or otherwise of risk, by establishing and comparing the level of risk against predetermined standards, target risk levels or other criteria" [1][2].

Risk matrix tables are the most commonly used tools for the risk evaluation [5]. Risk matrix represents the ranking of risks and should be quantitative. The axes correspond to frequency and severity. The most general categorization of risks based on estimates of probabilities and consequences is into four groups, as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** [19]. These groups define risk space and any risk/hazard/threat can be located in this risk space. However, the categorization of probabilities and consequences only to two categories, low and high, may seem too rigid. Common practice is to include more levels between the low and high categories for better estimation and description of risks. The most suitable dimensions for risk matrix are 4x4 or 5x5 [5]. A risk matrix can be used for both the assessment of original risks and for the assessment of residual risks. In other words, it can be tracked on how the risk changes from one category to another after the risk treatment. As mentioned, risk matrix is used as a tool which helps decision makers to assess and rank all risks identified. The main aim of risk matrix is making decisions in three priorities: action to be taken (risk not accepted), further investigation (risk accepted after consideration), and no action needed (risk accepted).

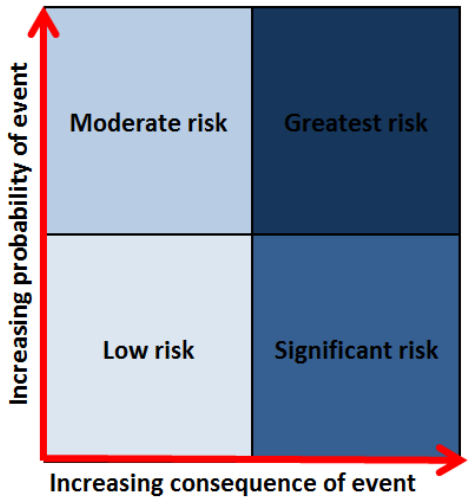

Figure 5: Classification of risk (adopted from [19])

A general risk matrix is commonly dimensionless [5]. However, risk matrices should be calibrated within their own context, and, if applicable, their own dimensions. For example, a numerical basis can be accompanied with green/yellow/red representations, or a descriptive basis can be used, like in, for example, company's "top twenty" risks.

Setting the threshold values for the risk evaluation can be related to various parameters. For example, these values can be: the potential number of persons affected by a hazard or threat, financial costs of replacing a lost asset and the extent to which an asset is vital for the operation of the system [25]. Table 6 Figure 6and Table 7 provide examples of rating the risks by their estimated likelihood [2].

Table 6: Rating the Likelihood of a Threat

Likelihood	Probability [short term activities]	Frequency [long term activities]	Description [occurrence of the threat / knowledge of the threat]	Rating
Likely	> 50%	Greater that once per year	can be expected / a very poor knowledge	5
Quite common	20% - 50%	Once per 1-5 years	Will quite commonly occur / a poor knowledge	4
Unlikely	10% - 20%	Once per 5-10 years	may occur occasionally / a moderate knowledge	3
Unusual	1% - 10%	Once per 10-50 years	Could infrequently occur/ good knowledge	2
Rare	<1%	Less than once per 50 years	May occur in exceptional circumstances / very good knowledge	1

Table 7: Rating the Likelihood of an Opportunity

Likelihood	Probability [short term and long term activities]	Description [realization of the opportunity / confidence in delivering the gains for the opportunity]	Rating
Almost certain	>90%	Almost certain / very high	5
Expected	75% - 90%	Expected to be realized/ high	4
Likely	50% - 75%	Will probably be realized / moderate	3
Unlikely	25% - 50%	Unlike to be realized / low	2
Very Unlikely	<25%	Very unlikely to be realized / very low	1

Traditional risk management techniques evaluate risks as the product of the probability of risk appearance and the magnitude of risks consequences [27]. However, this traditional approach fails to account the social aspects of risks perceptions and risks acceptance. Thus, the risk management process has to be adjusted to provide a more holistic approach and to include social aspects in determining what risks are acceptable and defining the acceptable thresholds for risk evaluations. Also, strategies have to be prepared and implemented to foster the risk awareness and trust of road users. The limit of acceptable risk depends on the environment and the country [28].

For the risk evaluation, there are two possible approaches for its implementation [17]. First, defining the threshold values as a risk criterion one can compare if the risk value is lower than the threshold value thus making the risk under observation acceptable. The second approach is the relative comparison approach. If the reference system exists and it is adopted and, for example, fully complies with the EU Directive regarding the safety measures, then all observed assets can be compared to this reference.

It is possible to create a set of risk profiles for assets of interest in the network, i.e. a risk register [22]. This risk register in form of a risk matrix essentially includes information about the asset condition (representing the probability of hazard) and consequences (expressed as the consequence grade). The risk matrix can be accompanied with the list of chosen mitigation options expressed with the cost/benefit analysis and assessment of the residual risks, if any.

Regarding risk criteria definition, the ISO 31000:2009 [31] advises:
"*The organization should define criteria to be used to evaluate the significance of risk. The criteria should*

- *reflect the organization's values, objectives and resources. Some criteria can be imposed by, or derived from,*
- *legal and regulatory requirements and other requirements to which the organization subscribes. Risk criteria*
- *should be consistent with the organization's risk management policy, be defined at the beginning of any risk management process and be continually reviewed.*

When defining risk criteria, factors to be considered should include the following:

- *the nature and types of causes and consequences that can occur and how they will be measured;*
- *how likelihood will be defined;*
- *the timeframe(s) of the likelihood and/or consequence(s);*
- *how the level of risk is to be determined;*
- *the views of stakeholders;*
- *the level at which risk becomes acceptable or tolerable; and*
- *whether combinations of multiple risks should be taken into account and, if so, how and which combinations should be considered"*

Every organisation has to develop a risk management policy that defines the severity levels of risk (often represented in colour coding in a risk matrix). Again the ISO 31000:2009 states:

"The risk management policy should clearly state the organization's objectives for, and commitment to, risk management and typically addresses the following:

- *the organization's rationale for managing risk;*
- *links between the organization's objectives and policies and the risk management policy;*
- *accountabilities and responsibilities for managing risk;*
- *the way in which conflicting interests are dealt with;*
- *commitment to make the necessary resources available to assist those accountable and responsible for managing risk;*
- *the way in which risk management performance will be measured and reported; and*
- *commitment to review and improve the risk management policy and framework periodically and in response to an event or change in circumstances."*

2.2.6 Risk treatment

Risk treatment is "… (the) process of selection and implementation of measures to modify risk" [2]. Under the risk treatment, usually there are four options [1, 5]:

- risk avoidance,
- risk reduction,
- retention/acceptance and
- transfer/sharing.

Risk avoidance represents the avoidance of the activity which generates the risk [1]. The risk reduction option can be addressed to the reduction of the likelihood of occurrence or the reduction of the consequences. The option to retain the risk represents the approach with the planned development for management of consequences in the case of risk occurrence. Risk transfer mainly includes the risk insurance and it is appropriate for treatment of financial risks.

With the similar concept, but slightly different definitions of possible options, a set of actions to treat both opportunities and threats can be defined as follows:

(i) actively accept – accept the risk and consider options for the action,
(ii) passively accept – accept the risk as it is, no further action at this time,
(iii) transfer/share – pass the risk in whole or in part to others through, for example, contractual agreements or insurance, and
(iv) avoid (threats) or reject (opportunities) – change so that there is no longer any threat/opportunity [2].

Another strategy for the risk treatment could be the application of the "5T" strategy [8]:

- Threat – The most commonly used, take the action to mitigate the risk.
- Tolerate– The secondly most commonly used. This means the likelihood of the risk materializing is so low or if does materialize the impact would be so low that there is no need to worry about the risk. However, monitor the risk to make sure it does not become worse.
- Terminate – This does not mean to terminate the risk, but to terminate the activity.
- Transfer – This is where accountability for managing the activity is transferred to another agent.
- Take Advantage – To be used in relation to opportunities.

A different strategy has been implemented for the risk treatment for road tunnels - a risk optimization strategy [28]. This methodology optimizes overall costs by including risk reduction techniques and associated consequences' costs.

However, risks which arise due to the climate change events have a somewhat different approach for the risk treatment. Risks are treated through the mitigation and adaptation strategies [25]. Mitigation represents the set of action to prevent or reduce the climate change effects, while adaptation represents an effort to deal with the anticipated or experienced climate change impacts. Some countries already have developed strategies for adaptation of the road network to climate changes.

2.3 Existing risk management tools, methods and practices

The PIARC Technical Committee on Risk Management for Roads developed in 2007 the Road Risk Management Toolbox [25]. This tool represents a database of useful technologies for all phases of road risk management. The tool contains inventory sheets and their appendices. The inventory sheets consist of information of the applicability and the perspective for further use of existing tools and technologies. They are divided into two groups – natural event management and man-made event management, and they are classified into risk management steps: risk analysis, risk assessment, risk treatment, risk communication and risk management. A total of 124 inventory sheets were prepared which represent the management techniques mainly used in New Zealand and in Japan. A web-based application updated the existing Excel based tool and provided a more user friendly version which has an easy online access for PIARC members.

The National Cooperative Highway Research Program (NCHRP) funded research which developed a methodological approach for risk management of different assets and transport modes called “Costing Asset Protection: An All Hazards Guides for Transportation Agencies – CAPTA” [25]. The CAPTA Tool is specific as it considers the risk tolerance thresholds and the budget considerations for risk mitigation actions of all hazards. Furthermore, it takes into account categories of consequences, the number and types of threats and hazards, and transportation modes so the decision makers have relevant information for allocation of resources between different interests and modes.

