CEDR Transnational Road Research Programme
Call 2013: Ageing Infrastructure Management

funded by Denmark, Germany, Ireland, Netherlands, UK, Slovenia

X-ARA

Cross-asset risk assessment

Risk framework and modelling specifications

Deliverable D1.2

Deliverable D2.1

May 2015

CEDR Call 2013: Ageing Infrastructure Management
X-ARA
Cross-asset risk assessment

Scoping Document "Risk framework and modelling specifications"

Due date of deliverable: 28/02/2014
Actual submission date: 22/06/2015

Start date of project: 01/04/2014 End date of project: 30/03/2016

Authors of this deliverable:
Roland Spielhofer – AIT, Austria
Mark Oldfield, Chris Britton, Hanneke Levine – Parsons Brinckerhoff, UK
Barbara Brozek, Alfred Weninger-Vycudil – PMS-Consult, Austria
Philippe Lepert – IFSTTAR, France
Goran Mladenovic – UoB Belgrade, Serbia
Gaelle Le Bars, Jean Pohu – EGIS, France
Hans Litzka –Technical advisor, Austria

PEB Project Manager: Alex Tam, Highways Agency, UK

Version: final, 08 2015

Table of contents

List of Figures

List of Tables

Executive summary

This report covers the findings concerning the risk framework (Deliverable 1.2), that has been developed in the course of workpackage 1, and the findings concerning the full risk modelling, that has been developed in the course of workpackage 2 of the X-ARA project.

The report covers the topics input data, high-level influence factors and risk modelling and closes with an example of the risk calculation method. The risk tool that will be developed in X-ARA serves two main purposes: 1) to establish the relative risk across a network. 2) to enable the user to work with “what-if” scenarios to determine the change of the risk according to a scenario that deviates from the baseline scenario. The output of the tool will be a map showing “heat maps” (i.e. a colouring scheme) of the network that visually represents the overall maintenance risk for each section and therefore allows a visual comparison of sections.

The input data is defined for the underlying network that is structured as maintenance sections that represent homogeneous conditions (number of lanes, type of pavement, traffic volume, etc.).

The asset categories considered in the risk tool are pavement, structures (bridges and retaining walls), tunnels, road furniture, drainage and geotechnical assets. For each asset category, condition indicators have been defined based on literature or common practice.

High level influencing factors have been defined: Climate change, that includes all aspects associated to climate change and its consequences; Funding, that covers the availability of funding for proper maintenance and Safety regulations that allows the introduction of safety related improvements. These three external factors are complemented by a “functional” high level factor that reflects changes in the functional importance of a road or sub-network. Three categories are proposed for each high level influencing factor: ‘positive’ to reflect a situation that lowers the asset specific risk; ‘standard’ to reflect the expected development and ‘negative’ to reflect a development that increases the asset specific risk. The influencing factors are established for each asset of the network.

The risk for each asset will then be calculated using pre-defined matrices that cover condition of asset and the importance of the asset or – in other words – the consequences of failure of this asset. At first, the risk per each single asset (on object level) is assessed and cumulated on the maintenance section. Following up, for each maintenance section, an overall risk score is calculated to combine the asset specific risks using different transformation laws.

The report closes with a worked-out example using a small road network to demonstrates the risk calculation approach.

The next steps to be taken in the project are the implementation of the risk modelling approach into the X-ARA-tool by using the prototype in the course of workpackage 3. In this prototype, the risk matrices and the weighting functions have been developed and adjusted. Transformation laws for combining asset specific risks have been verified and adjusted if necessary. High-level influencing factors have been investigated concerning applicability and consequences.

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 assess '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). A 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 a 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 Scope of the report

This document provides a description of the risk modelling approach in X-ARA.

The risk considered in the report is "the risk for the road operator" to either perform non-cost-efficient maintenance on his network, or to provide unsatisfying services to the other stakeholders (users, neighbours, Society, owner…). As not all these "elementary" risks could be developed within the X-ARA project, it was decided to illustrate the approach by considering:

- The risk for the road operator to lose money (too expensive maintenance, excessive loss in asset valuation, etc.) in the short, medium and long terms by applying maintenance strategies which do not adequately anticipate on high level influencing factors
- The risk for the road operator to provide users with significantly unsatisfying services after some improbable event(s).

The same approach could be used to assess other risks (to users or other stakeholders) that the road operator could have to face. It is assumed that these different "elementary" risks could then be merged into a single "overall" risk by a weighted sum. The weights would reflect the relative importance of each risk

As the risk modelling methodology itself is the core part of workpackage WP2, which is also a part of this comprehensive document. Thus, the report covers the following topics:

- Which input-data is needed to successfully run the risk tool?
- Which high-level influence factors are considered in the approach?
- How does the risk model work?
- What will be the output of the tool?
- How is the maintenance risk defined in general?
- How to define the maintenance risk for different types of asset?
- How does the risk model work?
- What will be the output of the risk assessment modelling?

The risk tool of X-ARA has two main purposes:

1. To establish the relative maintenance risk across a network
2. Enable the user to use "what-if" scenarios to determine the change of the risk according to a scenario that deviates from the baseline scenario

The output of the tool will be a visual representation (map) showing "heat maps" (i.e. a colouring scheme) of the network (as shown as example in Figure 1) that visually represents the overall maintenance risk for each section and therefore allows a visual comparison of sections.

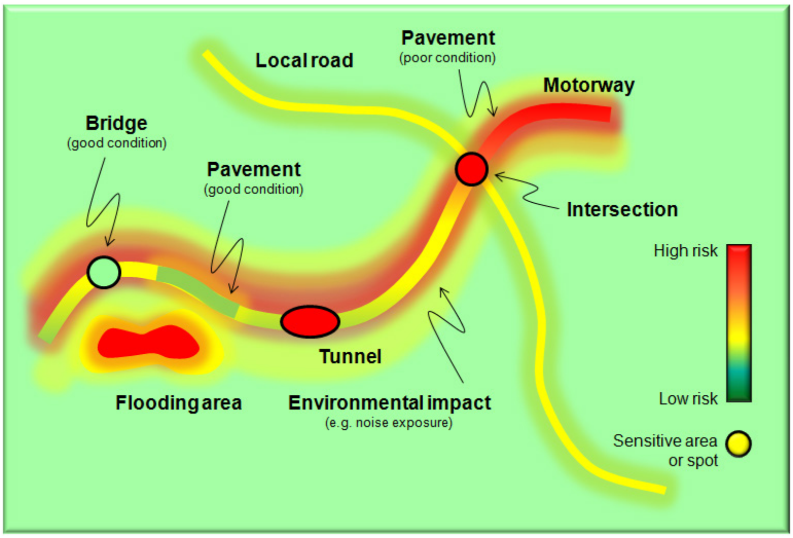


Figure 1: Visualisation of maintenance risk on the network. Additional information like "flooding area" is shown for illustrating influencing factors and depends on availability of GIS representation.

By applying "what-if" scenarios, the impact of the influencing factors will be calculated and can then be compared to the baseline scenario. This will be visualized by changing of the colours.

Furthermore, the output will be provided as tables (CSV-files) that list the risk scores per section.

In the Appendix, a worked-out example using a small road network demonstrates the risk calculation approach.

2 Input data needed

The risk tool works based on maintenance sections. A maintenance section can be defined as a section of the road network that has in general homogeneous conditions (number of lanes, traffic load, sensitivities against different high level influencing factors, etc.). For each section (which can be of constant and/or arbitrary length), a number of attributes has to be known. The number of attributes is not fixed, although there is a minimum number of attributes required to make the tool work. Different road operators have different datasets and datasets of different grade of detail that could be used by the tool. As a consequence, the number of attributes or type of assets considered is not fixed.

The settings for data requirements are based on the experiences of the projects members, the discussions with road administrations and other European research projects (e.g. COST354, EVITA, PROCROSS). They can be seen as common denominator in data availability over a high number of European national road administrations and lead to the following categorization of road infrastructure assets, defined as the risk framework within X-ARA:

- Network data to describe the maintenance sections
- Condition data for asset performance
    - Pavements
    - Structures (bridges, retaining walls, etc.)
    - Road furniture (lighting, safety barriers, etc.)
    - Drainage
    - Geotechnical assets
    - Tunnels (including electro-mechanical equipment)
- Cross-asset data for combining asset-specific risks on maintenance sections

The data specifications in the following tables are the basis for the definition of the risk framework within the X-ARA risk tool prototype. An adjustment and extension of these tables is possible during the project execution.

2.1 Network data for maintenance sections

With regard to the project description and the requirements for the X-ARA risk tool (input and output) the network has to be provided in the form of a shape file [2]. As mentioned above, the network has to be structured in the form of maintenance sections. Table 1, Table 2 and Table 3 list the minimum attributes for the network sections.

Table 1: General attributes for each network section

Attribute	Database type[1]	Input	Description
Name	Text	yes	Road section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (e.g. from shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

[1] Standardized data types according to MS SQL or ORACLE

Table 2: Inventory attributes for each network section

Attribute	Type	Input	Description
AADT	Integer	yes	Annual Average Daily Traffic
PHGV	Double	yes	% of heavy vehicles
Road_category	Table	yes	Road category (M-motorways; E-expressways; O-ordinary road)
Regional_Info	Table	ye	Regional info (F-Flat/Coastal; M-Mountainous; U-Urban)

Table 3: Sensitivity attributes for each network section

Attribute	Type	Input	Description
SEN_Climate	Table	yes	Sensitivity to climate (L-low; M-medium; H-high)
SEN_Funding	Table	yes	Sensitivity to funding (L-low; M-medium; H-high)
SEN_Safety	Table	yes	Sensitivity to safety regulations (L-low; M-medium; H-high)
SEN_Network	Table	yes	Sensitivity to network (L-low; M-medium; H-high)

The sensitivity attributes will be used to incorporate the high level influencing factors, which are described in detail in chapter 3. Especially, in the context of “What if?-scenario” calculation and assessment the sensitivities will have an essential influence to the results. It has to be stated, that the results will define a quality level of risk and not a monetary risk number. Thus, it is possible to make comparisons with user definable “What if?-scenarios” from the quality point of view subject to the sensitivities of the network in the different areas (climate, funding and safety regulations).

2.2 Condition data for asset performance

Different road administrations have different strategies for routine condition monitoring and different datasets are available. The X-ARA tool therefore uses dimensionless performance indicators for the representation of condition of the different assets. Establishing these performance indicators has to be done outside the risk tool, but this is a very common step in asset management systems in use today. For clarity reasons, additional attributes, which will be filled by transferring data from the network table into the asset specific tables and attributes, which will be used to store intermediate results, will not be listed (e.g. AADT).

2.2.1 Pavement

The condition of carriageway pavement is defined in dimensionless units per section. Two main elements are covered in the pavement condition: Comfort and safety as combined index (CSI) and structural strength as structural index (SI) according to COST 354 [1]. The use of these two indicators is very common in current pavement management systems. The asset specific attributes are given in Table 4 to Table 6.

Table 4: General attributes for each pavement section

Attribute	Type	Input	Description
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Pavement section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 5: Asset specific attributes for each pavement section

Attribute	Type	Input	Description
Pavement_type	Table	yes	Pavement type (A-asphalt; C-cement concrete)
CSI	Integer	yes	Comfort and safety index (class 1 to 5 according to e.g. COST354)
SI	Integer	yes	Structural index (class 1 to 5 according to e.g. COST354)

Table 6: Risk attributes for each pavement section

Attribute	Type	Output	Description
RISK_CSI	Decimal	yes	Risk comfort and safety index (0-100)
RISK_SI	Decimal	yes	Risk structural index (0-100)
RISK_P_Total	Decimal	yes	Total risk pavement (0-100)
RISK_P_Total_Alt	Decimal	yes	Total risk pavement alternative analysis (0-100)

2.2.2 Structures

Structures comprise bridges and retaining walls. Beside the structure condition indicator SCI, the severity and extension of distress will be included in the risk assessment based on the British standard BE11/94 [6] for bridge inspection. The general and specific attributes for structures are given in Table 7 and Table 8. The risk attributes are listed in Table 9.

Table 7: General attributes for each structures object

Attribute	Type	Input	Description
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Object section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 8: Asset specific attributes for each structures object

Attribute	Type	Input	Description
SCI	Integer	yes	Structure condition index (Score 1…5)
SED	Text	yes	Extent of defects (scale from 1 to 5)
SVD	Text	yes	Severity of defects (scale from 1 to 3)

Table 9: Risk attributes for each structures object

Attribute	Type	Output	Description
RISK_S_Total	Decimal	yes	Total risk structures (0-100)
RISK_S_Total_Alt	Decimal	yes	Total risk structures alternative analysis (0-100)

2.2.3 Road furniture

Road furniture is incorporated in the risk model as well. The term ‘road furniture’ covers different types of assets, e.g. street lighting, traffic signs, gantries etc. For the condition of road furniture no common agreed condition indicator exists. The condition is defined on an uniform 1 to 5 scale in form of a dimensionless index, where 1 is very good condition and 5 is very poor condition (see COST354 [1]). Road furniture will be defined as linear elements, although some road furniture shows a point nature (e.g. street lighting, gantries). Because of low data availability in general and a pragmatic handling of data in the risk tool, point related road furniture has to be cumulated over a certain length, where the condition index represents the average condition of the single assets or sub-assets respectively over a certain road section. Table 10 lists the general attributes for road furniture objects. Table 11 lists the asset specific attributes for each object while Table 12 lists its risk attributes.

