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Cross-asset risk assessment on network level

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Abstract

The CEDR-project "X-ARA – Cross-Asset-Risk-Assessment" aims at the development of a comprehensive framework for the network level assessment of asset risks and impacts. A literature review on risk assessment in road asset management has been carried out and several European road administrations have been interviewed on the current practice of risk assessment in their asset management procedures. Based on asset-specific risk assessment considering pavement, structures, drainage, tunnels, road furniture and geotechnical assets, a procedure for the transformation and accumulation of these risks onto network level is an essential part of the project. X-ARA will enable a road administration to execute a risk-based assessment and comparison of different maintenance strategies on network level, and then "overlay" the effects of broad influencing factors to assess "what if" outcomes. In considering a bottom-up-approach (from object level to network-level) the risk can be calculated and finally cumulated by using asset-specific information, which are available for most of the European road administrations.

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Keywords: *Asset management; cross asset management; risk assessment; road infrastructure*

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1. Introduction

1.1. Introduction and project goals

This paper presents an outline of the research project “X-ARA – Cross-Asset-Risk-Assessment” which is funded in the CEDR Transnational Road Research Programme Call 2013 “Ageing Infrastructure Management”.

The increasing importance of the road infrastructure leads to an increasing responsibility in maintaining the road infrastructure assets and terms like availability, safety, sustainability, environment-friendliness, etc. express the expectations of the different stakeholders, which have to be taken into consideration to the highest possible extent. Over the last years, asset management became a complex task in finding the optimum solution in form of a balance between the expectations (from the different stakeholders), the technical needs and, of course, the budgetary constraints under the condition of an acceptable risk. Thus, an essential improvement of road infrastructure maintenance is the integration of risk analysis into the asset management processes on different levels.

The main objective of the project X-ARA 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. X-ARA considers different asset categories and the cross-asset risk on network level. A working tool fit for use by National Road Administrations around Europe is to be delivered at project end. The output of the tool is a visual representation (map) showing “heat maps” (i.e. a colouring scheme) of the network (as shown as example in Fig. 1) that visually represents the overall maintenance risk for each section and therefore allows a visual comparison of sections.

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

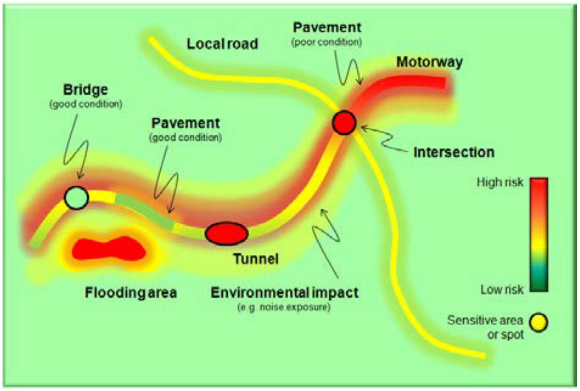

Fig. 1. Visualisation of maintenance risk on the network. Additional information like “flooding area” is shown for illustrating influencing factors.

1.2. Project approach

The project started with an initial desk study that put together the current status of risk assessment in the field of road asset management. A literature review using various sources (PIARC library, Reports of the FHWA, Reports from EraNet Road/CEDR projects, IEEE/IEL Electronic Library, Thomson Reuters Web of Science, ScienceDirect and Documents from governmental and other organizations members of the project team were aware of) has been carried out.

To reflect current practice, a workshop and consecutive interviews with road operators have been conducted.

Road operators in Austria, Denmark, Hungary, Slovenia, The Netherlands and United Kingdom have been consulted using a set of questions about how they implement risk management in their asset management processes. The results of the desk study are outlined in chapter 1.3.

After the desk study, the risk framework has been developed. The framework was implemented as prototype in commercial asset management software to allow the quick tuning and adjustment of the framework. After the prototype was working satisfactorily, a standalone tool was created that can be used by the road operator. In parallel, documentation for the tool and demonstration datasets are prepared. The project finishes with a training workshop with potential users of the risk assessment tool.

1.3. Current practice of considering risk in road asset management

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, 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 Fig. 2 below) and detailed to the different needs.