The CAPTA Tool has eight predefined categories of assets: road bridges, road tunnels, transit/rail bridges, transit/rail tunnels, transit/rail stations, administrative and support facilities, ferries, and fleets [25]. As an input, users have to provide information about assets under consideration such as annual average daily traffic, length, construction type, occupancy of rail cars and ferries etc. The user can choose between pre-defined risks (hazards and threats) and specify the initial consequence threshold values. The output provides a summary of multimodal risks, consequence thresholds, and estimation for projects that require mitigation strategies in order to reduce the exposure above the thresholds.

NCHRP Report No. 706 addresses the use of risk management in the US transportation agencies by presenting case studies for: Minnesota Department of Transportation - DOT, Washington State DOT, Georgia DOT, Texas DOT and California DOT [20]. In the report it is noted that Georgia DOT wants to move from a "worst-first" pavement and bridge selection approach to a "most-at-risk" approach that considers the current condition of the asset and its risk of failure. Failure is not only catastrophic failure in this context, but also failure to provide the desired level of service. In Minnesota, the DOT is applying risk-based decision making to bridge rehabilitation and replacement projects. Texas DOT applied a risk approach to freight mobility by evaluating the resiliency or redundancy of the state-wide network to continue moving freight if key nodes were taken out of service by events such as earthquakes, floods or terrorism. Washington DOT uses risk as a consideration in bridge retrofits while Caltrans has used risk for more than a decade for its seismic retrofit program.

Hatcher et al. developed the service framework which allows the alignment of many stakeholders and objectives of an organization to its day-to-day activities [29]. The implementation of this framework was undertaken for UK Highways Agency. If the asset performance is defined as the ability to provide the required level of service to stakeholders, then the achievement of the required levels of service should be the organization's strategic goals. This service framework assists the Agency in communication with stakeholders and managing overall objectives and the measures to support those objectives. It also provides a basic concept for risk-based management in the case of service delivery failure.

2.3.1 Climate change

Risk management regarding climate change includes the two main strategies: *mitigate* and *adapt*. The mitigation of climate change by reducing the emissions of greenhouse gases is a major global task. However, even if this strategy is powerful and successful it is clear that the climate is going to change and that there is a need for adaptation [5].

Response to climate change on transportation infrastructure includes the following steps:

1. Assess how climate change is likely to affect various regions of the country and modes of transportation.
2. Inventory transportation infrastructure essential to maintaining network performance in light of climate change projections to determine whether, when, and where their impacts could be consequential.
3. Analyse adaptation options to assess the trade-offs between making the infrastructure more robust and the costs involved. Consider monitoring as an option.
4. Determine investment priorities, taking into consideration criticality of the infrastructure components as well as opportunities for multiple benefits (e.g., congestion relief, removal of evacuation route bottlenecks).
5. Develop and implement a program of adaptation strategies for the near and long terms.
6. Periodically assess the effectiveness of adaptation strategies and repeat Steps 1 through 5.

The UK has an approach for climate change risk management - Highways Agency's Adaptation Framework Model – HAAFM [25]. It deals with both adaptation (changing behaviour to be more appropriate for anticipated climate changes) and mitigation (taking actions to reduce greenhouse gas emissions) strategies. From the research perspective, EraNet Road funded four research projects: IRWIN, SWAMP, P2R2C2, and RIMAROCC. Risk Management for Roads in a Changing Climate – RIMAROCC – is a fully integrated approach for risk management in the road organizations that deals with the changing climate risks. Research in the US delivered a special report "Potential Impacts of Climate Change on U.S. Transportation" which main objective was to study consequences of climate change on transportation infrastructure and operations [25].

National Cooperative Highway Research Program (NCHRP) Report 750, Volume 2, deals with the climate changes management strategies [15]. Climate and weather changes will have long term effects on safety and functionality of the highway systems. It is important to understand these effects and how the transportation agency's activities and asset management practices can be adapted to increase transportation system resiliency and reduce asset's vulnerability to these expected changes. The report consists of two parts: practitioner's guide and research report. The approach used in the development of this report draws from the climate change research activities and associated guides developed all over the world, e.g. Australia, the USA, Canada, the UK, Sweden, New Zealand, European Union, and several agencies in the US. Climate change impacts are observed as impacts to highway infrastructure and impacts to operation and maintenance. Main categories of climate/weather change covered in this report are changes in temperature, precipitation, sea level and hurricanes. Highway assets which are considered are bridges, culverts, storm water infrastructure, slopes, walls, and pavements.

Within the Federal Highway Administration report it is stated that if risk is the effect of uncertainty upon objectives, then climate change is one of the largest risks facing asset management objectives [10]. Climate change forecasts emphasize uncertainty and greater variability. Effects of climate change are explained through several examples:

- Climate change scenarios predict that storm events will increase, both in frequency and intensity. This can bring increased flooding but also increased soil saturation that could increase rock fall sand slope failure.
- Higher temperatures and changing weather patterns can lead to droughts that bring increased numbers of wildfires that damage infrastructure, higher temperatures that cause pavements to rut, crack or shove.
- Less snowfall and greater rainfall change mountainous hydraulic patterns with effects upon culverts and ditches.
- Rising sea levels will affect coastal storm surges, drainage outflows and even the inundation of low-lying roads.

2.3.2 Road assets

Three different methodologies and approaches can be used for the risk management of asset security vulnerability:(i) the first methodology was developed in the US and presented in a guide “A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection, May 2002”, (ii) the second methodology is also developed in the US and considers bridge and tunnel security and safety, and (iii) the third methodology is a computer based program “CARVER2” (Criticality Accessibility Recoverability Vulnerability Espyability Redundancy) (see [5]). These methodologies can be used individually or in combination with each other.

The New Zealand State Highway Asset Management Plan covers all infrastructure assets that form the highway network [24]. It includes carriageways, structures, drainage features, traffic facilities, lighting, traffic management etc. The Plan addresses current and future demands on the network, its performance and the related risk.

Beauvais et al. developed the risk-based asset management methodology for the Virginia Department of Transportation - VDOT [30]. This methodology uses condition (lifetime remaining) and cost as performance indexes. Risks, costs and benefits are calculated for each asset and then combined to total costs and benefits at the Regional, District and Asset Management level at which VDOT currently operates. Information for all assets is acquired and an asset classification plan was developed where an asset may be classified as a must, non-must, or reconstruction. Assets are prioritized based on two filters: operational filters and contingency filters. Both filters have a set of criteria based on how the asset classification is performed. If the asset is scheduled for reconstruction, it is removed from further consideration for the maintenance. Next, it is considered if the asset is in the critical condition or if it is critical for the operation of the system. If the asset falls into one of these two categories, then it is categorized as a must. Remaining assets are categorized as a non-must. Further, a cost-benefit analysis is conducted using the multi-objective decision tree. The objectives are to minimize short-term cost, minimize long-term cost, and maximize lifetime remaining. Based on findings, the VDOT can define organizational objectives for all three levels.

One example of the risk management for road assets is the management of risks associated with natural hazards [25]. In Japan, inspections concerning risks due to heavy rainfalls are performed every five years and include examination of roadside conditions considering nine road elements: rock fall/slope failure, rock failure, landslide, avalanche, debris flow, embankment, snowdrift, scouring of bridge foundation, and retaining walls. Inspections of roads concerning risks due to earthquakes are similar. The types of road assets inspected are: bridges, pedestrian bridges, embankments, utility ducts, retaining walls, rock and snow sheds, depressed roads and cut-and-cover tunnels.

Another example is the risk management based maintenance strategy for urban expressways, also developed in Japan [23]. The main concept is that the inspection and the maintenance work play a key role for safety of road users. High quality inspections and maintenance activities cause high costs for the agency, while low quality items cost less but also lead to the higher risks for road users. The idea is to find the optimum of efficiency and adequacy of inspection work (see Figure 6). Here, the risk is defined as the product of the probability of encounter obstacle and the volume of traffic. It is assumed that the risk of the entire network can be managed by controlling the risk level of each section at its target values. Figure 7 represents the risk management cycle for the inspection and maintenance work.

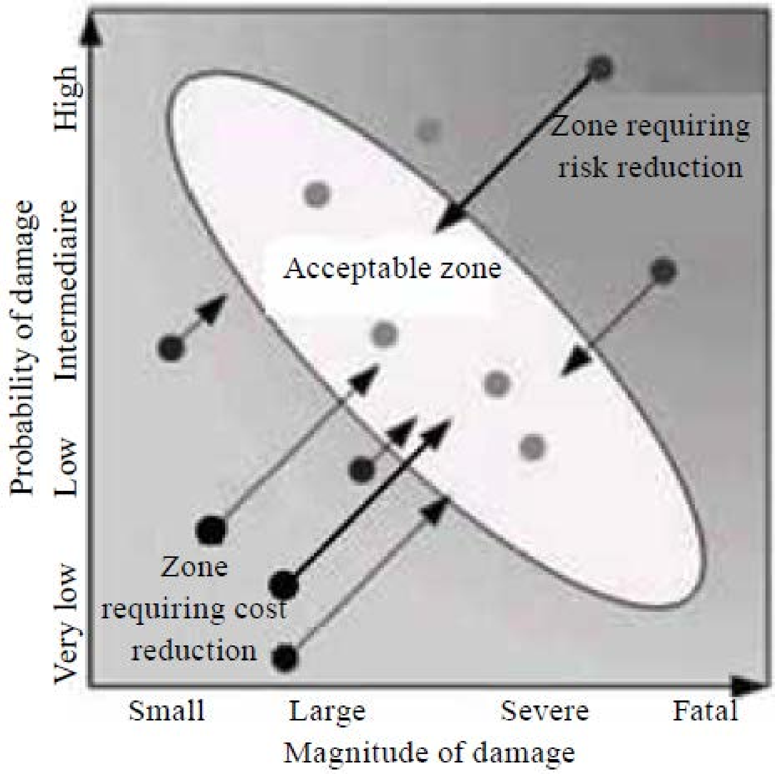

Figure 6: The concept of the risk management based maintenance strategy [23].