Table 10: General attributes for each road furniture section

Attribute	**Type**	**Input**	**Description**
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Road furniture ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 11: Asset specific attributes for each road furniture section

Attribute	**Type**	**Input**	**Description**
Condition index (RFCI)	Integer	yes	Condition rating 1 to 5 (Class according to e.g. M25 DBFO, COST354)
Consequence	Text	yes	Consequence of failure - H, M, L

Table 12: Risk attributes for each road furniture section

Attribute	Type	Output	Description
RISK_RF_Total	Decimal	yes	Total risk RF (0-100)
RISK_RF_Total_Alt	Decimal	yes	Total risk RF alternative analysis (0-100)

2.2.4 Drainage

For drainage sections, there are two performance indicators, the “drainage condition index” (DCI) and the design category (reflecting how well the drainage section is able to serve its function). Both performance indicators have been developed in the EVITA project [3]. Table 13 lists the general attributes for each drainage section, Table 14 lists the asset specific attributes and Table 15 lists the risk attributes.

Table 13: General attributes for each drainage section

Attribute	Type	Input	Description
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Drainage section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (e.g. based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 14: Asset specific attributes for each drainage section

Attribute	Type	Input	Description
DCI	Integer	yes	Drainage condition index (class 1 to 5 according to EVITA)
Design_category	Table	yes	Design category drainage (0-under designed, 1-well-designed, 2-over designed)

Table 15: Risk attributes for each drainage section.

Attribute	Type	Output	Description
RISK_D_Total	Decimal	yes	Total risk drainage (0-100)
RISK_D_Total_Alt	Decimal	yes	Total risk drainage alternative analysis (0-100)

2.2.5 Geotechnical assets

The definition of geotechnical asset is taken from [4]: "The term 'geotechnical asset' refers to all earthworks (cuttings and embankments) and ground underlying highway." In principle, the method presented in X-ARA can be extended to other geotechnical assets, but will be limited to cuttings and embankments in this project. With regard to COST 354 [1] a condition scale of 5 condition classes of the geotechnical condition index (GCI) will be recommended for this type of assets as well. GCI is based on the condition assessment procedures used in Highways Agency Drainage Data Management System (HADDMS) [5]. The sensitivity against erosion is the second indicator for this type of asset. Table 16 lists the general attributes, Table 17 lists the asset specific attributes and Table 18 lists the risk specific attributes of each geotechnical object.

Table 16: General attributes for each geotechnical object

Attribute	Type	Input	Description
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Geotechnical object section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 17: Asset specific attributes for each geotechnical object

Attribute	Type	Input	Description
GCI	Integer	yes	Geotechnical condition index (scale from 1 to 5)
SER	Integer	yes	Severity against erosion (L-low, M-medium, H-high)

Table 18: Risk attributes for each geotechnical object

Attribute	Type	Output	Description
RISK_G_Total	Decimal	yes	Total risk GeoTECH (0-100)
RISK_G_Total_Alt	Decimal	yes	Total risk GeoTECH alternative analysis (0-100)

2.2.6 Tunnels

Although tunnels can be seen as structures they will be treated separately because of their specific nature. Especially the electro-mechanical part (condition, availability of spare parts) has to be included into the procedure. The structural condition of the tunnel will be described by a dimensionless condition index with a scale from 1 to 5. Table 19 lists the general attributes, Table 20 lists the asset specific attributes and Table 21 lists the risk specific attributes of each tunnel object.

Table 19: General attributes for each tunnel object

Attribute	Type	Input	Description
RoadName	Text	yes	Reference to road section ID
Name	Text	yes	Object section ID (unique ID)
From	Decimal	yes	From (starting point)
To	Decimal	yes	To (ending point)
Length	Decimal	yes	Length calculated automatically (based on shp)
Mapping	Geometry	yes	Mapping attribute for GIS mapping (shp, path)

Table 20: Asset specific attributes for each tunnel object

Attribute	Type	Input	Description
TCI	Integer	yes	Tunnel (structural) condition index (scale from 1 to 5)
SVD	Text	yes	Severity of defects (scale from 1 to 3)
Age_EM	Integer	yes	Age electro-mechanical equipment
Availability_EM	Table	yes	Availability of spare parts of electro-mechanical equipment (0-low; 1-medium; 2-high)

Table 21: Risk attributes for each tunnel object

Attribute	Type	Output	Description
RISK_T_Total	Decimal	yes	Total risk tunnel (0-100)
RISK_T_Total_Alt	Decimal	yes	Total risk tunnel alternative analysis (0-100)

3 High level influencing factors

3.1 General

High level influencing factors are needed and used to include high level effects on the assessed road infrastructure network and enable to express the expectations of the different stakeholders, which have to be taken into consideration to the highest possible extent. Most of these influencing factors have a general nature and thus they have to be translated or transformed into technical parameters, which can be used within the risk analysis algorithm. From the high level point of view, the following three main areas for such high level influencing factors were defined in X-ARA:

1. Climate change
2. Funding
3. Safety regulations

All three areas can be described by effects on the risk. E.g. the environment will be strongly influenced by the climate change and this will have effects on the functionality of road infrastructure assets like drainage. Thus, the effect on the risk caused by a change in one or more of these three areas has to be included in the context of X-ARA. This will be done by a correlation between the high level influencing factors (areas) and the sensitivity of asset specific parameters and indicators. With regard to the example above, the drainage system will show a higher risk if it is highly sensitive to climate change, which is strongly dependent on the design and the functionality of the system. A well designed drainage system will be able to mitigate the effects caused by climate change in comparison to a system, which is under-designed and/or in poor condition.

Each of these three areas covers, in fact, several influencing factors. For instance, climate change may result in rain fall intensity change (higher vs. lower), or in frost severity and duration (decrease vs. increase), etc. And eventually, all these factors could be quantified in a probabilistic model. However, due to both, the complexity of dealing with a so detailed approach, and the lack of relevant data at local level (region, country), within the X-ARA modelling, each area is considered as a whole and classified into the following 3 categories:

‘P’ Positive impact of high level influencing factor: the influencing factor leads to a reduction of asset specific risks, subject to those factors, which are sensitive to this area.

‘S’ Standard impact of high level influencing factor = standard set for risk analysis: the influencing factor describes a ‘normal’ or ‘expected’ situation.

‘N‘ Negative impact of high level influencing factor: the influencing factor leads to an increase of asset specific risks, subject to those factors, which are sensitive to this area.

A detailed description of the significance of each high level area can be taken from the following chapters. The high level influencing factors are established as sliders (P, S, N) and are related to asset specific attributes, which are describing the sensitivity of different asset specific properties. For the what-if scenarios, these factors can be changed globally and the risk calculation is repeated to show the impact of the altered high level influencing factors on the risk scores on the whole network.

The combination of different settings of the high level influencing factors or areas respectively enables to model different situations for different what-if scenarios. E.g. environment on ‘S’ (standard), economy on ‘N’ (negative) and safety on ‘P’ (positive) defines a possible situation, where new safety regulations under a stressed economy (low maintenance budget) have to be implemented on the road network. Although the new safety regulations improve the safety situation and thus reduce the risk, the efforts increase the risk because of not enough money available for the implementation of the new safety regulations.

Beside the three main influencing factors the sensitivity of a road section within the network has to be taken into consideration, but will not have a similar influence in the context of the what-if-scenarios. This influencing factor will have an impact, when combining the section specific risk to a network-level risk.

3.2 Climate change

Climate change includes all aspects that can be associated with climate change and its consequences for the assessed road infrastructure assets. Climate change cannot be considered as influence factor itself; however the effects of the climate change will of course have consequences for the road network. Expected outcomes of climate change include higher occurrence of periods with heavy rain, more severe winters with more thunderstorms or more heavy storms. On the one hand, most of these issues will lead to an increased risk and the climate change slider in the X-ARA-tool has to be set to ‘N’. On the other hand, a sustainable environmental policy on the high level can offer positive effects and reduce the risk on the assessed road network. For modelling different situations, the following

Table 22 can be used as a basis.

Table 22: Categorisation of climate change high level influencing factor

Category	**Description**
‘P’ (positive)	The positive category should be used to model a situation, where political decision will reduce the negative impacts of the climate change in a sustainable form and measures will be set to minimize the effects.

'S' (standard)	The standard category should be used to model the expected situation, where the climate change will lead to average negative impacts. The models in the X-ARA-tool are including these negative effects.
'N' (negative)	The negative category should be used to model a situation, where the climate change has an above-average effect on the assessed road network. It can be used to model a road network, which is located in a highly sensitive area (costal area, mountainous area, flooding area, etc.)

3.3 Funding

The high-level influencing factor for funding allows investigating the consequences of the question "What happens if there is not enough funding received to continue to do proper maintenance". The extent and intensity of doing maintenance treatments on the different assets is strongly dependent on the available maintenance budget. A reduction of the maintenance budget does not lead directly to a quick deterioration of the asset specific condition, but usually increases the maintenance intervals on both, routine or minor maintenance and capital maintenance. The consequence will be that the residual life will be reduced and the structural condition moves to worse condition classes.
An increase of maintenance budget or efforts has contrary effects, where the maintenance interval will be reduced (optimum time point) and the residual life of the whole structure can be extended. In addition, more long-life-structures can be built because of higher investments at the beginning. For modelling different situations, the following Table 23 can be used as a basis.

Table 23: Categorisation of funding high level influencing factor

Category	**Description**
'P' (positive)	The positive category should be used to model a situation, where high level funding for construction and maintenance is available. It can as well be used to model scenarios, where long-life-structures and solutions will be applied to a high extent.
'S' (standard)	The standard category should be used to model a situation, where enough budgets for investments and maintenance is available to keep the current level and to reach the estimated life spans of the assets.
'N' (negative)	The negative category should be used to model a tense budgetary situation, on both investments and maintenance. The current standard (condition) cannot be kept and the estimated life spans of assets will not be reached because of reduced maintenance activities.

3.4 Safety regulations

Safety regulations as the third high-level influencing factor is necessary to include especially safety related improvements on the road infrastructure assets. This can be the implementation of new safety regulations (e.g. coming from the European Community like the Tunnel Safety Regulations) or the use of new and better materials and equipment, which lead to a safer use of the road infrastructure assets. A reduction of existing safety standards will usually not be possible, but in combination with a reduced maintenance budget the safety area could cause a situation, where only the minimum requirements will be fulfilled and a failure is more probable. For modelling different situations, the following Table 24 can be used as a basis.

Table 24: Categorisation of safety regulations high level influencing factor

Category	Description
'P' (positive)	The positive category should be used to model a situation, where new or improved safety regulations and standards and/or new and better materials and equipment will be applied. It can also be used to incorporate a strategic target in increasing the safety or reducing the number of accidents and fatalities.
'S' (standard)	The standard category should be used to model a situation, where the actual safety regulations and standards are implemented and the safety level can be hold under given preconditions.
'N' (negative)	The negative category should be used to model a tense budgetary situation, which leads of having a minimum safety level on the network to be assessed.

3.5 Network sensitivity

In addition a fourth important influencing factor is related to the importance of a road section within the network. In general, a road (or road section), which is the only connection between two points of interest, has to be treated or maintained earlier as a road (road section), where parallel alternatives are available. Thus, from the network level point of view the risk on such a single connection should be weighted higher in comparison to a road section, where alternatives are available. Especially, for the presentation of risk results on network level, the network sensitivity of the single maintenance sections, has to be taken into consideration.

3.6 Asset specific sensitivity against high level influencing factors

As already mentioned, the first three high level influencing factors will increase or decrease the risk subject to the pre-selected category. The connection between the high level influencing factors and the risk is given by the sensitivity of asset specific properties, which are listed in chapter 2.2. A sensitive property against one of these influencing factors will be taken into consideration directly by a risk factor, which increases or decreases the asset specific risk or indirectly by the change of an asset specific property.

In principle, an asset can be sensitive to one or more of the high influencing factor. Thus, more than one of these risk factors can be used subject to the asset. A calibration of these risk factors and the underlying models will be carried out within the testing phase of the X-ARA-tool during the practical application of the tool as a part of WP4.

4 Risk framework

The risk modelling is the core task of WP2, which is to follow WP1. The risk framework and modelling has to be seen from the road administration point of view in form of a risk on asset performance. Other point of views, like the risk of road users, neighbours, etc. will be incorporated indirectly by adding different weights and sensitivities into the models.

Figure 2 shows the main attributes of the risk framework. The road network itself consists of several maintenance sections. On these sections, the different asset categories are located. These can be network sections with uniform pavement condition, structures like bridges or retaining walls, road furniture, drainage, geotechnical assets and tunnels. The network and the assets are organized in tables, and each element has a certain number of attributes, which are described in detail in chapter 2. The relation between the different tables is shown in Figure 3.

4.1 Basic definitions

The following definitions are used for the prototype risk framework. The relations of the tables are shown in Figure 3.