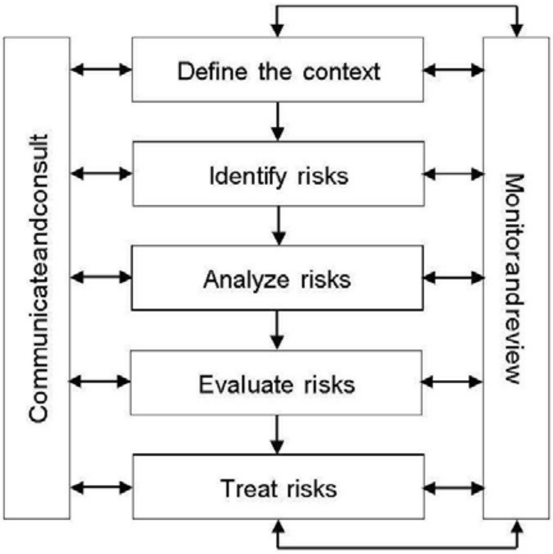

Fig. 2. General risk assessment process as in PIARC (2010), PIARC (2005), ISO (2009).

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 characterised by two basic questions: What can happen, and how and why it can happen? If restricted to the maintenance aspect of the work of road operators, this step is not commonly applied. 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.

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". Quantitative methods as well as qualitative methods are used in risk analysis. If enough historical data is available (often the case for pavements and bridges), quantitative methods are suitable. For the consequences, often a qualitative scale is used if the impacts are difficult to monetize. 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 (see AAHSTO (2013)). These are the key assets - based on the importance to public safety, network continuity, connectivity, economic activity or social well-being etc. This fact is often reflected by separate budgets for certain important assets; Denmark for example has a separate maintenance budget for large bridges which are considered the most important ones.

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 in the Netherlands 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.

1.4. Understanding of risk within asset management

The understanding of risk within asset management is "the risk for the road operator" to either perform a non-cost-efficient maintenance on his network, and/or to provide unsatisfying services to the other stakeholders (users, neighbours, Society, owner, etc.). 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.

2. Risk modelling methodology

2.1. 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) 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.

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 Fig. 3 (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

Fig. 3. Maintenance risk matrix for X-ARA (general example).

The failure axis is defined by using a scale with 5 condition classes, which is consistent with the condition scale definition of COST354 (2008) and EVITA (2012). 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 (annual average daily traffic [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 shown in Fig. 4. As already mentioned, the assessment of the risk will be based on a qualitative level only, which enables a comparison of different maintenance strategies and different “what-if-scenarios”.

To use monetary risk values will be problematic on the European level because of different cost levels and different calculation procedures. Thus, it was decided to use a risk quality, which enables a much easier benchmarking between different European countries.

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

Fig. 4. Risk classification within X-ARA.

2.2. High level effects

High level influencing factors are needed and used to include high level effects on the assessed road infrastructure network. It enables to express the expectations of the different stakeholders, which have to be taken into consideration to the highest possible extent. The following aspects are included in the assessment procedures:

- Climate change
- Funding
- Safety regulations

All three areas can be described by effects on the risk. This is done by a correlation between the high level influencing factors (areas) and the sensitivity of asset specific parameters and indicators. Each of these 3 areas covers, in fact, several influencing factors. However, due to both the complexity of dealing with such a detailed approach and the lack of relevant data at local level (region, country), 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.

The high level influencing factors 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 are included. In general, the following mathematical formulation is used:

$$F_{HLF} = f(impact_{HLF}, sensitivity_{HLF}) \quad (1)$$

$$M_{risk,HLF} = M_{risk} \times F_{HLF} \quad (2)$$

with:

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

The high level influence factor can increase or decrease the risk and is defined in a range from 0.6 to 1.4.

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”.

3. Risk calculation procedure

The workflow in the X-ARA tool follows the approach shown in Fig. 5. To start, a network consisting of several maintenance sections has to be defined. Maintenance sections are meant to have uniform properties, e.g. the traffic volume or the number of lanes should not vary in one section. Each maintenance section holds a number of assets, for which the conditions have to be known.

Furthermore, a network sensitivity factor is assigned to each maintenance section that takes the topography and location of the section into account. This factor can have on of three values: flat, mountainous or urban. The location factor represents a weighting factor when the total network risk is calculated and allows reflecting the sensitivity of each maintenance section

If these initial procedures are settled, the risk calculation may start.