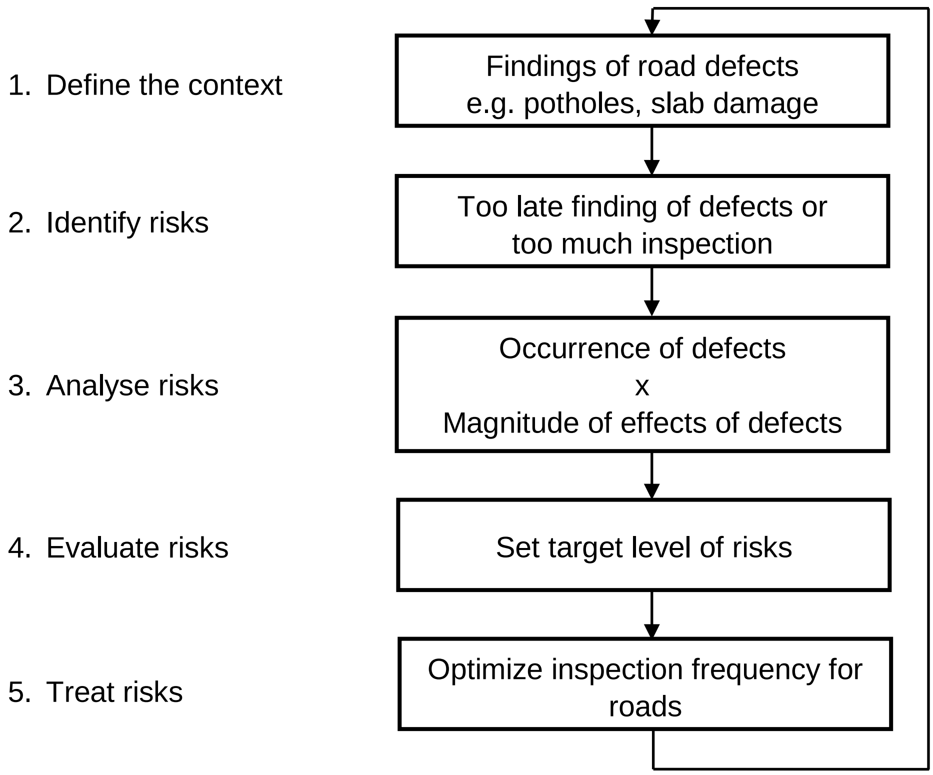

Figure 7: Risk management cycle of inspection and maintenance strategy [23]

The Austrian tunnel risk model TuRisMo is a system based approach with both frequency and consequences analysis based on quantitative methods [17]. Risk evaluation is twofold: how application of different safety measures reduces the risk under consideration, and comparison of the tunnel under consideration and the reference tunnel which fully complies with the EU Directive. The risk assessment can be complemented with the cost-effectiveness analysis.

The Dutch scenario analysis for road tunnels is a deterministic method and helps in the assessment of the effectiveness of different measures on possible developments of adopted scenarios [17]. In this tool, only traffic accidents are taken into account: breakdowns, collisions, fire, explosion, and spill of dangerous goods. Scenario analysis is performed in time-steps and quantitative data can also be added to the analysis such as the number of the people in the tunnel, the fire load, the hazard distances and the number of casualties. The output consists of the set of information such as a description of scenarios under consideration and comparison with the adopted threshold values.

The Dutch TUNPRIM model is also a system-based model which calculates risks for the twin tube tunnels with one way traffic and with or without vertical ventilation [17]). There are several types of incidents, all traffic related, that can be considered: collisions, fire, explosion and leakage of dangerous materials. Consequences are determined as the number of fatalities. The output is the risk presented as either the individual risk (expected value, average number of fatalities per year), or as the societal risk (as FN curves).

The French specific hazard investigation - for every tunnel longer than 300 m, uses a scenario-based approach is to evaluate the compliance with regulations and known measures for the risk reduction regarding the accidents – both probability of occurrence and the consequences of accidents [17]. The output allows the decision makers to assess the need for improvements to reach the reference case and to have valuable data for each tunnel investigated which may help in the development of the emergency response plans.

Italian risk analysis for road tunnels is also scenario-based analysis with quantitative methods and deals mainly with fire incidents in tunnels [17]. Consequences are measured in terms of fatalities, but some additional parameters may be considered such as injuries and damage to the infrastructure. The model can be applied both to the existing and new tunnels.

The OECD/PIARC Dangerous Goods (DG) QRA model represents the risk analysis (quantitative methods) for the transport of dangerous goods in tunnels longer than 300 m and it is in use in France [17]. The model has two steps: first, societal risk or, in this case, intrinsic risk (yearly expected number of victims due to dangerous goods transported through the considered tunnel, assuming all dangerous goods are allowed) is calculated. If it is above a certain threshold value, the second step is performed which allows the choice of up to three alternative routes and their comparison in terms of the expected values (FN curves) with the tunnel under investigation. Petelin et al. [28] expanded this methodology by using the combination of QRA model and scenario-based analysis. Quantitative risk assessment is used to identify the most dangerous scenario which is then analysed in detail.

3 Current practice of risk assessment in asset management

Several road operators have been consulted to discuss the current practice concerning external factors and their impact on the road operator's work and how risk assessment is incorporated into their processes. In a workshop in London on September 3rd, information from the Highways Agency and Transport for London (United Kingdom) was collected. In a series of interviews (personal meetings, via Skype, phone and e-mail) the views of Austria (ASFINAG), Hungary, Slovenia, The Netherlands (Rijkswaterstaat) and Denmark (Danish Road Directorate) were gathered. Finally, the opinion of a private road concessionaire (EGIS, partner in X-ARA project team) is described. The following subchapters all follow the same structure. This structure was proposed for the workshop. All case studies give a short introduction when and how the information was collected including a paragraph about the road operator and its network. Then three blocks are to follow:
A - Are external factors currently considered in asset management procedures and how?
B - On what stages is risk assessment currently in place?
C - Experience with current approach and future expectations

3.1 Austria

Date	08.10.2014; 10:00-12:00 (Asfinag, Modecenterstraße)
Attendants	Christian Honeger (Asfinag), Mario Krmek (Asfinag), Karl Gragger (Asfinag), Christoph Antony (Asfinag), Roland Spielhofer (AIT), Barbara Brozek (PMS-Consult)

ASFINAG builds, operates and maintains the motorway network of Austria. It is an incorporated company with one holder, the Austrian state. Funding is not provided by the state; revenue is derived from a truck toll (dependent on number of axles and weight) and passenger cars toll (with a vignette). The network length is 2.183 km of motorways, with ~5.100 bridges and 146 tunnels (covering a length of 340 km).

A - Current situation
Are external factors currently considered in asset management procedures and how?

Climate change: There is a current project on the definition of critical structures that are considered as key elements of the network. Selection criteria are size, age, condition and replacement cost, impact of closure on traffic and importance for the network. This reflects the availability of alternative links both on roads and rails. Effects of closure due to maintenance of failure are considered both for the surrounding road and rail network.

Austria is a mountainous country and hence winter maintenance plays an important role in the asset management and weather conditions and usage of de-icing salt are thoroughly monitored. During the past years, emphasis was set on the optimization of the amount of de-icing salt used and optimization routes of winter services. An increase in the number of heavy rain and heavy snow events is to be expected in the future but currently no special considerations are taken.

Regarding flooding, no special considerations are taken. The whole network is designed for a 100 year flood. However, as the flood levels may change due to climate change in the coming years, this would have to be considered in planning as well as in maintenance.

Funding: As ASFINAG gets its financing mainly from toll, dependency on politics with regard to funding is low. The overall economic situation has an apparent impact on the traffic demand which directly affects toll revenues. However, this mainly affects the volume of new construction projects that can be financed and has only marginal impact on maintenance and asset management.

Traffic demand: For traffic development one long term scenario exists with a conservative traffic increase. The scenario is based on historic data.

Macro-economic factors: Macro-economic factors have an influence on the traffic demand and this is directly related to toll revenues. This is discussed above.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

Planning stage: A spatial definition of "areas of natural hazard" is currently taking place which should be used as basis for planning protective structures. Risk of seismic events is included with respect to the current national standards. In general, Austria has a low exposure to seismic hazard.

Construction: When carrying out construction projects, a risk-management for the project itself is in place. This risk-assessment considers risks like delay, budget overdraw, claim management, etc.)

Operation: Considering climate change as this might cause intense rain and snow events

Safety: A road safety inspection is carried out every ten years. The findings of these inspections directly feed back into maintenance to reduce risk of accidents.