Network level tables

The basic network elements are visualized in Figure 2

Network	Base table for definition of the network - basis for relationship to other asset specific tables
Cross-Asset risk	Risk table based on network sectioning – the table, that sums up the asset specific risk for each single network section (1:1 relationship to Network)

Asset specific tables

Pavement	Pavement data table for pavement sections (1:n relationship to Network)
Structures	Structures (bridges, retaining walls) data table for structure objects (1:n relationship to Network)
Road furniture	Road furniture data table for road furniture sections (1:n relationship to Network)

Drainage	Drainage data table for drainage sections (1:n relationship to Network)
Geotechnical assets	Geotechnical assets data table for geotechnical assets sections (1:n relationship to Network)
Tunnels	Tunnel data table for tunnel objects (1:n relationship to Network)

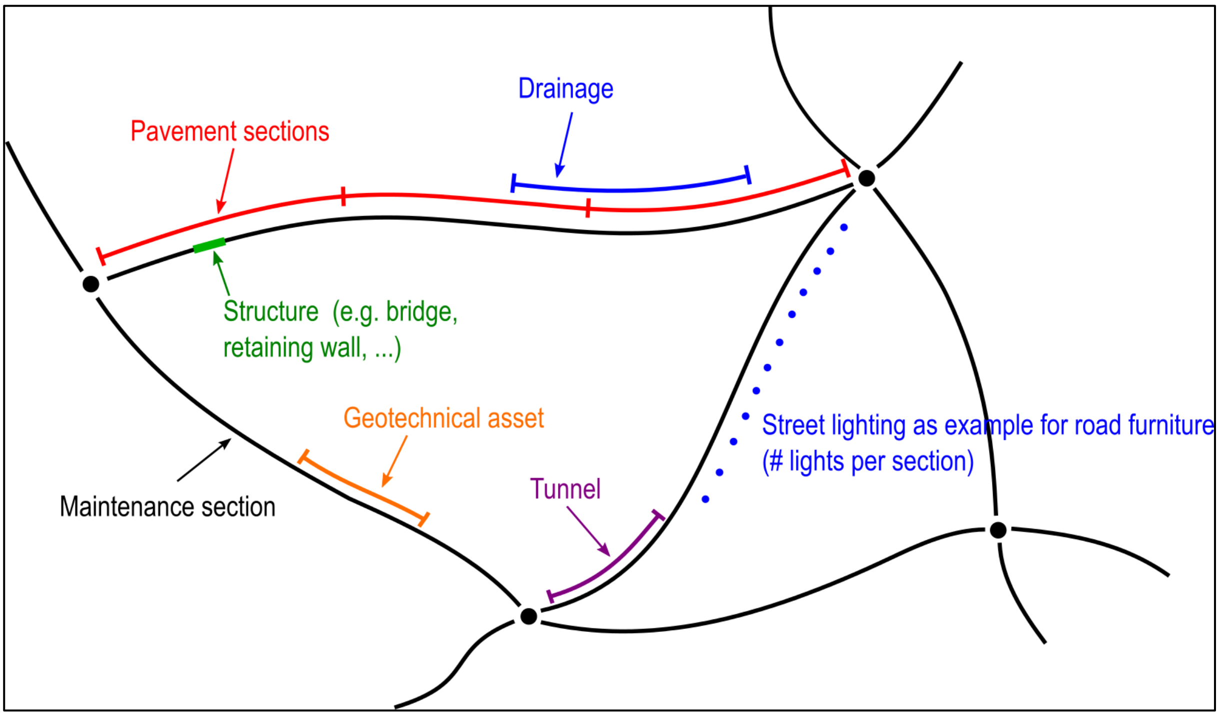


Figure 2: Example of network and asset definitions for the risk tool

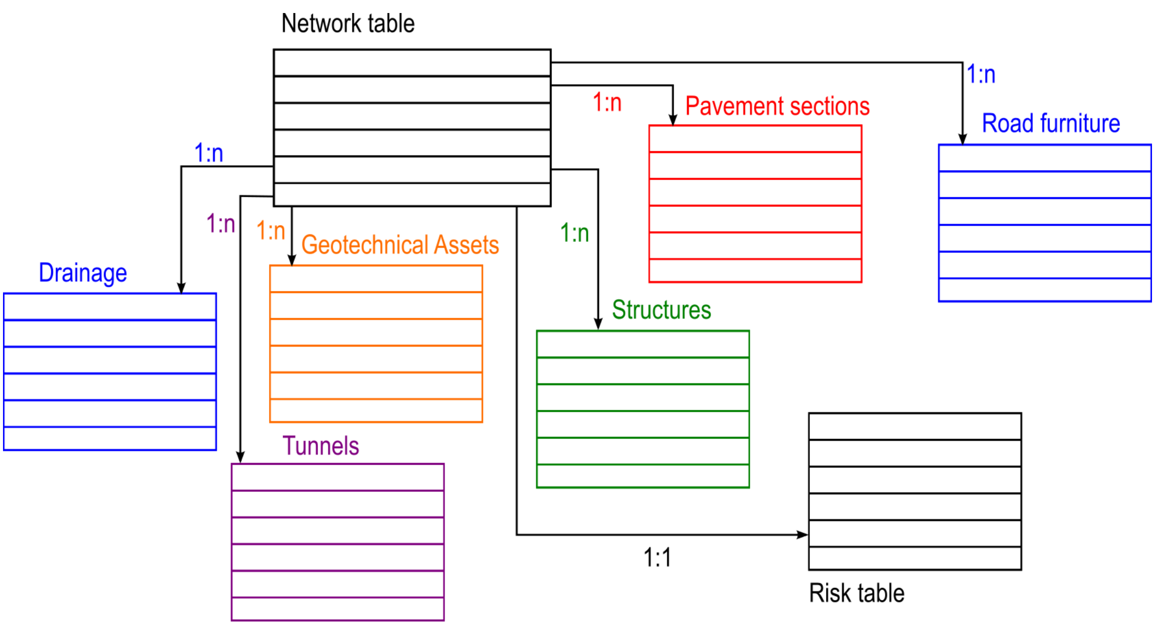


Figure 3: Relationship between tables of network and assets

4.2 Implementation of what-if scenarios

The first three high-level influencing factors described in chapter 3 will be implemented as “sliders”. This will allow changing these factors in three steps (negative – standard – positive). The standard state represents the development of these factors “as expected”, with no large deviations from the standard scenario. The state “negative” represents a negative impact on risk while the state “positive” represents a positive impact on risk. The status of each impact factor is user-selectable.

Certain combinations of sliders states will be integrated to so-called “What-if?--scenarios”. Each scenario will be given an explanatory description. The “What-if?-scenarios” and their descriptions will be developed in the course of WP2.

5 Risk modelling methodology

5.1 Definition of maintenance risk

The basic for the calculation of the risk through the project X-ARA is a unified definition of the maintenance risk. With regard to the general definition of technical risks based on ISO 31000: 2009 (risk management) [7] the maintenance risk in the context of asset management will be defined for X-ARA as follows:

The maintenance risk is a function of distress probability depending on asset condition or age and the consequences (effects) with respect to the affected stakeholders in the context of asset maintenance management.

$$M_{risk} = f(failure\ probability, consequences)$$
$$= f(condition\ or\ age, indicators\ for\ consequences)$$

For the practical application of maintenance risk calculation and assessment different maintenance risk matrixes will be used to assess the risk on asset level (object level) but also on network level. The general definition of the maintenance risk matrix can be taken from the following Figure 4 (general example).

Condition and/or age (5 classes based on COST354)	low	medium	high
1 - very good	20	30	40
2 - good	30	40	50
3 - fair	40	50	60
4 - poor	50	70	80
5 - very poor	60	80	100

Consequences derived from representative indicators

Figure 4: Maintenance risk matrix for X-ARA (general example).

In the context of X-ARA, the failure axis is defined by using a scale with 5 condition classes, which is consistent with the condition scale definition of COST354 [1] and ENR EVITA [3]. The 5 classes are representing the condition of asset specific properties, where class 1 implies a “very good” condition and class 5 implies a “very poor” condition. By using a condition scale, the correlation to the failure probability can be made on a quality level, where no asset specific failure distributions, which are usually not available on network level, are necessary. Thereby, a “very good” condition (class 1) means that the failure probability is low in comparison to a “very poor” (class 5) condition, where the failure probability is usually much higher.

The consequence axis is defined in form of at the least 3 categories (low, medium, high), which are either describing the consequences directly or derived by specific indicators (AADT, design category, availability of spare parts, etc.). In many cases direct consequences cannot be calculated because of missing data or underlying information. Thus, it is recommended to use specific indicators, which can be linked to the extension of effects or consequences respectively.

The combination of both, failure (condition) axis and consequences axis leads to a qualitative risk, which is based in the context of X-ARA on a scale from 0 to 100. In principle, this scale is open and can be defined individually. Nevertheless, to avoid misunderstandings and misinterpretations of the output it should be different to the scales and classifications on both axes. To enable a qualitative assessment of the calculated maintenance risk of X-ARA the scale from 0 to 100 will be subdivided into three qualitative risk categories as follows:

Table 25: Risk classification within X-ARA

Maintenance risk scale	Maintenance risk categories
[0-60)	Low
[60-90)	Medium
[90-100]	High

As already mentioned, the risk considered in X-ARA is the **risk for the road operators** either to lose money (too expensive maintenance, excessive loss in asset valuation, etc.) by applying maintenance strategies, which do not adequately anticipate on high level influencing factors or to provide users (and other stakeholders) with significantly unsatisfying services.

5.2 Consideration of high-level influencing factors

As already mentioned, the high level influencing factors are established as sliders (P, S, N) and are related to asset specific attributes, which are describing the sensitivity of different asset specific properties. For modelling the maintenance risks according to the sensitivity and the influencing factors specific risk factors will be defined. In general, the following mathematical formulation will be used:

$$F_{HLF} = f\left(impact_{HLF}, sensitivity_{HLF}\right)$$

$$M_{risk,HLF} = M_{risk} \times F_{HLF}$$

with

$M_{risk,HLF}$ .... maintenance risk including high level influence
F_{HLF} .... risk factor for high level influence
M_{risk} .... maintenance risk

For the what-if scenarios, the factors can be changed globally and the risk calculation is repeated to show the impact of the altered high level influencing factors on the risk scores on the whole network. The combination of different settings of the high level influencing factors or areas respectively enables to model different situations for different what-if scenarios.

5.3 Asset specific maintenance risk modelling

5.3.1 General

In the following chapters give a comprehensive overview about the maintenance risk modelling and calculation for those assets. The framework can be seen as common denominator over a high number of European national road administrations and leads to the following categorization of road infrastructure assets:

- Pavements [P]
- Structures (bridges, retaining walls, etc.) [S]
- Road furniture (lighting, safety barriers, etc.) [F]
- Drainage [D]
- Geotechnical assets [G]
- Tunnels (including electro-mechanical equipment) [T]

Beside the definition of the asset specific maintenance risks, the calculation procedure of the risk factors, taking into account the sensitivity and the high level impacts will be given as well in the following up chapters.

For a better understanding of the following procedures an example is attached to this deliverable (seen appendix A).

5.3.2 Pavements

Maintenance risk matrixes for pavements

With regard to the data describing the properties of the pavement construction, two condition indices will be used for the failure axes:

- Comfort and safety index (CSI, based on COST354 [1]) to describe the road safety and the riding comfort from the road user point of view
- Structural condition index (SI, based on COST354 [1]) to describe the structural condition of the pavement construction

On the consequence axis the total traffic AADT categorises the effects of maintenance activities to the users as well as to the efforts of the road administrations (higher efforts for maintenance activities on roads with high traffic and lower efforts on roads with lower traffic).

For the two condition indices, which are defining different properties of the pavements the following two maintenance risk matrixes (Figure 5 and Figure 6) will be used:

CSI		AADT class: low	medium	high
	1 - very good	40	50	60
	2 – good	50	60	70
	3 – fair	60	75	80
	4 – poor	80	85	90
	5 - very poor	90	95	100

Figure 5: Maintenance risk matrix pavement CSI

SI		AADT class: low	medium	high
	1 - very good	40	50	60
	2 – good	50	60	70
	3 – fair	60	70	80
	4 – poor	70	80	90
	5 - very poor	80	90	100

Figure 6: Maintenance risk matrix pavement SI

The following Table 26 gives a first idea about the definition of the 3 consequences classes subject to the road category. The road category is related to the CEDR road categorization [8].

Table 26: AADT subject to road category (proposal)

AADT class	CEDR road catgory		
	motorways	expressways	ordinary roads
Low	[0-10000)	[0-5000)	[0-2000)
Medium	[10000-50000)	[5000-25000)	[2000-10000)
High	>=50000	>=25000	>=10000

The combination of both, maintenance risk for CSI and maintenance risk caused for SI will be done by using an advanced maximum criterion, which is described in detail in COST 354 [1]. The advanced maximum criteria guarantees, that the value of the lower risk will be taken into consideration, so that total risk calculations with different lower values will also cause different total risk values. This means, that there will be a difference in the total risk, between two pavement sections, which have different lower values. Thus, an effect on the lower partial risk (e.g. comparing two maintenance treatment strategies) can be seen directly in the total risk subject to portion of significance (at the least 20%, recommendation given in COST

354 [1]). Because of the higher importance of safety issues, the structural component will be reduced by a weight of 0.8, which is in accordance with COST 354 [1]. The expression to calculate the total risk for pavements (without high level influencing factors) is as follows:

$$M_{risk,P} = max(M_{risk,P,CSI}, 0.8 \times M_{risk,P,SI}) + 0.2 \times min(M_{risk,P,CSI}, 0.8 \times M_{risk,P,SI})$$
$$0 \leq M_{risk,P} \leq 100$$

with

$M_{risk,P}$ .... total maintenance risk pavements
$M_{risk,P,CSI}$......... maintenance risk pavements CSI
$M_{risk,P,SI}$ .... maintenance risk pavements SI

Risk factors for pavements

To include high level influencing factors and the sensitivity of the pavements against these factors the following tables (Table 27 and Table 28) for the calculation of the risk factors can be used. For the CSI the safety regulations will be used as the main high level influencing factor, for the SI the funding. The recommendations given in Table 27 and Table 28 will be assessed again during the testing phase, where the effects can be seen by using data from existing road infrastructure assets.