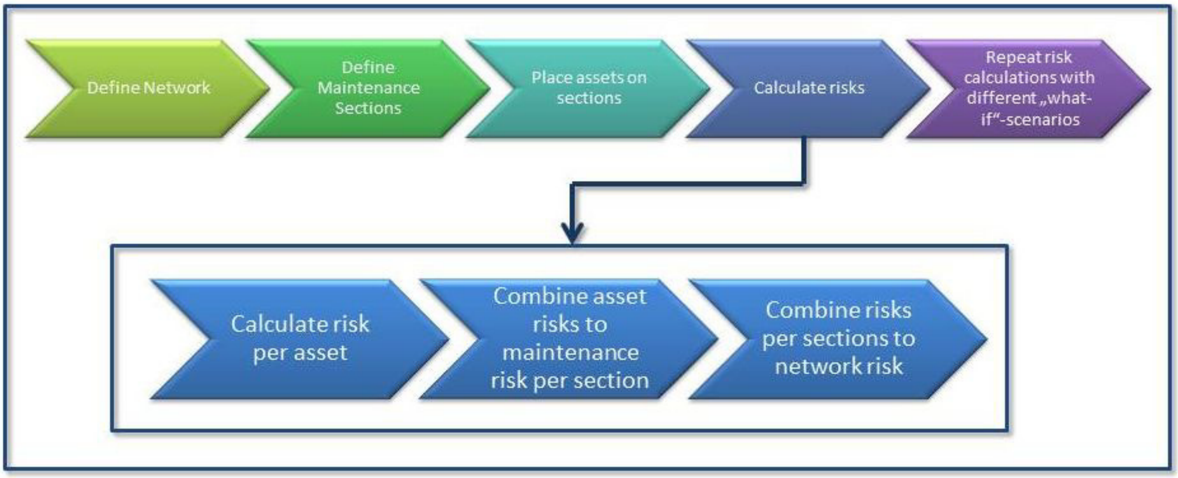

Fig. 5. General workflow of the X-ARA tool and workflow of risk calculation.

3.1. Asset specific risk modelling

As already mentioned, the risk calculation has to be based on asset specific assessment procedures, which are the basis for the combination on network level. Thus, the types of assets, which should be taken into consideration has to be defined in an asset framework. This 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;
- Structures (bridges, retaining walls, etc.);
- Road furniture (lighting, safety barriers, etc.);
- Drainage;
- Geotechnical assets;
- Tunnels (including electro-mechanical equipment).

For each of the asset categories listed above, the following parameters and risk modelling objects are defined:

- Indicators and parameters describing the condition of the asset (as basis for the probability of failure axis);
- Indicators and parameters describing directly or indirectly the consequences of failure;
- Risk matrixes on quality level;
- Combination procedures of combining single (sub)risks (if necessary);
- Asset specific risk factors to include high level influence and the sensitivity.

As an example, the following risk matrix (see Fig. 6) is used to describe the safety and comfort aspects of the pavement risk by using the CSI (comfort and safety index, based on COST 354) and the AADT, which 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).

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

Fig. 6. Maintenance risk matrix pavement CSI.

Beside comfort and safety the structural situation of the pavements (SI) can be included in a similar way. Finally both sub-risks will be combined to a total pavement risk using the following advanced maximum criteria (based on COST 354 ,2008):

$$M_{risk} = max\left(M_{risk,CSI}, 0.8 \times M_{risk,SI}\right) + \\ +0.2 \times min\left(M_{risk,CSI}, 0.8 \times M_{risk,SI}\right) \\ 0 \leq M_{risk} \leq 100 \tag{3}$$

with:

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

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 approach for these assets is a general recommendation, which can be adapted or extended to the specific preconditions of different types of road furniture.

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).

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 is limited to cuttings and embankments in this project.

3.2. Combination of asset specific risk to total risk

3.2.1. Transformation of asset specific risk into maintenance sections

The total risk calculation over all types of assets and sub-assets works will be based on so called “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 maintenance risk it is necessary to transform the asset specific risks onto the longer maintenance sections. 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 asset level sectioning onto the maintenance sections will be carried out using the length weighted average, because almost every asset or group of assets, which are listed in the previous chapter, has a longitudinal extent.

3.2.2. Calculation of total risk on maintenance section

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.

E.g. 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 need to be related to the regional situation.