Project level: For tunnel safety, a detailed directive ("Tunnel Safety Methodology of Risk-analysis", RVS 09.03.111) for risk assessment is in place.

Maintenance level: Concept of keeping the level as designed (according to standards at time of design). Usually no updates or strengthening due to changing standards is done.

Risk categories and their use in asset management processes

The different risk categories were discussed, but none of them is currently used in asset management processes.

[1] Austrian Guideline RVS 09.03.11 Tunnel Safety - Methodology of Risk-Analysis, Austrian Association for Research on Road - Rail – Transport (FSV), Vienna, 2009

C – Future expectations

Experience with current approach and future expectations?

Funding for maintenance: Funding is derived from toll revenues. These are expected to stay at a constant level in the future in respect to a correct reporting.

Maintenance: Currently, routine-treatments like patching are not considered in asset management and the occurring costs are not directly related to the section where they occur, but are part of a global budget. In certain sections with a high number of such treatments, this distorts the view on the total maintenance costs. Relating these costs to the corresponding sections is planned for the future. If these costs are considered in the asset management system it is expected to influence the selection of maintenance and the prioritization process, leading to an optimized budget allocation.

Maintenance: ASFINAG has a large number of structures (retaining walls, anchor walls, etc.) to maintain. While the number of failures of these structures is very low, the impact of a failure is considered severe. Condition monitoring of these structures is generally difficult and a better insight into condition would be appreciated. For newly built structures, monitoring facilities are incorporated already during the design and planning phase. For existing structures, the monitoring procedures have been reworked.

Data: Routine monitoring is in place on pavements, bridges and tunnels that allows effective asset management. Currently, there are no special needs for additional data collection.

3.2 Slovenia

Date 21.10.2014; Skype call, 14:00-15:00

Attendants Julia Jamnik (Cestel Ltd., formerly DRI Investment Management Ltd.), Goran Mladenovic (UoB FCE)

The information presented in this chapter covers the approach used in Motorway Company in the Republic of Slovenia (DARS d.d.) which is responsible for building, operating, and maintaining the motorway network of Slovenia. DARS is the Joint Stock Company, the only holder is Government of Slovenia. Funding is not provided by the state; revenues are derived from a truck toll (dependent on number of axles and weight) and passenger cars toll (with a vignette). The total length of the network is 600 km.
The findings from the interview are complemented with literature review.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Climate change: The climate change is not considered in the management of road assets. The pavement design takes into account climate zone. However, no other impacts are considered for other assets. Regarding flooding, no special considerations are taken. The engineering objects are designed taking into account 100 year return period.

Funding: DARS gets its financing mainly from tolls. The overall economic situation has an impact on the traffic growth which directly affects toll revenues. However, this mainly affects the volume of new construction projects that can be financed and has only marginal impact on maintenance and asset management.

Traffic demand: For traffic development one long term scenario exists with a conservative traffic increase. The scenario is based on historic data.

Macro-economic factors: Macro-economic factors have an influence on the traffic growth and this is directly related to toll revenues.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

Planning stage: Planning of works on pavements at the network level is based on traffic forecast and the pavement current condition. Risk of seismic events for structures is included according to the current national standards. The future surface condition (skid resistance and rutting) is considered through performance models to take safety into account.
Construction: When carrying out construction projects, a risk-management for the project itself is in place. This risk-assessment considers risks like delay, budget overdraw, claim management, etc.

Operation: No special consideration about risks for the operational phase, except for safety risks that are described further in this document.
Safety: As described above, road safety is taken into account through regular survey of skid resistance and transversal evenness and corresponding performance models. However, independent analysis on safety and black spots is regularly performed. Comprehensive Risk Mapping for 6,500 km of the state road network within the EuroRAP programme has been carried out in Slovenia - state roads covering both motorways and other state main and regional routes[2].
The risk analysis on long tunnels (longer than 500 m) on roads that are part of Trans European Network (TEN) has been performed, as required by the EC Directive 2004/54/EC3. The Directive is transposed in the Slovenian law with the Decree UL RS št. 48/20064.
In addition, an independent study on the risk assessment related to the transportation of radioactive materials on Slovenian road network has also been conducted5.
Maintenance level: DARS takes into account only capital maintenance expenditures over the 15 years-period. It is assumed that routine maintenance of all sections is performed regularly and that all road sections are treated once within that period, depending on the condition, defined in Technical Specifications for Public Roads.

[2] http://eurorap.org/partner-countries/slovenia/, accessed October 24, 2014

[3] Kohl, B., M. Žibert. *Risk analysis study for Slovenian motorway tunnels*, 10. Slovenian Road Congress, Portorož, 2010. pp. 606 - 617.

[4] Decree UL RS št. 48/2006 „Uredba o tehničnih normativih in pogojih za projektiranje cestnih predorov v Republiki Sloveniji“

[5] Breznik, T., M. Gerbec, B. Smodiš. *Task Analysis and Risk Assessment of the Transport of the Radioactive Material by Road in the Republic of Slovenia*. Proceedings of the International Conference Nuclear Energy for New Europe, Bovec, Slovenia, Sept. 12-15, 2011.

Risk categories and their use in asset management processes

Different risk categories were discussed, but none of them is currently used in the asset management processes.

C – Future expectations

Experience with current approach and future expectations?

Funding for maintenance: Funding is derived from toll revenues from a truck toll (dependent on number of axles and weight) and passenger cars toll (with a vignette). These are expected to stay at a constant level in the future.

Maintenance: Capital maintenance expenditures for pavements for a planning period of 15 years are calculated using the Pavement Management System. It is assumed that routine maintenance is being performed where needed, but the funds are assured from a separate budget for routine maintenance. For the engineering structures there is no Management System at the moment.

Currently, routine-treatments, like patching and crack sealing, are not considered in asset management. The recurring routine-treatment costs are directly related to the section where they occur, but are a part of a routine maintenance budget.

Data

Routine monitoring is in place on pavements, bridges/structures and tunnels that allows effective asset management. For newly constructed geotechnical structures sensors for monitoring are placed during the construction. However, it is not clear if this data are used and how. Drainage system inventory data is available, but condition is not systematically surveyed. The collectors for dangerous fluids are built and regularly monitored and cleaned. Data on condition of road furniture (safety barriers, noise barriers) have been collected two years ago and have been included in the PMS. However, no change/treatment on road furniture is triggered until the treatment on pavement takes place. They have also collected inventory data on traffic signs.

Currently, there are no special needs and plans for additional data collection.

3.3 Denmark

Date 17.11.2014; phone call, 13:00-14:00

Attendants Søren Fogh (Vejdirektoratet), Roland Spielhofer (AIT)

Vejdirektoratet (Danish road directorate) is part of the Danish Ministry of Transport (Transportministeriet) and responsible for the construction, operation and maintenance of the high level road network of Denmark. This network consists of 3.797 km of roads, of which 1.167 km are motorways. Although its length is only 5 % of the total Danish road network, it serves 45 % of the road traffic. The other 95 % of the road network are operated by the municipalities. The funding for maintenance is provided by the state.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Climate change: Climate change is currently considered in planning of new roads. Mainly the drainage system is designed larger to withstand expected more severe weather events. In maintenance and operation, climate change is currently not considered. The risk of flooding is considered by the municipalities. They check whole areas, not roads in particular. Mitigation measures include regular maintenance of drainage to avoid blocking and to reserve land where flooding water can spread without damaging infrastructure.

Funding: From 2006 to 2011 there was a large increase in the maintenance and operation budget (a quadruplicating from 0.4 to 1.6 billion Kr, equals 54 to 215 million EUR), from 2012 the budget remained on a constant level (between 1.1 and 1.3 billon Kr. per year, equals 150 to 175 million EUR). This was because of the large maintenance backlog which has been constantly decreased since 2006. Budgeting is done in advance for a four year period and is based on condition of the network and calculated residual lifetimes. For the upcoming period 2018-2021 no large changes in budget are expected.

Traffic demand: Traffic demand is currently considered in maintenance and operation at planning of construction sites only. At highly trafficked sections, maintenance is scheduled to be done at night to minimize disruption although higher costs occur. Congestions costs are calculated for all construction sites but they are currently not used for optimization.

Macro-economic factors: Macro-economic factors are currently not considered in asset management.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

Planning stage and construction stage: When carrying out planning and construction projects, a risk-management for the projects itself is in place. This risk-assessment considers risks like delay, budget overdraw, claim management, etc.)

Maintenance and operation: Currently no risk assessment is in place.

C – Future expectations

Experience with current approach and future expectations?

Funding for maintenance: Funding is provided by the government.Itis expected tostay at a relatively constant level for the upcoming period 2018-2021.

Asset management approaches: Currently, the budget for maintenance is divided into asset classes (roads, small bridges, large bridges and street lighting). The separation between small and large bridges is done because of the topography of Denmark. It consists of mainland and several islands that are connected with large bridges. A failure of these large bridges would affect large parts of the country and would have a big economic impact. So the distinction between the two budgets could be seen as an indirect form of risk assessment as the large bridges have a separate maintenance budget.

There is a desire for more transparency in maintenance investments. Different approaches from staying with the current approach of dedicated systems for each asset class to an ERP approach with integrated optimisation across all assets are currently discussed, but there is no decision yet on how to proceed.

Incorporation of risk assessment is currently not on the agenda but may be a topic for the future.