Table 27: Risk factor pavement $F_{HL,CSI}$

Input values		All types of pavement constructions
Sensitivity safety regulation	**Impact safety regulation**	
H	*N*	1.20
M	*N*	1.10
L	*N*	1.05
H, M, L	*S*	1.00
L	*P*	0.95
M	*P*	0.90
H	*P*	0.80

Table 28: Risk factor pavement $F_{HL,SI}$

Input values		Type pavement construction	
Sensitivity funding	**Impact funding**	**Asphalt**	**Cement concrete**
H	*N*	1.20	1.40
M	*N*	1.10	1.20
L	*N*	1.05	1.10
H, M, L	*S*	1.00	1.00
L	*P*	0.95	0.90
M	*P*	0.90	0.80
H	*P*	0.80	0.60

The calculation of the total risks for pavements using these risk factors can be seen in the following expression:

$$M_{risk,P,HL} = max\left(F_{HL,CSI} \times M_{risk,P,CSI}, 0.8 \times F_{HL,SI} \times M_{risk,P,SI}\right)$$
$$+0.2 \times min\left(F_{HL,CSI} \times M_{risk,P,CSI}, F_{HL,SI} \times 0.8 \times M_{risk,P,SI}\right)$$
$$0 \leq M_{risk,P,HL} \leq 100$$

with

$M_{risk,P,HL}$ .... total maintenance risk pavements including high level influences
$M_{risk,P,CSI}$......... maintenance risk pavements CSI
$M_{risk,P,SI}$ .... maintenance risk pavements SI
$F_{HL,CSI}$ .... risk factor for high level influence for CSI
$F_{HL,SI}$.............. risk factor for high level influence for SI

5.3.3 Structures

Maintenance risk matrixes for structures

With regard to the definition of the risk calculation procedure for pavements a similar approach for structures was selected, which is based in principle on the British standard BE11/94 [9] for bridge inspections. For the two failure axes the following 2 indicators will be used:

- Structure condition index (SCI) to describe the total condition of the structure (British scale from 0 to 10, transformed to a scale from 1 to 5 subject to COST354 [1])
- Extent of defects (SED) (British classification from A to D, transformed to a scale from 1 to 5 subject to COST354 [1])

For the consequence axis of both risk matrixes the severity of defects according to British standard BE11/94 [9] has been selected to describe the effects on maintenance actions.

For the two indices, the following two maintenance risk matrixes (Figure 5 and Figure 6) will be used:

SCI	1 – no significant defects or minor defects of non urgent nature	2 – defects to be included within the next maintenance program	3 – defects, where urgent action is needed
1 - very good	20	50	80
2 – good	30	60	85
3 – fair	40	70	90
4 – poor	50	80	95
5 - very poor	60	90	100

Severity of defects

Figure 7: Maintenance risk matrix structures SCI.

SED	1 – no significant defects or minor defects of non urgent nature	2 – defects to be included within the next maintenance program	3 – defects, where urgent action is needed
1 – no significant defects	10	10	10
2 – slight, not more than 5% of length or area affected	20	60	60
3 – moderate, between 5 and 10% of length or area affected	30	70	90
4 – high, between 10 and 20% of length or area affected	40	80	95
5 - very high, more than 20% of length or area affected	60	90	100

Severity of defects

Figure 8: Maintenance risk matrix structures SED.

The combination of both, maintenance risk for condition (SCI) and the maintenance risk derived from the extent of defects will be done by using a maximum criterion as follows. A normal maximum criterion is possible, because condition and extent of defects are dependent indicators.

$$M_{risk,S} = max\left(M_{risk,S,SCI}, M_{risk,S,SED}\right)$$

$$0 \leq M_{risk,S} \leq 100$$

with

$M_{risk,S}$ .... total maintenance risk structures
$M_{risk,S,SCI}$......... maintenance risk structures SCI
$M_{risk,S,SED}$........ maintenance risk structures SED

Risk factors for structures

To include high level influencing factors and the sensitivity of structures against these factors the following Table 29 for the calculation of the risk factor can be used. For the total risk on structures the funding will be used as the main high level influencing factor.

Table 29: Risk factor structure $F_{HL,S}$

Input values		Material structure	
Sensitivity funding	**Impact funding**	**Cement concrete**	**All others**
H	*N*	1.20	1.40
M	*N*	1.10	1.20
L	*N*	1.05	1.10
H, M, L	*S*	1.00	1.00
L	*P*	0.95	0.90
M	*P*	0.90	0.80
H	*P*	0.80	0.60

The calculation of the risks for drainage using these risk factors can be seen in the following expression:

$$M_{risk,S,HL} = F_{HL,S} \times M_{risk,S}$$

$$0 \leq M_{risk,S,HL} \leq 100$$

with

$M_{risk,S}$ .... total maintenance risk structures
$F_{HL,S}$............... risk factor for high level influence for structures

5.3.4 Road furniture

Maintenance risk matrix for road furniture

Road furniture covers different types of assets, e.g. street lighting, traffic signs, gantries etc. Because of the different natures of different types of road furniture the following approach is a general recommendation, which can be adapted or extended to the specific preconditions of different types of road furniture. In addition, the Consortium decided to include road furniture from the completeness point of view.

For the condition of road furniture no common agreed condition indicator exists, thus the unified scale from COST354 [1] will be used to describe the condition of road furniture.

With regard to the data describing the properties of the road furniture a road furniture condition index (RFCI), which was defined in the British ILP TR22 guidance [10] (as an adequate example), will be used for the failure axis. On the consequence axis three consequences category (low, medium, high), which are also based on TR22 [10], define directly the effect on the users. The following maintenance risk matrix (Figure 9) for road furniture will be used in the X-ARA project:

RFCI	Low	Medium	high
1 - very good	40	50	70
2 – good	50	65	80
3 – fair	60	75	90
4 – poor	70	90	95
5 - very poor	80	95	100

Consequences of failure

Figure 9: Maintenance risk matrix road furniture

Risk factor for road furniture

As the main high level influencing factors for road furniture the safety regulations were identified, thus the sensitivity of the road furniture against safety regulation impacts leads to an increase or decrease of the calculated risk. In the following Table 30 the risk factors for road furniture are being presented:

Table 30: Risk factor road furniture $F_{HL,RFCI}$

Sensitivity safety regulations	Effect safety regulations		
	P	*S*	*N*
L	1.0	1.0	1.1
M	1.0	1.0	1.4
H	0.9	1.0	1.8

The calculation of the risks for road furniture using these risk factors can be seen in the following expression:

$$M_{risk,F,HL} = F_{HL,RFCI} \times M_{risk,F,RFCI}$$

$$0 \leq M_{risk,RFCI,HL} \leq 100$$

with

$M_{risk,F,HL}$.......... maintenance risk road furniture including high level influences
$M_{risk,F,RFCI}$ .... maintenance risk road furniture RFCI
$F_{HL,RFCI}$........... risk factor for high level influence for RFCI

5.3.5 Drainage

Maintenance risk matrix for drainage

With regard to the data describing the properties of the drainage the drainage condition index, which was defined in the EVITA project [3], will be used for the failure axis. On the consequence axis design category of the drainage, which was defined in the EVITA project [3] as well, defines the effects on flooding events if a drainage system is under, well or over-designed. The following maintenance risk matrix (Figure 10) for the drainage system will be used in the X-ARA project:

DCI \ Design category	o-over	w-well	u-under
1 - very good	40	50	60
2 – good	50	60	70
3 – fair	60	70	80
4 – poor	70	80	90
5 - very poor	80	90	100

Figure 10: Maintenance risk matrix drainage

Risk factor for drainage

As the main high level influencing factors for drainage system the climate change was identified, thus the sensitivity of the drainage system against climate change impacts leads to an increase or decrease of the calculated risk. In the following Table 31 the risk factors for drainage are being presented:

Table 31: Risk factor drainage $F_{HL,DCI}$

Sensitivity climate change	Effect climate change		
	P	*S*	*N*
L	1.00	1.00	1.00
M	0.90	1.00	1.20
H	0.80	1.00	1.40

The calculation of the risks for drainage using these risk factors can be seen in the following expression:

$$M_{risk,D,HL} = F_{HL,DCI} \times M_{risk,D,DCI}$$

$$0 \leq M_{risk,D,HL} \leq 100$$

with

$M_{risk,D,HL}$ .... maintenance risk drainage including high level influences
$M_{risk,D,DCI}$ .... maintenance risk drainage DCI
$F_{HL,DCI}$ .... risk factor for high level influence for DCI

5.3.6 Geotechnical assets

Maintenance risk matrix for geotechnical assets

The definition of geotechnical asset is taken from [4]: “The term 'geotechnical asset' refers to all earthworks (cuttings and embankments) and ground underlying highway”. In principle, the method presented in X-ARA can be extended to other geotechnical assets, but will be limited to cuttings and embankments in this project. With regard to COST 354 [1] a condition scale of 5 condition classes of the geotechnical condition index (GCI) will be recommended for this type of assets as well. GCI is based on the condition assessment procedures used in Highways Agency Drainage Data Management System (HADDMS) [5]. On the consequence axis three consequences category (low, medium, high), which are related to the sensitivity against erosion will be used and lead to the following risk matrix.

GCI	Low	Medium	High
1 - very good	10	20	30
2 – good	50	50	50
3 – fair	60	70	80
4 – poor	70	80	90
5 - very poor	80	90	100

Sensitivity against erosion

Figure 11: Maintenance risk matrix geotechnical assets

Risk factor for geotechnical assets

As the main high level influencing factors for geotechnical assets the climate change was identified, thus the sensitivity of the geotechnical assets against climate change impacts leads to an increase or decrease of the calculated risk. In the following Table 32 the risk factors for geotechnical assets are being presented:

Table 32: Risk factor geotechnical assets $F_{HL,GCI}$

Sensitivity climate change	**Effect climate change**		
	P	*S*	*N*
L	1.00	1.00	1.00
M	0.90	1.00	1.20
H	0.80	1.00	1.40

The calculation of the risks for geotechnical assets using these risk factors can be seen in the following expression:

$$M_{risk,G,HL} = F_{HL,GCI} \times M_{risk,G,GCI}$$
$$0 \leq M_{risk,G,HL} \leq 100$$

with

$M_{risk,G,HL}$ .... maintenance risk geotechnical assets including high level influences
$M_{risk,G,GCI}$ .... maintenance risk geotechnical assets GCI
$F_{HL,GCI}$ .... risk factor for high level influence for GCI

5.3.7 Tunnels

Maintenance risk matrix for tunnels

Tunnels and long underpasses are sensitive elements of the road infrastructure. Especially the functionality of the electro-mechanical equipment is an important risk factor in the context of asset management (especially safety) and thus needs to be assessed beside the structural condition of the tunnel itself (constructive elements of the tube).

With regard to the data describing the properties of tunnels, the following information, which are based on the Austrian tunnel standard RVS 13.03.31 [11] and RVS 13.03.41 [12] will be used for the failure axis:

- Tunnel condition index TCI to describe the condition of the tunnel structure
- Age of electro-mechanical equipment to describe the condition of the tunnel equipment

The risk assessment of the tunnel structure can be carried out in a similar way as the structures, where the TCI on the failure axis and the severity of defects on the consequence axis will be used (see Figure 12).

TCI	1 – no significant defects or minor defects of non-urgent nature	2 – defects to be included within the next maintenance program	3 – defects, where urgent action is needed
1 - very good	20	50	80
2 – good	30	60	85
3 – fair	40	70	90
4 – poor	50	80	95
5 - very poor	60	90	100

Severity of defects

Figure 12: Maintenance risk matrix tunnel TCI.

Because of the complexity, the condition of electro-mechanical assets in tunnels will not be described by standardized condition indices. Furthermore, the condition of this equipment is related to the functionality or to the number of fails within a given time period. Both aspects are usually strongly related to the age of the equipment. Thus, it is possible to use the age instead of a condition index.

On the consequence axis the availability of spare parts is the indicator, which has the highest impact on the effects, especially to the tunnel operator. The axis will be sub-divided into three categories of spare parts availability. The following maintenance risk matrix (Figure 13) for tunnel will be used in the X-ARA project:

AGE_{FM}	low	medium	high
1 – new < 2 years	40	50	60
2 – young, between 2 and 5 years	50	60	70
3 – medium between 5 and 10 years	60	70	80
4 – old, between 10 and 15 years	70	80	90
5 - very old >15 years	80	90	100

Availability of spare parts

Figure 13: Maintenance risk matrix tunnels AGE_{EM}

The combination of both, maintenance risk for TCI and maintenance risk caused by AGE_{EM} will be done by using an advanced maximum criterion, which is described in detail in COST 354 [1]. The advanced maximum criteria guarantees also for tunnels, that the value of the lower risk will be taken into consideration, so that total risk calculations with different lower values will also cause different total risk values. The expression to calculate the total risk for tunnels (without high level influencing factors) is as follows:

$$M_{risk,T} = max\left(M_{risk,T,TCI}, M_{risk,T,AGEEM}\right) + 0.2 \times min\left(M_{risk,T,TCI}, M_{risk,T,AGEEM}\right)$$

$$0 \leq M_{risk,T} \leq 100$$

with

$M_{risk,T}$ .... total maintenance risk tunnels
$M_{risk,T,TCI}$ .... maintenance risk tunnels TCI
$M_{risk,T,AGEEM}$ .... maintenance risk tunnels AGE_{EM}

Risk factor for tunnels

As the main high level influencing factors for tunnels the safety regulations were identified, thus the sensitivity of the tunnels against safety regulation impacts leads to an increase or decrease of the calculated risk. In the following Table 33 the risk factors for tunnels are being presented:

Table 33: Risk factor tunnels $F_{HL,T}$

Sensitivity safety regulations	Effect safety regulations		
	P	*S*	*N*
L	1.0	1.0	1.0
M	0.9	1.0	1.2
H	0.8	1.0	1.4

The calculation of the risks for tunnels using these risk factors can be seen in the following expression:

$$M_{risk,T,HL} = F_{HL,T} \times M_{risk,T}$$

$$0 \leq M_{risk,T,HL} \leq 100$$

with

$M_{risk,T,HL}$.......... maintenance risk tunnels including high level influences
$M_{risk,T}$ .... maintenance risk tunnels
$F_{HL,T}$............... risk factor for high level influence for tunnels

5.4 Combination of asset specific risk to total risk

5.4.1 Transformation of asset specific risk onto maintenance sections

As already described, total risk calculation over all types of assets and sub-assets works is based on maintenance sections. A maintenance section can be defined as a section of the road network that has in general homogeneous conditions (number of lanes, traffic load, sensitivities against different high level influencing factors, etc.). Usually, the maintenance sections will be links between nodes, where the nodes are (main) intersections. Nevertheless, the definition of such maintenance sections (level 1 sectioning) is up to the road administrations and the homogeneous conditions.