The following expression shows the combination of asset specific risk into a total (cross asset) risk.

$$M_{risk,total} = \frac{\sum_i M_{risk,i} \times G_i}{\sum_i G_i} \quad (4)$$

with:

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

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.

3.3. Cross asset risk results

Beside the definition of the models and the methods for calculating risk within asset management, the output of such an approach is an important factor in convincing decision makers to spend more money into the total road infrastructure assets. Thus, the risk assessment in the context of X-ARA focuses on the following results:

- Risk of single assets (pavement, structures, etc.) on object level;
- Risk on maintenance sections for different types of assets;
- Cross asset risk on maintenance sections;
- Average risk and risk distribution over a whole network for the total risk and for the asset specific risks (network level results);
- What-if-scenarios in form of a comparison to the actual risk situation.

The different types of results can be used by different levels of users, beginning from the technical level and ending at the high management or political level. For displaying the results graphical interfaces are recommended in form of charts and maps (example see Fig. 7).

4. Results and Conclusions

Risk management as a part of asset management becomes more and more important in the decision processes. The lack of models and methods of using risk assessment within asset management is a decisive factor and has to be closed by actual research activities. The CEDR-project X-ARA is a first step into a more holistic asset management, where decisions should be carried out on an objective basis including uncertainties in form of risk. X-ARA has the potential to aid a national road administration 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, it is capable of further exploitation across CEDR member countries and it gives transnational benefits by providing a common framework for assessing risk which can be configured for each country location.

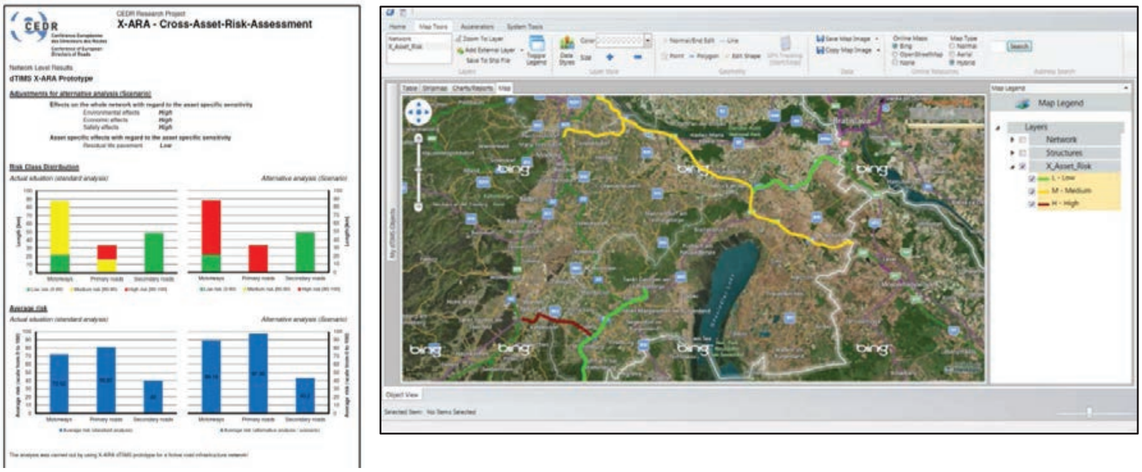

Fig. 7. Network level results (example) and Risk mapping within X-ARA prototype (dTIMS^{TM}).

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References

AASHTO Transportation Asset Management Guide, A Focus On Implementation – Executive Summary, U.S. Department of Transportation, Federal Highway administration and American Association of State highway and Transportation Officials, Washington D.C., June 2013

COST 354. COST European cooperation in the field of scientific and technical research: The way forward for pavement performance indicators across Europe – COST-Action 354 “Performance Indicators for Road Pavements”. Final Report, FSV – Austrian Transportation Research Association, COST, Vienna – Brussels, 2008

EVITA – Effective asset management. ENR-project, Deliverable D3.1- Report on recommended E-KPIs; ISTTAR, Nantes, France, August 2012Acknowledgements

ISO 31000, The International Organization for Standardization, Risk management: Principles and Guidelines, ISO 31000:2009.

PIARC Technical Committee on Risk Management for Roads C18, Study on Risk Management for Roads, World Road Association (PIARC), France, 2005.

PIARC Technical Committee Risk management for roads 3.2, Towards Development of a Risk Management Approach, World Road Association (PIARC), France, 2010.