Data

Routine monitoring on pavements is done on network level once a year. This includes visual inspection and laser measurements (transversal and longitudinal evenness) and skid resistance. Deflection measurements are done on project level for certain road sections. Bridges are inspected every 6 years. The routine monitoring data is considered sufficient for condition forecasting and calculation of residual lifetimes so currently there are no special needs for additional data collection in these fields.

A lack of data is observed for street lighting and it is planned to bring the condition data about street lighting to the same level as pavement and bridge data.

3.4 Hungary

Date	17.10.2014; e-mail communication, questionnaire
Attendants	Laszlo Gaspar (Institute for Transport Sciences Ltd. (KTI, in Budapest, Hungary), Goran Mladenovic (UoB FCE)

The information presented in this chapter covers the approach used in the State Motorway Operation Company that is in charge of some 1000 km of state expressway network management in Hungary. Its owner is the State (Ministry for National Development), and it is financed partly using state budget, partly by EC Commission Funds. (Some 250 km motorway sections are managed by foreign private concessionaires; their risk management policies are not public).
The findings from the interview are complemented with literature review.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Funding/politics, demand (traffic growth) and macroeconomic factors are considered in the asset management. The continuous funding of motorway maintenance-operation can be risky due to the eventually changing priorities of Governments (ruling parties) elected. Traffic growth of a given section also depends on regional and/or country-level economic changes that are not foreseeable in the design phase yet. Indirect risk management means a certain level of “overdimensioning” of the motorway structure.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

Risk assessment is currently used just in the planning phase (indirectly), as it was outlined before.

Safety: Independent analysis on safety and black spots is regularly performed. Comprehensive Risk Mapping of the state road network within the EuroRAP programme has been carried out for 92% of the Trans-European trade route network[6].
There are virtually no tunnels on the Hungarian road network.

Risk categories and their use in asset management processes

The different risk categories were discussed. The risks – that are currently suggested by researchers, but not implemented yet – in the asset management system include unexpected underfunding due to unfavourable macro-economic situation and unexpected traffic growth.

C – Future expectations

Experience with current approach and future expectations?

Currently no formal methods for risk assessment are incorporated in the asset management system.

Data

The main data necessary for risk assessment on the network level are already available for the national highway network (about 31.500 km), including bridges. Routine monitoring is in place on pavements, bridges/structures, drainage, road furniture, and lighting.

Pavement surface condition is surveyed on a yearly basis, while bearing capacity, roughness (unevenness), rutting and skid resistance are surveyed every 3rd year. Main condition parameters for bridges are collected on a yearly basis and stored in the PONTIS BMS.

Gross and net asset values for both pavements and bridges are estimated every fifth year.

Checking condition and functioning of drainage system, condition of road furniture and condition and functioning of lighting is performed on a yearly basis.

3.5 The Netherlands

Date 29.10.2014; 10:00-11:30, Skype meeting

Attendants Arjen van Maaren (RWS), Roland Spielhofer (AIT)

Rijkswaterstaat (RWS) is part of the Dutch Ministry of Infrastructure and the Environment and responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. This includes the main road network, the main

[6] http://www.eurorap.org/partner-countries/hungary/, accessed October 27, 2014

waterway network and the main water systems. The road network maintained consists of 3.046 km of motorways. The funding for maintenance is provided by the state.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Climate change: The Netherlands are situated mainly in a delta and large areas are below sea level. After the North Sea flood of 1953, the so-called Delta works has been initiated to protect large areas of the Netherlands from further flooding. Sea levels are expected to rise due to climate change. A long history of water level measurements exists and due to a new policy these measurements has been recently reassessed to identify the effects of climate change. Scenarios of expected climate change impacts are developed from the national weather agency for a period of 50 years. Flooding of rivers and flooding from rainfall is differentiated. In general, sea level rise is considered as biggest issue resulting from climate change.

Funding: Due to the ageing of assets a higher budget for maintenance is needed. A program for determining end of lifetime of bridges, sluices and road foundation is in place to allow a better budget planning and long-term forecast. RWS is aiming at making their performance more transparent. Therefore, the function level of the network is directly dependent on the budget. Three budget scenarios (low/reasonable/high funding) are developed and the impact on network availability as cumulated time loss due to congestion are calculated. These scenarios are then given to politics for the budget decision. Congestion is permanently monitored and so hot spots can be identified. The maintenance budget is decided every year for a four year period.

Traffic demand: In planning and construction phase, traffic demand is the trigger for budget discussions. The construction of new road is very rare, only gaps are filled or bottlenecks are widened. Most construction is done for additional lanes. Optimizing capacity with the help of ITS is the favoured approach to react on increased demand. Road safety work to reduce the number of accidents and related traffic jams are also considered as capacity optimization.

Macro-economic factors: Macro-economic factors are considered in planning, construction and maintenance. Due to the economic crises, a stimulus program has been set up by the Dutch government for anti-cyclic investments into infrastructure. In this context, a multi-year reconstruction program has been issued. In general, a vision for the next 20 years exists on how capable the infrastructure should be.

B - Risk assessment in asset management process – current situation

Risk categories and their use in asset management processes

Risk of flooding: This is considered as the most severe risk in the Netherlands. Not the road alone, but the whole area that is affected is considered. A certain probability of flooding is calculated and a certain risk is accepted (e.g. once every 1000 years). This risk is linked to the cost that would occur to reduce the risk and the possible harm. Densely populated areas are given a higher priority than rural areas. There is also an economic differentiation, e.g. the Rotterdam area is given a high priority due to its importance for the Rotterdam harbour although it is not densely populated. Flooding from rivers is anticipated already during the construction phase of roads.

Risk of failure after a seism: The largest part of the Netherlands is not affected by earthquakes. There is an area in the north where natural gas is exploited and earthquakes happen. However, none of the earthquakes has caused any damage, so there is no special consideration made on that risk.

Risk of large infrastructure deterioration after a very severe winter or frost: The top layer of pavements on highways is mainly porous asphalt that is used for reduction of noise and splash and spray. Although porous asphalt is more prone to frost damage than non-porous asphalt, the average life span is only 1 year shorter (*i.e.* 17 yrs on left lanes). Frost damage is largely monitored and acted upon during the winter. After severe winters it can result in an enlargement of the maintenance programme in the following summer when relatively old pavements are affected. A yearly inspection programme provides the basis for efficient programming. The planning and design of bridges has been improved to make the bridges more resilient to ice on the water. At existing bridges, measures on the water side have been taken to reduce formation of ice (air is pumped into the water and the air bubbles prevent freezing).

Risk of major traffic accident: Most efforts for increased road safety are set in design and operation. During construction, a standardized construction site layout is used to make orientation for the road users recognizable and safe. ITS is used to improve traffic safety.

Economic risks - Reduction of economic activity inducing reduction of traffic:Variation in basic economic needs is considered for RWS networks by using different design standards (for example for N and for A roads and for the amount of lanes on every road). The maintenance strategy for every object category itself uses the same standard in every region. (People have the same right on save networks in every region.) Regional differentiation in the cost of maintenance programs occurs although the amount of traffic and for example heavy loads differ. In regions were the networks are less stressed by economic traffic, they last longer and cost less.

Financial risks - sudden, significant and unexpected reduction of budget: The expected maintenance need is calculated for up to 20 years. This forecast is communicated to the politics. The maintenance budget has a duration of four years and is revised every year. A sharp budget reduction is considered very unlikely as politics is aware of the importance of a well maintained road network.

Risks in relation with innovation:To test new materials RWS mainly uses in situ tests as they provide insight in relation to the weather and other variables that cannot be reproduced in the lab. RWS also uses- and develops laboratory testing methods as often produce insight faster than in situ tests. Currently the main risk for innovation is the budget to invest in them. Budget cuts are affecting the number of innovative projects. One of the solutions is to incorporate more innovations into running projects. Risks of that are that these projects are insufficiently long to monitor the effect of the innovation.
In recent years, a new type of contract has been introduced (Design – build – finance – maintain-contracts) with very long contract durations (30 years). This is considered as innovation and also as risk. Due to the length there was no small scale introduction phase and the associated risks had to be accepted.

C – Future expectations

Experience with current approach and future expectations?

The current approach of (6) yearly monitoring keeps RWS in control as far as the condition of the highways is considered. For pavements the bearing capacity is underexposed, but for that, RWS is starting an new monitoring programme in 2016-19.

The Dutch risk assessment procedures are based on an insightful programming of technical necessities for our largest cost drivers (pavements, bridges, tunnels and dynamic traffic systems) in relation to practical boundaries (money and capacity) and policy goals or limitations (e.g. noise reduction).

In order to determine the technical necessities efficiently, RWS runs (6) yearly monitoring programmes. For pavements they measure the right hand lanes for rutting and unevenness. Skid resistance is also measured on part of the adjoining lanes. Cracking and ravelling are inventoried by visual inspection and by laser techniques on all lanes because it is the most occurring damage on porous asphalt. The main reason for monitoring cracking on all lanes is because it leads to costly repairs.

Data

For highways the most important issue is knowledge of the road constructions. The current monitoring is deemed sufficient.

For pavements on highways, periodical assessment of the bearing capacity is necessary to prevent major breakdowns in the network. Testing a reliable method for measuring earing capacity without traffic hindrance is subject of study.