To calculate cross asset risk and finally a total risk it is necessary to transform the asset specific risks (from level 2 sectioning or pointing) onto the longer maintenance sections (level 1 sectioning). For this purpose, there has to be defined different transformation routines according to the type of the asset. In the context of X-ARA the transformation of data and results from level 2 sectioning onto the maintenance sections (level 1 sectioning) will be carried out using the length weighted average.

5.4.2 Calculation of total risk on maintenance section (level 1)

Once the asset specific risk is transformed from the level 2 sectioning onto the maintenance section (level 1 section), the total risk as a combination of the asset specific risk can be calculated.

For the calculation of the total cross asset risk the significance of the asset has to be taken in consideration in form of different weighting factors. This significance or importance of different assets can be different for different types of road and their surrounding area. Especially the number of different types of assets is different in different regions. A high percentage of structures can be found in mountainous areas as well as in urban areas, where the distance between intersections leads often to a complex road infrastructure in comparison to roads, which are crossing flat regions. Thus, the weighting factors needs to be related to the regional situation.

The following expression shows the combination of asset specific risk into a total (cross asset) risk. In the following up Table 34 the different weighting factors are shown for the 3 different road categories.

$$M_{risk,total} = \frac{\sum_i M_{risk,i} \times G_i}{\sum_i G_i}$$

with

$M_{risk,total}$ .... total (cross asset) maintenance risk
$M_{risk,i}$ .... maintenance risk of asset type i
G_i................... weight asset type i (see Table 34)

Table 34: Typical weights asset types

Asset type	**Regional situation**		
	Flat area	**Mountain**	**Urban**
Pavement	30	35	35
Drainage	10	5	5
Tunnel	15	15	15
Structures	25	30	35
Road furniture	10	5	5
Geotechnical assets	10	10	5
Sum	100	100	100

In case of maintenance sections, where a specific asset type is not existing, the weights has to be changed in such a way, that the relation of the weights between the existing asset types remain the same and the total sum of all used weights equals to 100. E.g. in case of existing pavements and bridges only on a motorway maintenance section, the weight for the pavements will change from 30 to 54.54 and for the structures from 25 to 45.45. The following expression enables to calculate the factor, which changes the weight for all asset types, which are existing on a maintenance section:

$$F_G = \frac{\sum_i G_i}{\sum_i G_i \times X_i}$$

with

F_G .... factor weights
G_i .... weight asset type i
X_i .... 1 if asset type i is existing on maintenance section; 0 of asset type i is not existing on maintenance section

The total (cross asset) risk including high level influences will be calculated based on the following expression (summation over i, where i includes only the assets that exist on that section):

$$M_{risk,total,HL} = \frac{\sum_i M_{risk,i,HL} \times F_G \times G_i}{\sum_i F_G \times G_i}$$

with

$M_{risk,total,HL}$ .... total (cross asset) maintenance including high level influence
$M_{risk,i,HL}$ .... maintenance risk of asset type i including high level influence
G_i .... weight asset type i (see Table 34)
F_G .... factor weights

5.4.3 Calculation of total risk on network level

To get an overview of the whole network (network level) it is necessary to combine the maintenance section specific total risk to network level values. This can be either the sum of length of maintenance section in a certain risk category or a length weighted average over all maintenance section.

As described in the high level influencing factor the maintenance sections have a specific sensitivity from the network level point of view. Thus, it is possible to take this sensitivity into consideration in the context of total risk calculation on network level. The following Table 35 can be used as basis for the definition of an additional weight against the network sensitivity.

Table 35: Network level weighting factor F_{NL}

Network sensitivity	Regional situation		
	Flat area	Mountain	Urban
L	1.00	1.00	1.00
M	1.10	1.20	1.20
H	1.20	1.40	1.40

For the calculation of a total risk distribution over the whole network or an average total risk the network level weighting factor should be taken into consideration. The weight of a single maintenance section i can be calculated as follows:

$$W_i = \frac{Length_i \times F_{NL,i}}{\sum_i Length_i \times F_{NL,i}}$$

with

W_i .... weight of maintenance section i for network level assessment
$Length_i$ .... length of maintenance section i
$F_{NL,i}$................ network level weighting factor of maintenance section i

6 Results

6.1 Risk quality

The results of calculation procedure represent the risk quality in 3 different categories and not as an absolute number. As already described in chapter 5.1 the risk scale from 0 to 100 will be subdivided into three qualitative risk categories as follows:

Table 36: Risk classification within X-ARA

Maintenance risk scale	Maintenance risk categories
[0-60)	Low
[60-90)	Medium
[90-100]	High

6.2 Type of results

Based on this classification the results can be prepared for different purposes and for different end-users (technician, manager, policy or decision maker). Independently from the group of users, the results can be categorized as follows:

- Maintenance section specific results:
  - Risk tables of asset specific risk
  - Risk tables of total (cross asset) risk
  - Risk maps of asset specific risk
  - Risk maps of total (cross asset) risk (example, see Figure 14)

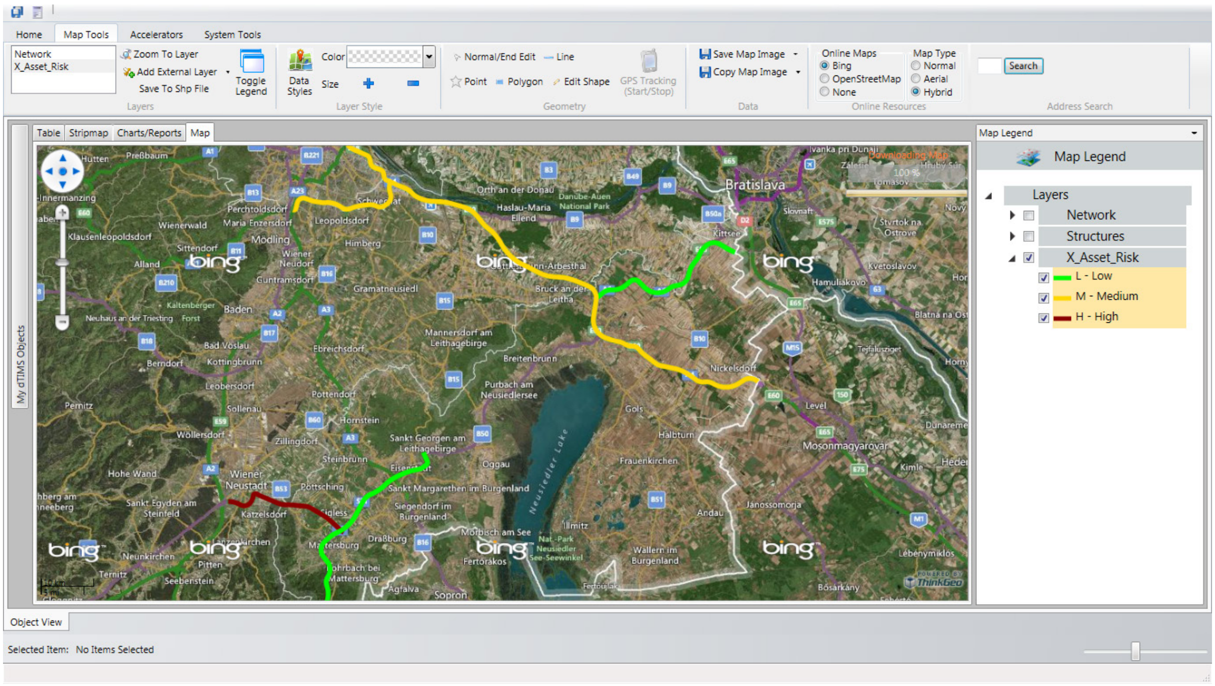
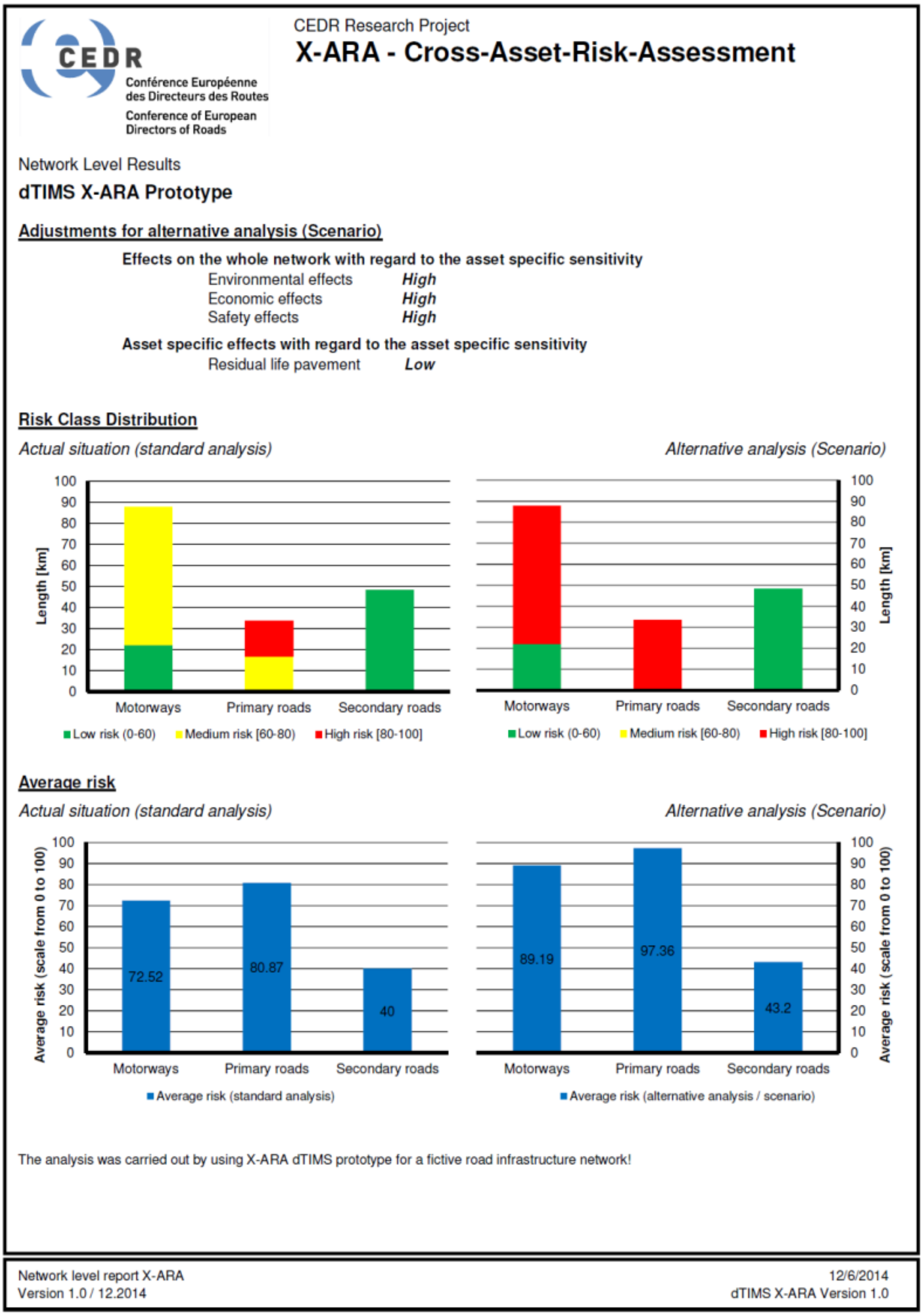


Figure 14: Map with maintenance section risk quality (dTIMS X-ARA-prototype).

- Network level results:
    - Risk class distribution of asset specific risk
    - Risk class distribution of total (cross asset) risk (see Figure 15)
    - Average risk of asset specific risk
    - Average risk of total (cross asset) risk (see Figure 15)


CEDR Research Project

X-ARA - Cross-Asset-Risk-Assessment

Network Level Results

dTIMS X-ARA Prototype

Adjustments for alternative analysis (Scenario)

Effects on the whole network with regard to the asset specific sensitivity

Environmental effects	High
Economic effects	High
Safety effects	High

Asset specific effects with regard to the asset specific sensitivity

Residual life pavement	Low

Risk Class Distribution

Average risk

The analysis was carried out by using X-ARA dTIMS prototype for a fictive road infrastructure network!

Network level report X-ARA
Version 1.0 / 12.2014

12/6/2014
dTIMS X-ARA Version 1.0

Figure 15: Network level risk reporting (dTIMS X-ARA-prototype).

7 X-ARA-prototype

The input data framework, the high level influencing factors, the risk framework and of course the whole risk modelling methodology was implemented into the commercial asset management tool dTIMS™ (version 9.0) to generate a prototype for testing and for quality control of the planned X-ARA tool. dTIMS™ is an open asset management decision support tool, which enables the user to define the database structure as well as calculation procedures individually. Thus, this software was selected to define the X-ARA prototype. For the implementation of the models the following tasks have been carried out in dTIMS™:

- Definition of database structure subject to the input data framework
- Import of prototype data
- Implementation of risk matrixes
- Implementation of calculation procedures
- Definition of reports

The following screenshots give an overview of the dTIMS X-ARA prototype.