3.6 United Kingdom – Highways Agency

Date 03.09.2014; Workshop 10:00-16:00 (Parsons Brinckerhoff, London)

Source Alex Tam (HA), Ramesh Sinhal (HA), Jason Glasson (HA)

The Highways Agency operates, maintains and improves the strategic road network in England. The Highways Agency is an executive agency, sponsored by the Department for Transport. The strategic road network of England has a length of app. 6,900 km (4,300 miles) and consists of motorways and trunk roads. Toll is collected on some bridges and tunnels.
The information above is taken from the website of the Highways Agency (https://www.gov.uk/government/organisations/highways-agency). The case study is derived from the information gathered at the first X-ARA workshop on September 3rd, 2014 in London.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Climate change: Scenarios are available for rise of temperature and associated risk increase.

Traffic demand: Traffic increase is expected to lead to a higher risk of accidents. A scenario to include the introduction of automated driving (which may lower the accident risks) is thought about.

Macro-economic factors/social factors: Extreme events caused changes that were not foreseen. As an example big problems during very hard winter conditions in England a few years ago have led to the call of the politics “Make it happen never again.” This call could not be neglected and the maintenance strategy had to be adapted to this demand.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

For structures a scheme risk assessment approach is available, for other types of assets nothing comparable is available at the moment.
In the value management process, risk is inherited. Main topics are safety, value for money, and environment.

- Safety is considered as main trigger for capital maintenance
- Assessment of safety: Number of accidents per scheme
- Assessment of value for money: output of whole life cost model
- Assessment of environment: There are many indicators: noise, air pollution, accessibility, CO2, sustainability, and use of material.
- All assessments are done for different assets – this leads to a balancing of risks

Risk based funding: Currently, there are no monetized models; subjective ratings of serviceability and availability risks exist for schemes. What-if scenarios are used to describe risks, but they are not monetized or quantified. This is an open point for the future and would make them less technical.

C – Future expectations

Experience with current approach and future expectations?

For the last years a “do minimum” approach had to be worked on because of funding constraints. The goal was just to keep assets safe for another 12 months. This is about to change into “do something”, which is more expensive in the long run, however not possible due to budget restrictions.
For the future, a change of the focus to customer needs is expected. The impact of cross-asset management activities on the road user will have to be considered. A change of the company profile will lead to a change from mostly engineering based decisions to customer focused decisions.
Asset management is still a reactive process; it should be transformed into a pro-active process in the future. An upcoming target is “5 years without intervention”.

Data

There is different confidence in the data throughout the organization. The approach to the use of data will have to change in the future. People will have to learn to trust traditional information and data and take over “ownership” of the data. Currently there is a general lack of trust in data which results in an insufficient exploitation of available data.

For maintenance decisions, data is crucial. There is a danger of being lethargic of incorporating innovative solutions, e.g. using satellite imaging technology for earthworks and geotechnics.

An asset information strategy has to be thought out "from the cradle" taking into account the following questions:
- Which information is needed?
- How is it collected?
- What is the use of the information?
- How can information gaps be filled?

3.7 United Kingdom – Transport for London

Date 03.09.2014; 10:00-16:00 (Parsons Brinckerhoff, London)

Source Leigh Boswell, TfL.

Transport for London (TfL) manages London's buses, the Tube network, Docklands Light Railway, Overground, Tramlink and other public transport facilities. The major road network operated by TfL has a route length of 580 km and over 6,000 traffic lights. TfL also regulates the Congestion Charge Scheme for London. Funding is provided from the following sources:
- Income from fares and the Congestion Charging scheme
- Central Government funding, agreed to 2015/16
- A proportion of London's business rates
- Prudential borrowing (the amount and profile of the borrowing is set out in the terms with central Government)
- Commercial development of their estate, including advertising and property rental, and development
- Third-party funding for specific projects

The information above is taken from the website of TfL (http://www.tfl.gov.uk). The case study is derived from the information gathered at the first X-ARA workshop on September 3rd, 2014 in London.

A - Current situation

Are external factors currently considered in asset management procedures and how?

Climate change:In the Investment tool, scenarios and models for a period of 10 to 20 years and longer exist.
Different scenarios exist, e.g.one for hard winters and their influence on deterioration. With this, questions like "If winters change to be more severe, how much more money do we need to keep the current condition level on the network?" can be answered.

Traffic demand:The network of Transport for London is considered to be already at its capacity limit and capacity will not increase in the future. In contrast, traffic may reduce in some parts of the network as TfL actively implements traffic reduction initiatives.

Macro-economic factors/social factors:Customer satisfaction is getting more important. Willingness-to-pay-surveys are conducted and related to the network status. This helps to identify at which condition people expect maintenance and to relate this to the actual network condition. Dependent on the budget, a "do-nothing" approach is still common, provided that safety and function of the asset are still ok.

Politics: Several initiatives exist and put pressure on Transport for London; these can be considered in the network programming tool.

Environment: Projects like introduction of LED lighting and installing a central management of lighting (lamps have to be changed for that) are carried out and savings are expected. Associated risks are energy costs and carbon costs.

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

Risk scoring is done for reliability, safety, comfort, environment and financial. For safety, costs of accidents, likelihood of accidents caused by deterioration are estimated. The likelihood is derived from data and experience and is therefore subjective to some extent.

Objective datasets are used as the basis for planning and maintenance; maintenance is based on asset deterioration and network status.

Funding: A prioritised forward program of works that looks ahead for up to five years exists. If budget is cut, the forward programme is adjusted accordingly.

The current focus (during the last 3 years) was set on investment and scheme modelling; a program model is to follow.
When doing scenario modelling, asset criticality is evaluated as a first step. This is done with a focus on the asset's location and function. A maximum and minimum level of risk is established for all assets.

C – Future expectations

Experience with current approach and future expectations?

The risk categories that are currently in place are considered to be sufficient.
Transport for London tries to establish a set of standard scenarios that are used to develop the next strategies. Standard scenarios are in place locally but not standard across all TfL investment planning activities.
Maintenance contracts are currently renewed every 5 to 7 years. In budgeting, not the inflation is calculated and added, but savings and contract specific cost uplifts from one contract to another are expected.

Data

Data is lacking for risk calculation for drainage assets. The full number and location of these assets is currently not known. A strategy to fill the inventory in place; Closed Circuit Television (CCTV) is used whenever drainage works are carried out for inventory.
There is a feeling that maybe already too much data available for carriageways. In the future, a strategy for data collection and information management is needed with the goal of central and full visibility of the available data.
For inventorying cable ducting and traffic lights there are initiatives in place.
There is different confidence in the asset data across highways, structures and tunnels.

3.8 International – EGIS

Date 15.01.2015; per E-mail

Source Jean Pohu, EGIS

Egis operates and maintains a number of motorway networks throughout Europe through locally based O&M companies dedicated to the operation and maintenance of that network. These incorporated companies have one or several shareholders depending on the country and project environment.

A - Current situation

Are external factors currently considered in asset management procedures and how?

The main external factors that impact AM procedures are:

- Climate conditions/change
- Seismic risk
- Traffic characteristics
- Changes in Contract requirements, Law, Standards
- Availability of assets inventory information (as-built documents)
- Relationship between Concessionaire, Operator and Grantor
- Available funding for AM with consequences on the capacity to implement the required actions/activities/works/processes
- Asset management tools availability, suitability, quality of the update process, longevity and competence of the technical support
- Technology (IT) infrastructure suitability and condition
- Country/project social and economic environment

Inspections and Maintenance (routine & major repairs) are activities of the AMS and are therefore already contemplated in AM procedures. Consequently they should not be considered as external factors.

Climate change

- Safety critical structures (all tunnels >500m, non-standard bridges, major slopes…) that are considered as key elements of the network are identified. Selection criteria are size, replacement cost, impact of closure on traffic (typically, if failing, would close more than 50% of the capacity of one carriageway for over two days) and importance for the network.
- Regarding flooding, the network is designed for a 100 year flood. However, as the flood levels may change due to climate change in the coming years, this would have to be considered in planning as well as in maintenance.
- Drainage and geotechnical assets undergo a thorough risk analysis of the various events (e.g. landslide, flooding…) that may happen over the concession period, with mitigation measures. Provision is incorporated in the Whole Life Cycle (WLC) Plan to cater for repairs of the damaged assets should the event materialise.
- The pavement design takes into account climate zone: selection of materials/binders, reference temperature for the bitumen characteristics. No further impacts are considered for other assets.

- An increase in the number of heavy rain and heavy snow events is to be expected in the future but currently no special considerations are taken.

Funding for maintenance

Funding of a project is either provided:

- by the state (availability payment schemes)
- through toll (dependent on vehicle category).

From a private concessionaire perspective, dependency on politics with regard to funding is low, after the signature of the concession contract. Indeed, only a long term and significant change of the overall economic situation would translate into noticeable variation of the HGV traffic demand. However, this would have only marginal impact on maintenance and asset management.

In case of availability payment schemes (generally applied to Brownfield projects, i.e. existing networks with an established traffic), the revenue of the project is often not indexed on the traffic (sometimes traffic bands though). A decrease of the HGV traffic would then be beneficial to the concession financial model, through a decrease of the maintenance costs essentially for pavement assets.

Conversely, when funding is derived from toll revenues (generally applied to Greenfield projects), an increase of the overall traffic would be beneficial to the Concession financial model, and this increased revenue would only be partially offset by the increased cost of maintenance.

Toll tariffs are different for HGVs (generally dependent on number of axles) and LV. These are indexed to reflect inflation, but ratios between the different categories of vehicles are expected to stay at a constant level in the future, even though HGVs damage much more the infrastructure than LVs.