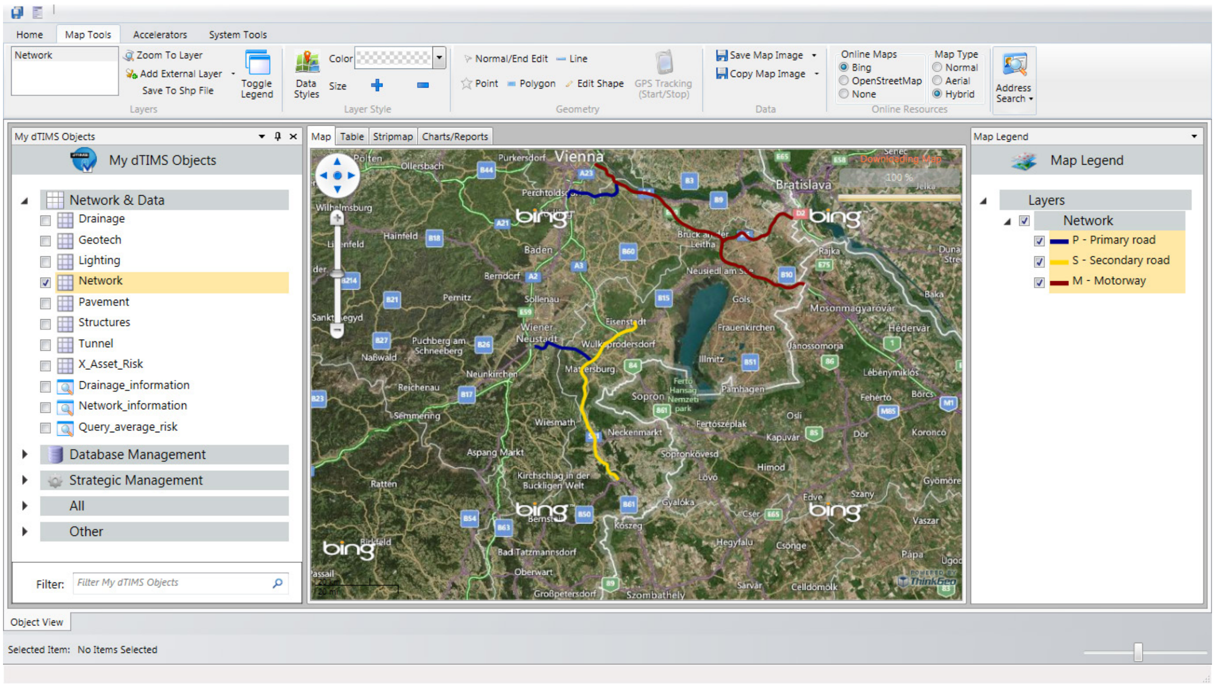


Figure 16: Database structure (dTIMS X-ARA-prototype).

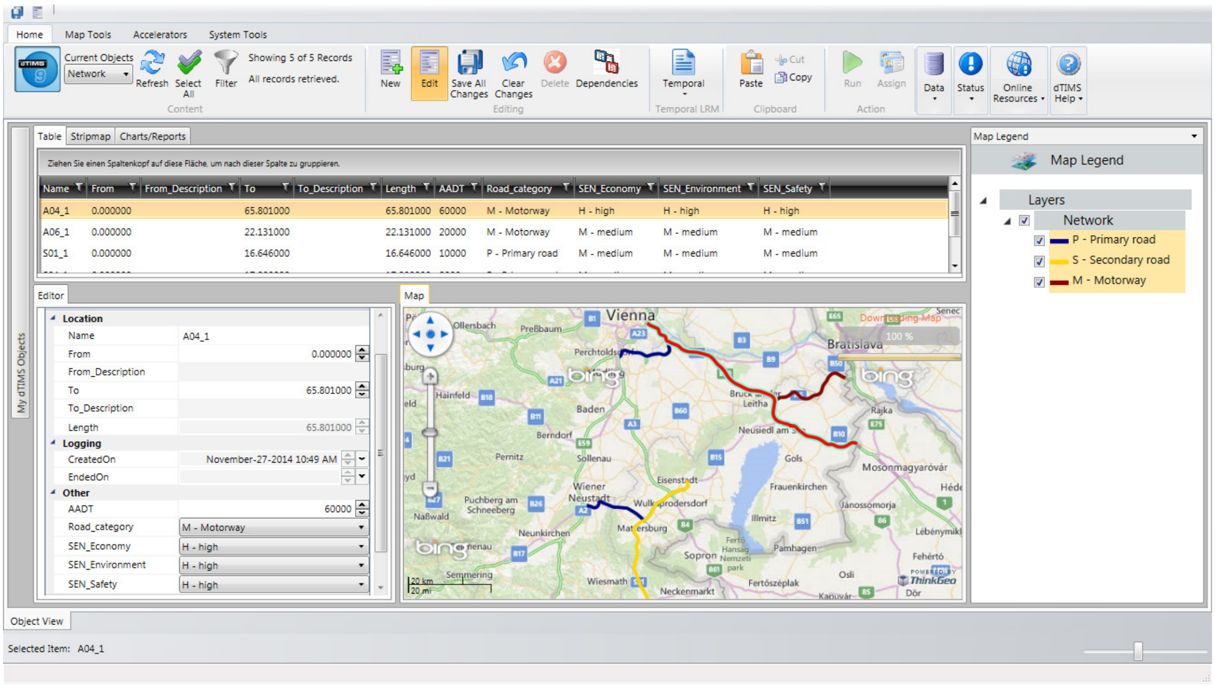


Figure 17: Data management (dTIMS X-ARA-prototype).

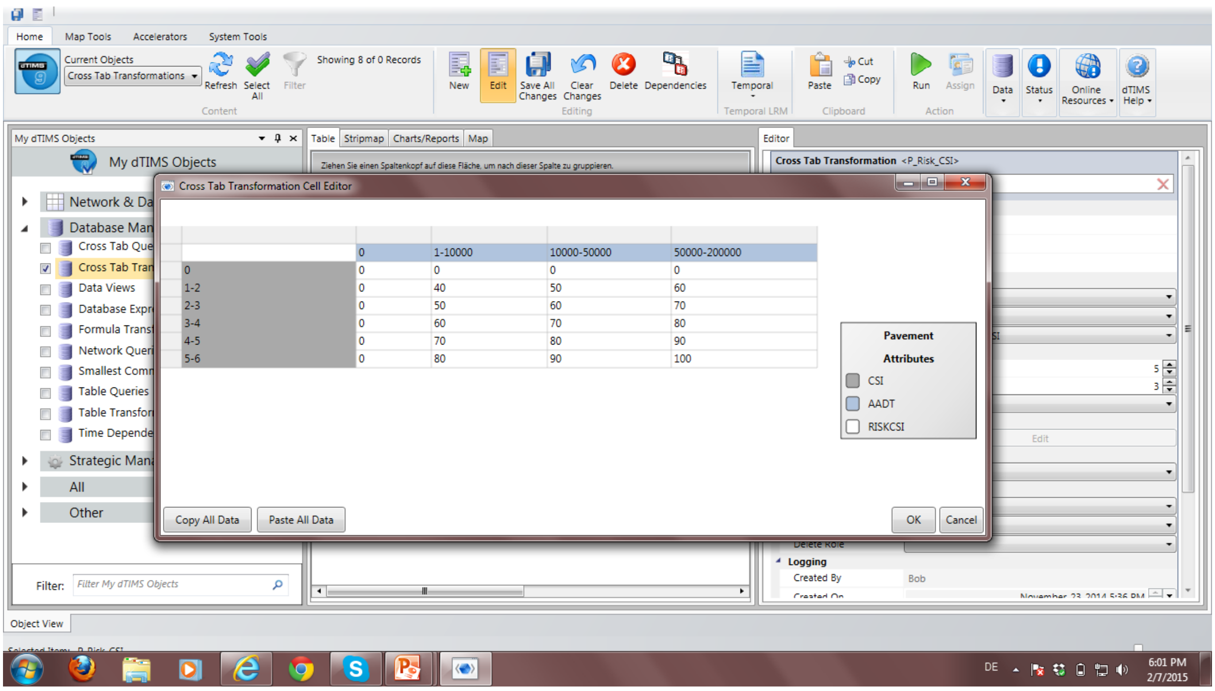


Figure 18: Risk modelling (dTIMS X-ARA-prototype).

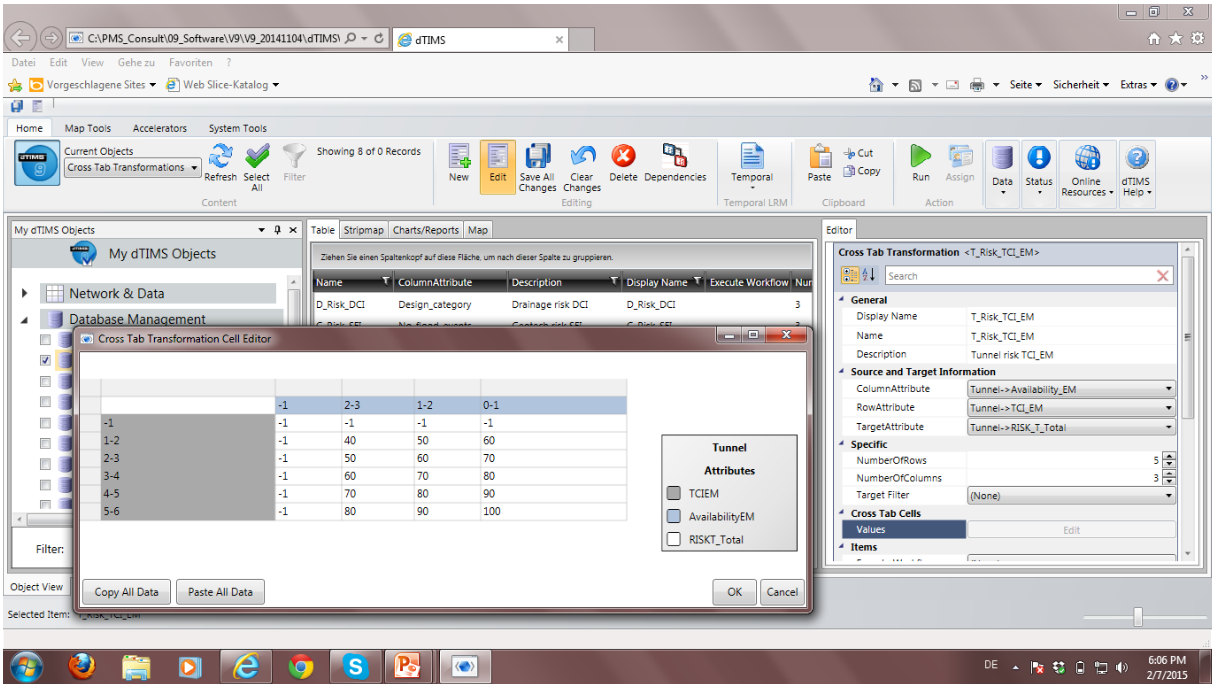


Figure 19: Risk modelling (dTIMS X-ARA-prototype)

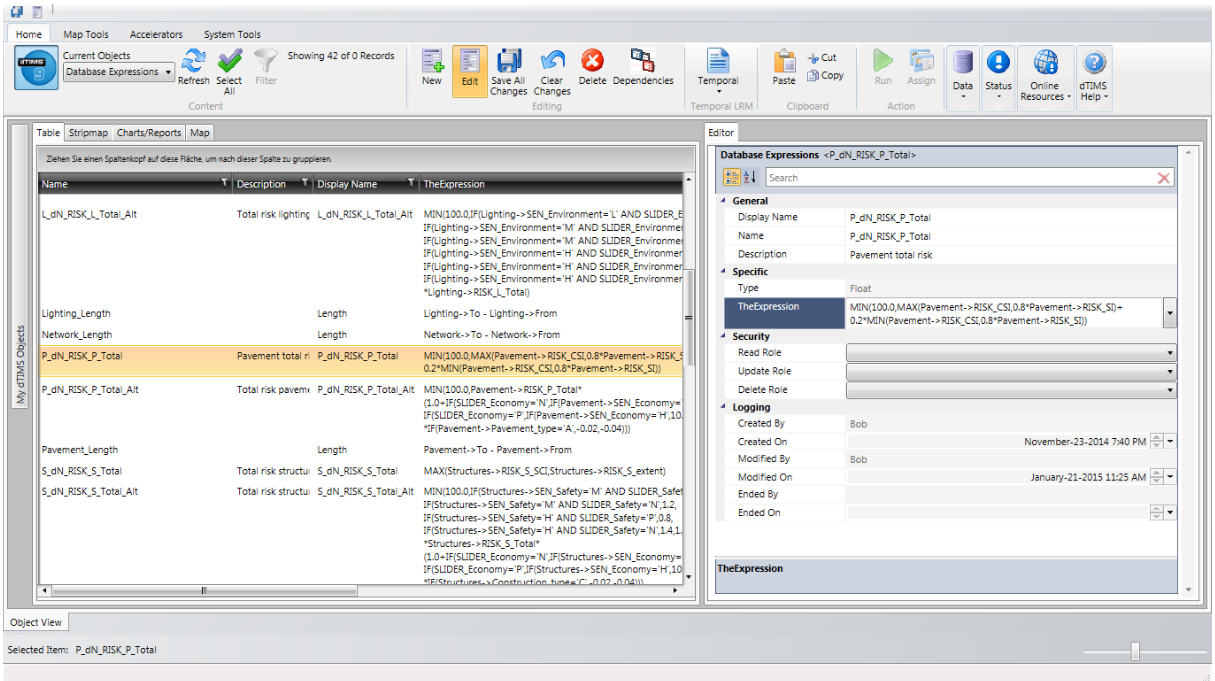


Figure 20: Risk modelling (dTIMS X-ARA-prototype)