Available funding for AM is essential in order to timely implement the required actions/activities/works/processes;

Maintenance

Maintenance activities comprise:

- routine maintenance (part of the O&M budget = Opex)
- heavy maintenance: repairs & renewals (considered as investments = Capex).

At planning stage, an allocation matrix is drawn to specify for each asset category the limit of scope between routine and heavy maintenance activities.

Routine-treatments like patching and crack sealing are considered as routine operations carried out by the maintenance team, not as asset management. However, routine maintenance is a key driver to asset management and should be aligned with the overall asset management strategy.

It is assumed that routine maintenance is being performed where required, but the occurring costs are covered from a separate budget for routine maintenance, part of the global O&M budget.

However, a Defect Management process shall be validated by the asset manager in order to ensure alignment of this process with the asset management strategy, and also to monitor the number of minor defects (initially cleared through a routine-treatment) since a high number of such defects on a given section is the symptom of a major degradation of the asset. Indeed, when it exceeds the identified threshold, it shall trigger some heavy maintenance.

Inspections & Monitoring

Periodic inspections are in place on all assets, thus contributing to effective asset management:

- pavements: typically SCRIM, TRACS and FWD surveys;
- structures (standard and strategic structures; tunnels; gantries);
- drainage (surface, buried, longitudinal and transversal);
- geotechnical assets (slopes, retaining walls, …);
- road furniture (road marking; signs, road restraint systems; fences…);
- energised equipment.

For all assets, inventory data is available and condition is systematically surveyed, thus enabling to draw an updated mapping of the network condition. Frequency and type of inspections are in line with the contract requirements, local or international standards; typically GI every 2y and PI every 6y. Needs for additional data collection (cores, instrumentation…) is decided in specific cases of identified risk (fast degradation identified, presence of water or movements of structures in seismic zone…) on given assets.

On some projects (in particular on the A24 - Portugal) Egis has a large number of structures and geotechnical assets (slopes, retaining walls, bridges/ viaducts/tunnels…) to maintain. While the number of failures of these structures is very low, the impact of a failure is considered severe. Condition monitoring of these structures was not contemplated at design/ construction stage and a better insight into condition trend would be appreciated. For some assets, monitoring facilities (instrumentation of slopes and retaining walls with sensors) were incorporated at design & planning phase. For others, the monitoring procedures have been reworked.

Asset Management IT support tool

Capital maintenance expenditures for major assets (pavement, structures, geotechnical assets, drainage…) are planned over the Concession Period [typically 30 years] using the Asset Management System (AMS = processes, procedures and IT support tools). A focus on mid-term and short term investments is made through the rolling 5-year and yearly Plans.

As part of the AMS, routine maintenance (for civil as well as equipment) is often monitored through different support tools: Routine Maintenance Management Systems (RMMS).

Besides, equipment (M&E, ITS and Road lighting) renewals are generally managed through a dedicated maintenance team using a specific software tool (RMMS) integrated into the overall AMS.

Traffic

This is clearly the driving factor for pavement assets:

- Overall traffic forecast (LV + HGV) over the concession period enables to anticipate the time when the motorway requires widening;
- HGV traffic forecast over the concession period enables to assess the lifespan of the pavement structure by calculation of the cumulative HGV axles;
- Focus is on HGV traffic, if possible with breakdown of different categories (2-axle, 3-axle and 4/5-axle HGV; Buses) to reflect the aggressiveness of this traffic;
- A detailed study is carried out (% of each HGV category and distribution over the different lanes…) to determine the renewal periods of the surface course and when the pavement structure needs to be reinforced to extend its lifespan over the concession period and beyond (hand-back conditions).

The traffic forecast, based on historical data, is developed by a specialist (traffic adviser) over the long term with a base case traffic increase. Upturn and downturn enables to assess the sensitivity of the revenue and maintenance costs to variations of the traffic.

Macro-economic factors

Macro-economic factors have an influence on the traffic demand and this is directly related to toll revenues. This is discussed above.

Changes

Change in Law, Change in Standards and Change in Services can have a strong impact on the maintenance, since it may require:

- New investments that were not initially budgeted.
  Typically the EU Directive 2004/54/EC required that all tunnels longer than 500 m on motorways that are part of Trans European Network (TEN), be equipped with safety equipment;
- New organisation with additional staff to be deployed at head office or on the field, to deliver the required upgraded service.
  Typically, additional patrols to monitor the traffic on the road and act as Incident Support Units (ISU) as and when required with shorter response time; requirement to have two operators in ISU vehicles

Country/project environment

This encompasses a number of diverse items:

- General approach of the NRA to enforcement of Road Laws (e.g. are overloaded vehicles enforced?), which impacts the level of acceptable risk the private sector will take with the lifespan of assets.
- Cycle cold winters/ hot summers, which prevents some techniques such as porous asphalt.
  In countries where winter is harsh, the usage of de-icing products on major structures is thoroughly monitored: using brine instead of salt is requested by the procedure, to avoid corrosion of the metallic elements of a bridge/ viaduct.
- General approach of the NRA to safety, enabling to decrease the level of lighting on the mainline while not compromising safety of road users.
- In countries prone to seismic risk, specific care will be taken at design stage on geotechnical assets (slopes, retaining walls) and structures (bearings, piles and cables) to ensure they would be resistant to soil movements.
- Country/project social and economic environment
  Beyond traffic demand, this could also impact
    - the labour market, with difficulties to recruit or retain talents in the field of asset management when the economy is booming
    - the increase of stolen assets (e.g. cables and other metallic elements for reselling) in case of economic crisis
    - the lack of maintenance (e.g. on drainage, on adjacent networks which in turn would damage or prevent access to our own network

Others

Other external factors that impact AM procedures are mainly:

- Availability of assets inventory information (as-built documents);
  Knowing one's asset is the starting point to build up an asset strategy. As-built inventory is to be regularly updated and timely delivered to the Asset Manager
- Relationship between Concessionaire, Operator and Grantor;
  Alignment of the strategy is a key success factor since the overall AM process (Inspections, development of the strategy with challenge and value management of the Heavy maintenance Plans, reporting on assets) runs through both the Concessionaire and the Operator, with the Grantor acting as overall monitor of the asset performance on behalf of the Public.
- Efficiency is generated by all stakeholders having the same understanding of the stakes and challenges on the asset maintenance

B - Risk assessment in asset management process – current situation

On what stages is risk assessment currently in place?

<u>Planning/Design stages</u>:
Essential phase with two objectives:
- orientate the design (Design for Maintenance) which is key, in particular for non-standard structures, geotechnical assets and drainage;
- ensure sufficient funding will be timely available to mitigate risks of assets underperforming after an event.

From a PPP perspective, at planning stage (bid), we ensure we will comply:

- with the minimum performance in the contract, typically:
  - Rutting, Longitudinal profile (IRI) and Skid resistance for pavement
  - Condition PI for structures
- with the contractual conditions (set by the Authority), typically
  - Widening if traffic > threshold
  - Maximum length of worksite

  using as driver the penalty regime for lane/ carriageway closure

In terms of risk, we carry out a risk analysis covering:
- Climatic events, mainly focused on geotechnical (slopes, soft soils) and drainage assets
- Seismic risk as applicable (depending on the project/ country) - such risk for structures is benchmarked against the current national standards
- traffic variations, in terms of
  - Volume (LV & HGV)
  - HGV distribution over the lanes and
  - HGV characteristics (axle loads,)

A spatial definition of "safety-critical areas" takes place, to be used as basis for planning protective structures.
Planning of works on pavements at the network level is based on traffic forecast and the pavement current condition.
The future surface condition (skid resistance and rutting) is considered through performance models to take safety into account.

Construction stage:
When carrying out construction, a risk-management for the project itself is in place. This risk-assessment considers risks like delay, budget overdraw, claim management, etc.). Asset should not be an issue provided that the Contractor does have a Quality Plan in place and delivers according to agreed process. If not, workmanship may be at stake
The main risk during this stage is to have assets not built in compliance with the design and/or having construction techniques and materials used of poor quality. For that reason, independent construction supervision would mitigate risk at this stage.
The other risk is the poor accuracy, availability and lack of organisation of the supervision data/information, necessary for AM purposes during the coming O&M stage.

Operation/ Maintenance stage
A concession project has a learning curve, to fully understand the extent of the network (inventory and asset condition) and how these assets degrade in a given environment.
To achieve this, it is necessary to document all actions (inspections, routine maintenance activities, renewal works) enabling to keep an updated mapping of the network condition.
The Operator carries out at least once a year a review of the major maintenance activities:

- review of the WLC long term plan, in order to identify the most appropriate strategy and relevant solutions to invest on;
- rolling 5-year and yearly plans to budget the required works.

In terms of risk, we carry out a value for money analysis, to prioritise investments over a rolling 5-year period.
Risk provisions (as set during planning stage) are managed and derived to profit only if the risk has not yet and will not materialised.
The definition of “safety-critical areas” is regularly updated to reflect the evolution of the network (e.g. ageing of some elements, movements of the soil…) to be used as the basis of a mitigation policy (preventive measures to reinforce an asset, by-pass of a ‘weak spot’…)
No other specific consideration about risks for the operational phase, except for safety risks that are described further in this document.