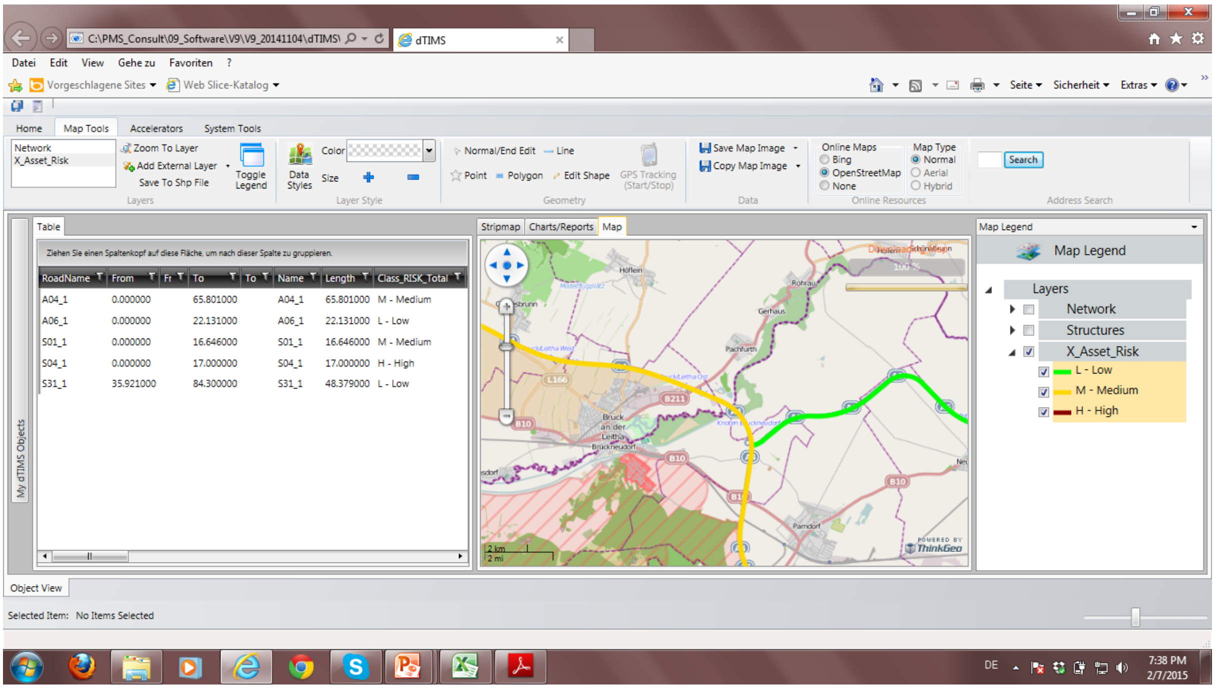


Figure 21: Results (dTIMS X-ARA-prototype)

8 Discussion and Outlook

During work on the desk study in WP1 it was found that the basic idea of the X-ARA approach has not been fully implemented at any road operator investigated. Most of the current asset management implementations are still driven by the condition of the assets. The addition of consequences and hence the calculation of risk have shown to be valuable extensions of the current practice. A first step towards this is the qualitative evaluation of the current risk and its distribution over the network. This was the main input for the development of the risk framework and the risk modelling methodology described in this document and is in consensus with the project-ideas and objectives of X-ARA, described in the underlying project proposal.

In the course of the work done that led to this report, the approach as described in the proposal has been refined and several definitions have been made for the implementation. The basic approach as presented in the proposal, has not been altered.

The risk framework elements have been specified in the course of WP1. The risk tool will be able to work with pavements, structures (bridges, and retaining walls), road furniture, drainage, geotechnical assets and tunnels. These are considered as main elements of the road and most maintenance costs are related to these assets.

The network definition is based on maintenance sections, which allows a flexible use and easy integration of existing road network databases.

For all asset classes, condition indicators have been defined. These were taken from literature (drainage condition from the EVITA project, pavement condition from COST 354) or best practice (street lighting condition from a recent motorway project in the UK).

For all asset classes, the sensitivity to high level influencing factors has to be determined and given as attribute to each asset. This provides the availability to adjust to the specific location and is a generic approach. The sensitivity to climate change e.g. would be high for locations that are vulnerable to landslides. The risk is then calculated for each asset using a risk matrix. The tweaking of the risk matrices to ensure that the calculation will lead to meaningful risk values was one of the main tasks of WP2.

The determination of the cumulated risk value per section uses transformation laws depending of the type of asset. Again, which type of transformation law will be used was subject to study in WP2.

It is important to state that the definition of the high-level influencing factors is preliminary. The practicability of the influencing factors was evaluated during the development phase in WP2 and the factors will be adjusted if necessary in the context of the practical application.

The next steps were the implementation of a prototype in commercial asset management software. The software "dTIMS" was used for this. In this prototype, the risk matrices and the weighting functions were studied and adjusted. The transformation laws could be verified and adjusted if necessary. After the prototype is working satisfactorily, the implementation of the tool will start in WP3.

A calibration of the risk factors and the underlying models will be carried out within the testing phase of the X-ARA-tool prototype in WP2 and during the practical application of the tool as a part of WP4.

9 Acknowledgement

The research presented in this report/paper/deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2013. The funding for the research was provided by the national road administrations of Denmark, Germany, Ireland, Netherlands, UK and Slovenia.

10 References

[1] La Torre, F. et. al., COST 354 WP 2 "Selection and assessment of individual performance indicators" – Report, 2007

[2] ESRI Shapefile Technical Description, http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf, retrieved 2014-11-06

[3] EVITA - Effective asset management, Deliverable D3.1- Report on recommended E-KPIs; August 2012

[4] Mian, J.F., Whittlestone, A.P., Patterson, D., and Rudrum, D.M. "A Risk-Based Approach for the Assessment and Management of Infrastructure Assets", Proceedings of the Asset Management Conference 2011, IET and IAM, 2011

[5] Highways Agency, “Highways Agency standards Volume 1”, SD15/03 and HD43/04.

[6] Highways Agency, “BE11/94 - Volume 3 Highway Structures: Inspection and Maintenance, Section 1 Inspection Part 4”, BD 63/07

[7] ISO 31000: 2009. Risk management. ISO standard, 2009

[8] CEDR road categorization

[9] BE11/94 Bridge inspection standard

[10] Institute of Lighting Professionals. ILP TR22, visual condition guidance, UK, 2012

[11] RVS 13.03.41 – Strassentunnel – Baulich Konstruktive Teile (Road tunnel – constructive elements). FSV, Austrian road research association, Vienna 2013

[12] RVS 13.03.41 – Strassentunnel – Betriebs- und Sicherheitseinrichtungen (Road tunnel – operational and safety equipment). FSV, Austrian road research association, Vienna 2014

11 Appendix – Example of risk calculation

The following example gives an overview about the practical application of the procedures and expressions, which are presented and described in this deliverable. It should help to understand the process of risk assessment and calculation defined in the project X-ARA.

General workflow

The following Figure 22 shows the general workflow of the X-ARA tool. The example focuses on the risk calculation and starts with a given network and asset definition.

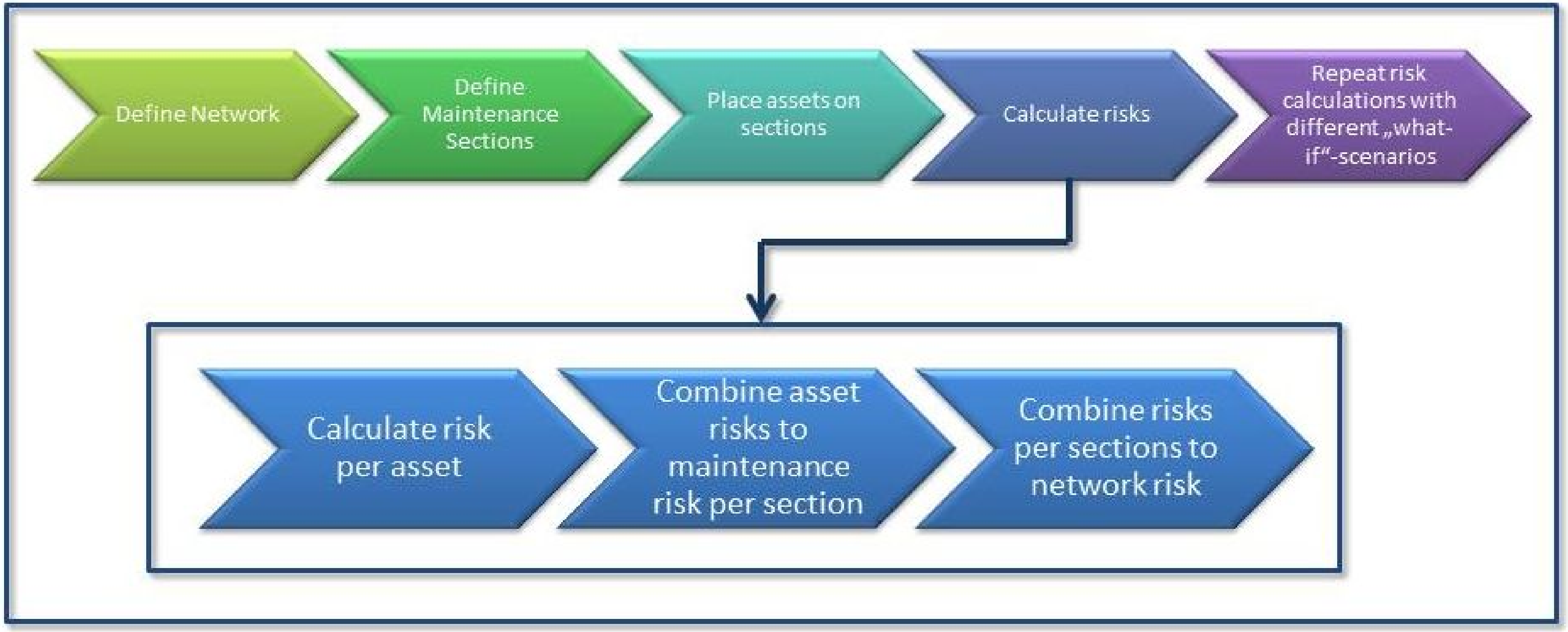


Figure 22: General workflow of the X-ARA tool and workflow of risk calculation

Road network definition and maintenance sections

The example is based on a simplified road network, which consists of 2 roads (A10 and B07) and is subdivided into 3 maintenance sections. The first maintenance section on A10 is an urban expressway, the second part of A10 is a motorway and the B07 is an ordinary road with a quite low traffic volume in a mountainous region. The following Table 37 gives an overview about the network including the sensitivities of the 3 maintenance sections with subject to the high level influencing areas (see chapter 3). Figure 23 shows a graphic overview of the network and its maintenance sections.

Table 37: Maintenance sections and network definition

Input Data for Maintenance Sections												
Section	Road Name	From km	To km	Length [km]	AADT [veh/day]	PHGV [%]	Road category	Sensivity climate	Sensivity funding	Sensivity safety	Sensivity network	Regional situation
M1	A10	0,00	15,00	15,00	23.000	12	E	L	H	M	H	Urban
M2	A10	15,00	22,00	7,00	52.000	9	M	L	H	H	H	Flat
M3	B07	0,00	12,00	12,00	5.000	8	O	H	L	L	M	Mountain