Other aspects to take into account
Safety:
In addition to the daily patrols (driving over the whole motorway up to [8] times per day on some networks), a road safety inspection is carried out every [year?] by Operator’s staff walking the whole motorway. The findings of these inspections directly feed back into maintenance to reduce risk of accidents.
Each road event (ex.: accidents, incidents, works), is separately identified with location, date & time, circumstances (rain, snow, sun…) and relevant features, enabling management actions, such as identifying black spots and patterns of accidents (if any) and then draw lessons and take action.
As described above, road safety is taken into account not only through the daily patrolling activity but also through regular surveys of drainage, structures and pavement characteristics (in particular skid resistance and transversal evenness) and corresponding performance models.
As required by the EC Directive 2004/54/EC, for all tunnels longer than 500 m on motorways that are part of Trans European Network (TEN), a risk analysis has been performed prior to

Opening of the section to define Minimum Operating Conditions (MOC) and a Tunnel Safety Officer (TSO) is in place throughout the concession duration.

C – Future expectations

Experience with current approach and future expectations?

The current approach has shown a good capacity to manage the assets and timely trigger the required investments (heavy maintenance works) to keep at all times the network above minimum operating conditions.

Maintenance

As Operator, Egis is in charge of the routine maintenance of all assets (civil and equipment). Major investments (pavement, structures, geotechnical assets, drainage) carry a risk profile that is not compatible with that of an O&M Company.

However, some assets (typically equipment and road furniture) do have a different risk profile, whereby the lifespan of these assets is directly linked to the performance of the routine maintenance team. Indeed, an operator is best placed to take over the full risk of maintenance renewal of such assets (turnkey maintenance), thus avoiding setting up a clear limit between routine and heavy maintenance activities.

Routine maintenance of “civil” assets is not always managed in accordance to AM strategy and asset managers/teams are often not involved on assets defect management process. Every time the AMS integrates all the relevant activities on assets, such as inspections, routine maintenance (Civil &FOE assets), major repairs, and traffic management, the AM process is more efficient. This approach is considered in the ISO 55000 standards and is the future trend/expectation for AM.

Data

Current Asset Management software tools (enabling to plan investments) are generally not interfaced with the RMMS (managing routine maintenance and inspections) thus making the communication between the maintenance team (in charge of carrying the routine activities) and the asset management team (often only in charge of managing inspections and developing the heavy maintenance plan) difficult.

It is the intention of Egis to integrate the necessary modules into an AM tool package not only to support the management of routine maintenance activities, including the Defect Management process, but also to ensure the integration of routine maintenance activities in the AM strategy and the availability of the routine maintenance data/information, required for AM purposes.

An optimisation module for all type of major assets (not only pavement and structures) will be developed.

4 Discussion

Literature review and existing practice

The literature survey has brought various definitions of the term "risk" in the scope of road asset management. Although the definitions vary to a certain extent, most of them refer to risk as the product of probability of occurrence multiplied with the consequences. The classic definition often implies a risk of failure. However, failure in the sense of sudden breakdown is a rare event in road maintenance. Through constant monitoring of the asset, the condition (and development of condition) of the assets is usually well known and maintenance and rehabilitation measures are programmed in due time to keep condition above a certain threshold. Speaking of a risk that assets do not deliver a certain level of service seems to be more appropriate in the field of road asset management.

Several sources of literature have shown the same approach when building a framework for risk assessment. Often, a five step approach is proposed (see Figure 8 below) and detailed to the different needs.

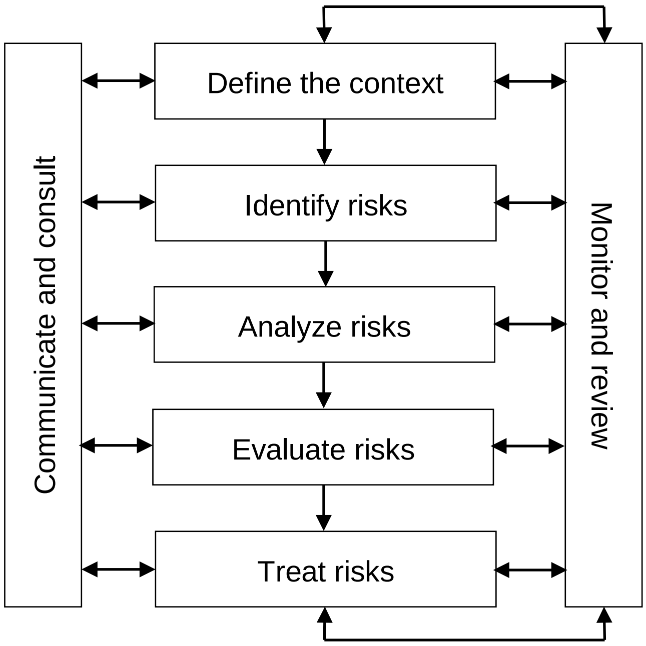

Figure 8: General risk management process [1][4][5]

The first step, *defining the context*, has shown to be a comprehensive task. Risk management for construction projects is often in place and covers claim management and risks that occur during the construction like the risk of delay and the risk of overdraw. Risk assessment in maintenance and operation is often implemented asset specific, e.g. for structures and tunnels.

The second step, *identifying risks*, is - if restricted to the maintenance aspect of the work of road operators – not commonly applied. It is often done in an indirect way; Denmark for example has a separate maintenance budget for large bridges which are considered the most important ones. The road operators are aware of the most sensitive parts of their network and give these parts special consideration. However, there is no systematic risk identification process behind this. The literature review has brought up a number of risk lists that could be used by asset managers. These lists are often just partly implemented by road operators, usually not following a systematic approach but picking the items depending on their own need and experience.

The next step, *evaluation of risks*, is hence again not fully implemented. The evaluation is sometimes based on expert judgement (which could be subjective); for accident risk the number of accidents per section normalized by the amount of traffic is commonly used. Techniques like FMEA (Failure modes and effects analysis) are in use at RWS for waterway assets (dams, sluices, etc.), but not for road assets. Such comprehensive risk evaluation techniques have not been found at the other road operators.

For the last step, *treatment of risks*, most road operators consider monitoring as sufficient. For specific asset classes, e.g. lighting and drainage, too little data is available to perform risk analysis and treatment. In one interview, a certain oversizing to treat the risk of changing demand is mentioned.

The literature revealed also more specific risk management tools, e.g. for managing tunnel safety risks. These tools are operational for some time now.

To sum up, no road operator has implemented the risk management framework in full scale for asset management.

A reason for that might be that current asset management systems have not been designed by scratch with risk assessment in mind but have evolved over a long time (often decades).

This is supported by the case studies derived from interviews and the workshop. To some extent, the majority of the road operators uses risk assessment in some way, although it is often not referred to. To a varying degree, scenarios are used to reflect possible future developments. In the planning and construction phase, the road operators have to rely on current technical standards and regulations – these often do not include possible effects of e.g. climate change yet. On the other hand, road operators have a number of assets of certain age that have been designed to outdated standards and where loads have increased beyond the original design standard.

Consideration of external factors

Climate change

Road operators are aware of the effects that can be expected from climate change – an increase of the occurrence of extreme weather events, larger severity of these events, etc. Road operators anticipate an adjustment of the design standards for road infrastructure in the future. Most assets currently in place are difficult to adapt to higher impacts. The first step to be taken is to determine the assets that have the highest exposure and the ones that have the highest importance for the network functionality. That is already done – explicitly or implicitly through other means – by the road operators. One operator has already different scenarios in use to predict the changes in maintenance needs according to climate change effects.

Funding

Road operators that rely on toll revenues do not consider funding as a major risk for maintenance. As demand is also not considered to change suddenly, toll revenues are considered to stay stable or slightly increasing. The road operators that have to rely on public funding face a different situation. However, none of these assume sudden decline in funding.

The opinion that a functional road network is essential both for economy and society seems to be broadly acknowledged and hence at the need for certain maintenance budget as well.

Demand / traffic growth

For future demand, a scenario with a slight increase is widely assumed. Development of demand is considered to be moderate and no special risk considerations are drawn. One operator considers his network to be already at the capacity limit. As building of new roads is considered unlikely, optimisation of traffic flow via telematics services is encouraged. Improvement of road safety leading to less accidents and optimisation of maintenance work (e.g. doing maintenance during night hours) are other capacity improvements.

Macro-economic factors

Regarding the influence of macro-economic factors, only the influence of politics has been mentioned. However, this is considered unpredictable and no special considerations are taken beforehand. On toll revenues, the state of economy has a very direct influence. However, the impact on maintenance is considered little, as the crisis years 2008-2009 have shown. More impact is to be expected on new construction works as they may have to be postponed.

Availability of data

Condition data of pavement and bridges is widely available, for both asset types routine-monitoring is in place for a long time now. Routine monitoring of road surface properties is done regularly, often on a yearly basis. Transversal evenness (rutting), longitudinal evenness, skid resistance and visual defects are monitored at all consulted road operators. Bridge inspection is also in place at all consulted road operators and hence condition of bridges is well documented. However, there was complaint that there may be too much data available in the meantime that is not improving maintenance decisions. The confidence in the collected data needs to be improved and the question “Do we collect the right data for optimal maintenance decisions?” was raised.

For other asset types, a lack of data was reported. Street lighting, drainage and geotechnical assets like retaining walls are often not monitored to the same extent as pavement and bridges. Road operators increase their efforts in inventorying and monitoring these assets.

From the literature it is clear that a solid dataset is the essential base for risk identification and analysis.

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