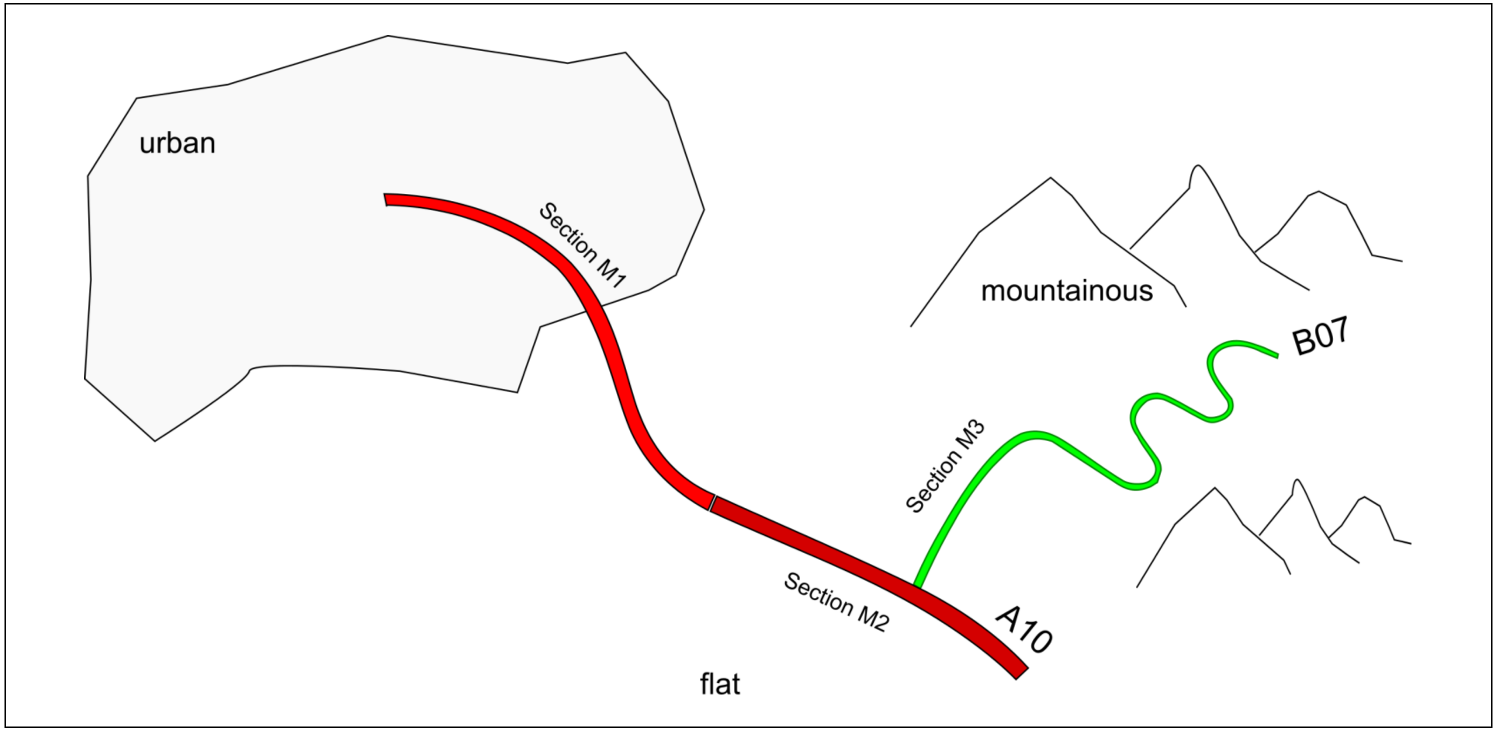


Figure 23: Network and maintenance sections overview

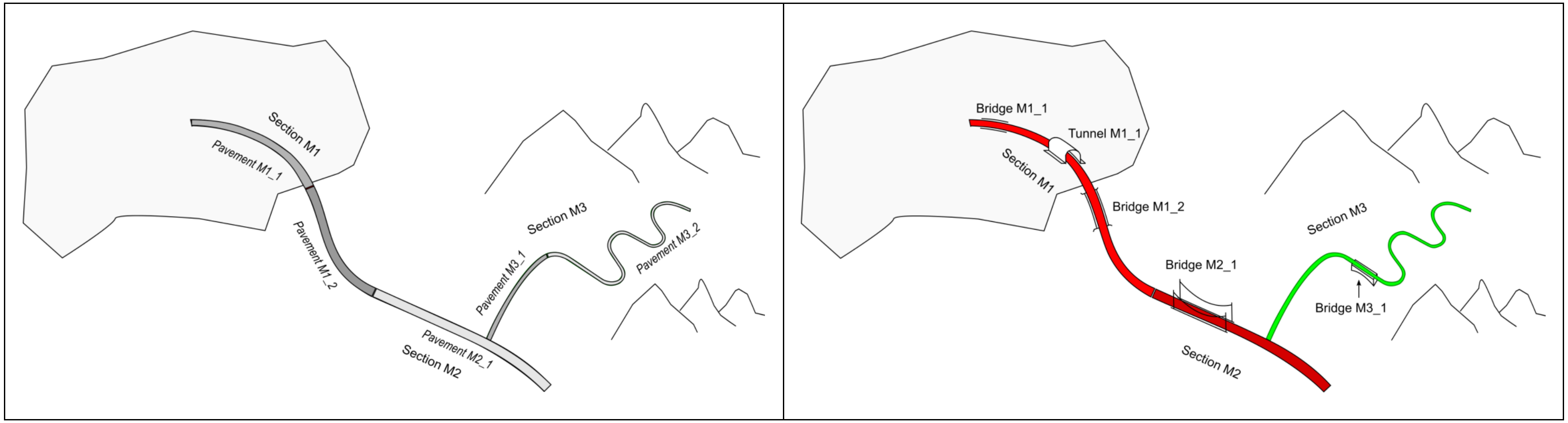


Figure 24: Pavement sections and structures/tunnels on the network

Beside the calculation of the actual risk for each single maintenance sections a "**what-if-scenario**" has been also included in this example. It takes the sensitivity of the different areas into consideration. To simplify the "what-if-scenario" all high level influencing factors show a negative outlook "**N**", which means that the climate change, the funding and the safety regulations leads to an increase of asset specific risks (see also chapter 3.1 to 3.4).

Asset specific risk calculation

At first, the asset specific risk calculation will be carried out for each asset individually and provides the basis for cross asset risk calculation. In this example the number of different assets within a single maintenance sections has been reduced to a minimum, so that the procedure is easy to understand. For each single asset the maintenance risk will be calculated by using the maintenance risk matrixes, which are represented in the respective chapter subject to the asset type (see chapter 5.3). Based on the calculated risks the factors for the high level influence will be selected and the risk of the "what-if-scenario" will be calculated as well and represented in the following up tables. Thus, a direct comparison between the actual risk and the risk of the "what-if-scenario" (alternative) is possible.

Pavement

The first asset is pavements. There are several pavement sections within the network (see Figure 24), showing different conditions from the comfort and safety point of view (CSI) and from the structural point of view (SI). The following Table 38 shows the input data and the risk assessment of the pavements by using the matrixes and expressions described in chapter 5.3.2.

Table 38: Pavements input data and calculated risks

Input data for pavement sections								Current risk				Risk"what-if-scenario"				
ID	Road Name	From km	To km	Length [km]	Pavement type	CSI [-]	SI [-]	AADT class	Risk CSI	Risk SI	Total risk	Risk factor CSI	Risk CSI (alter.)	Risk factor SI	Risk SI (alter.)	Total risk (alter.)
P_M1_1	A10	0,00	10,00	10,00	Asphalt	1	2	medium	50	60	59,60	1,10	55	1,20	72,00	68,60
P_M1_2	A10	10,00	15,00	5,00	Asphalt	4	4	medium	85	80	97,80	1,10	93,5	1,20	96,00	100,00
P_M2_1	A10	15,00	22,00	7,00	Concrete	3	2	high	80	70	91,20	1,20	96	1,40	98,00	100,00
P_M3_1	B07	0,00	2,00	2,00	Asphalt	2	1	low	50	40	56,40	1,05	52,5	1,10	44,00	59,54
P_M3_2	B07	2,00	12,00	10,00	Asphalt	3	5	low	60	80	76,00	1,05	63	1,00	80,00	76,60

The output is the actual total risk of each single pavement section and the alternative risk of the “what-if-scenario”.

Structures

Of course, structures are not covering the whole network or maintenance sections respectively. There are 4 structures (bridges) along the network, where two of them can be found on the first part of A10 (urban expressway). One structure is on the motorway part of A10 and the last is on B07 (see also Figure 24). The following Table 39 shows the input data and the risk assessment of the structures by using the matrixes and expressions listed in chapter 5.3.3. The condition of the structures is based on the structure condition index SCI and extent of defects SED.

Table 39: Structures input data and calculated risks

Input data for structure sections										Current risk			Risk "what-if-scen."	
ID	Road Name	From km	To km	Length [km]	Material	SCI [-]	Severity SCI	SED	Severity SED	Risk CSI	Risk SED	Total risk	Risk factor	Total risk (alter.)
B_M1_1	A10	0,30	0,50	0,20	Concrete	1	1	1	1	20	10	20,00	1,20	24,00
B_M1_2	A10	12,00	12,70	0,70	Concrete	3	3	3	2	90	70	90,00	1,20	100,00
B_M2_1	A10	17,00	17,10	0,10	Concrete	1	2	1	1	50	10	50,00	1,20	60,00
B_M3_1	B07	4,00	4,60	0,60	Steel	2	1	2	3	30	60	60,00	1,10	66,00

In comparison to the pavements, where the alternative risk of the "what-if-scenario" is based on factors for the single risks, there will be used only one single factor for each structure subject to the construction type (material) and the sensitivities on funding.

Road furniture, drainage and geotechnical assets

All these assets are very simplified in this example. There are no detailed or section specific information about these types of assets available, so that they are described in general on the maintenance section level only. Nevertheless, for each single asset a risk can be calculated using this generalized information about condition and consequences. The following tables show the input information and the risk assessment for road furniture, drainage and geotechnical assets. The respective matrixes and factors for high level influence can be taken from chapter 5.3.4 to chapter 5.3.6.

Table 40: Road furniture, drainage and geotechnical assets input data and calculated risks

Input data for road furniture							Current risk	Risk "what-if-scen."	
ID	Road Name	From km	To km	Length [km]	RFCI [-]	Conse-quence	Risk RFCI	Risk factor	Risk RFCI (alter.)
F_M1_1	A10	0,00	15,00	15,00	1	M	50	1,80	90,00
F_M2_1	A10	15,00	22,00	7,00	2	H	80	1,40	100,00
B_M3_1	B07	0,00	12,00	12,00	3	L	60	1,10	66,00

Input data for drainage							Current risk	Risk "what-if-scen."	
ID	Road Name	From km	To km	Length [km]	DCI [-]	Design cat.	Risk DCI	Risk factor	Risk DCI (alter.)
D_M1_1	A10	0,00	15,00	15,00	2	w	60	1,00	60,00
D_M2_1	A10	15,00	22,00	7,00	3	w	70	1,00	70,00
D_M3_1	B07	0,00	12,00	12,00	4	u	90	1,40	100,00

Input data for geotechnical assets							Current risk	Risk "what-if-scen."	
ID	Road Name	From km	To km	Length [km]	GCI [-]	Sensitivity erosion	Risk GCI	Risk factor	Risk GCI (alter.)
G_M1_1	A10	0,00	15,00	15,00	1	low	10	1,00	10,00
G_M2_1	A10	15,00	22,00	7,00	1	low	10	1,00	10,00
G_M3_1	B07	0,00	12,00	12,00	3	medium	70	1,40	98,00

Tunnels

The last asset type is tunnels. There is only one tunnel on the A10 expressway with a length of 700m having old electro-mechanical equipment with an average age of 12 years (see also Figure 24). Both, the structural condition as well as the condition of the equipment will be taken into consideration in the risk assessment (2 matrixes). The following table shows the input data and the risk assessment of the tunnel by using the matrixes and expressions listed in chapter 5.3.7.

Table 41: Tunnels input data and calculated risks

Input data for tunnel section										Current risk			Risk "what-if-scen."	
ID	Road Name	From km	To km	Length [km]	Age	TCI [-]	Severity defects	AGE EM	Avail. spare parts	Risk TCI	Risk AGE EM	Total risk	Risk factor	Total risk (alter.)
T_M1_1	A10	0,70	1,40	0,70	Concrete	1	1	12	m	20	80	84,00	1,20	100,00

Cross asset risk calculation

As already mentioned, the combination of the asset specific risk on each single maintenance section to a total cross asset risk is one of the main objectives of X-ARA. The cross asset risk represents an average risk on a maintenance section, which is the basis for the combination on the network level. The transformation of asset specific risk onto maintenance section will be carried out by using the length weighted average as described in chapter 5.4.1. This leads to the asset specific risk on the maintenance section as shown in Table 42. The calculation procedure, which brings up the total risk as a combination of asset specific risks can be taken from chapter 5.4.2 and leads to the results shown in Table 42 as well. The weights for the combination of the asset specific risk where taken from Table 34 (chapter 5.4.2) with subject to regional situation.

Table 42: Asset specific risk on maintenance section and total cross asset risk (current risk)

Current risk on maintenance sections															
Section	Road Name	From km	To km	Length [km]	AADT [veh/day]	PHGV [%]	Road category	Regional situation	Risk pavement	Risk structures	Risk road furniture	Risk drainage	Risk geotechn. assets	Risk tunnels	Total risk
M1	A10	0,00	15,00	15,00	23000	12	E	Urban	72,33	74,44	50,00	60,00	10,00	84,00	**69,97**
M2	A10	15,00	22,00	7,00	52000	9	M	Flat	91,20	50,00	80,00	70,00	10,00		**65,71**
M3	B07	0,00	12,00	12,00	5000	8	O	Mountain	72,73	60,00	60,00	90,00	70,00		**68,18**

A similar table can be shown for the alternative risk of the “what-if-scenario” (see Table 43).

Table 43: Asset specific risk on maintenance section and total cross asset risk (what-if-scenario)

Risk "what-if-scenario" on maintenance sections															
Section	Road Name	From km	To km	Length [km]	AADT [veh/day]	PHGV [%]	Road category	Regional situation	Risk pavement	Risk structures	Risk road furniture	Risk drainage	Risk geotechn. assets	Risk tunnels	Total risk
M1	A10	0,00	15,00	15,00	23000	12	E	Urban	79,07	83,11	90,00	60,00	10,00	100,00	**79,76**
M2	A10	15,00	22,00	7,00	52000	9	M	Flat	100,00	60,00	100,00	70,00	10,00		**74,10**
M3	B07	0,00	12,00	12,00	5000	8	O	Mountain	73,76	66,00	66,00	100,00	98,00		**74,95**

To combine the total risk of each maintenance section to a value, which represents the whole or partial network, the importance of the maintenance section within the network has to be taken into consideration. For the calculation of the total risk on network level the network sensitivity will be used to define a weighting factor (see chapter 5.4.3), which has a value of 1.4 on M1 (A10 expressway), a value of 1.2 on M2 (A10 motorway) and a value of 1.2 on M3 (B07). By using these weighting factors the **current total risk on network level** (using length weighted average) is **65.56** and for the "**what-if-scenario**" it is **77.10**. In both cases it will be a **medium risk** referred to risk scale presented in chapter 5.1 (Table 25).