ASSET SERVICE CONDITION ASSESSMENT METHODOLOGY (ASCAM PROJECT)

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ABSTRACT

Allocating financial resources among different sub-assets of a country's road infrastructure is a challenge that is highly dependent on the strategic priorities and organisational structure of the infrastructure operator. While some agencies in Europe deal with pavements, bridges, tunnels or road furniture completely independently, others find that they have one mutual budget that needs to be shared out among the different assets in a way that represents their respective need for maintenance. The criteria upon which such allocations are based may be political, empirical, or based on stakeholder/user interests. The goal of the project ASCAM – Asset Service Condition Assessment Methodology – was to develop a framework for cross-asset management that can be used to objectively assign a budget to certain assets. While previous research projects have already compiled lists of various key performance indicators, ASCAM aimed to find mutual indices such as an "end user service level" that could be used to judge all sub-assets on equal terms and thus compare their condition on the same scale.

By looking at asset management in the ASCAM partner countries and other European road agencies, the best-practice in individual asset management was extracted to develop the framework and perform a proof-of-concept for the project. While other projects such as PROCROSS within the same ERA-NET call also worked on cross-asset management – but from a top-down approach – ASCAM's bottom-up approach looked at the more technical aspects of evaluating infrastructure condition and making a budgetary assignment based on the current and predicted state of the assets.

1 BACKGROUND

In 2010, ASCAM was submitted to the ERA-NET road call “Effective asset management meeting future challenges” with the aim to improve the technical, economical and sustainable performance of the European road network. The idea was to create a framework upon which cross-asset management can be optimized from an objective viewpoint, allowing decisions on which sub-assets to invest in to be based on measureable performance indicators.

In contrast to a top-down decision pursued by some road agencies, where funds are allocated according to stakeholders’ interests regardless of the exact physical condition of the assets, ASCAM’s bottom-up approach took into account the inspection results of various assets and thus a degradation prediction that provides information on the state of the road network in a number of years’ time. One of the challenges in this project was to discover if enough information concerning the inspection or monitoring of assets would be available between the ASCAM partners and other European countries in order to come up with a sufficiently detailed forecast of the road infrastructure’s service level.

In order to anticipate the timing and volume of investments required along certain stretches of road, the operator must be able to compare different maintenance strategies so that the overall technical and economic performance of the network can be optimized. Again, the difficulty here lay in the ability to quantify the effect of different measures such as repairs e.g. patching, replacements, regular or preventive maintenance, and operative measures e.g. speed reductions, to different assets using a mutual metric. The framework eventually produced in ASCAM is a pro-active decision-making tool for road authorities and infrastructure operators, which integrates the technical knowledge about assets under the boundary condition of budgetary restraints and scarce natural resources.

2 ASCAM METHOD

It is important to note that the project was explicitly aiming to use existing knowledge on asset assessment and management, and did not set out to create new means of monitoring or alternative methods for repair. Nor did ASCAM set out to establish new key performance indicators as these had already been thoroughly researched in preceding works such as the COST Action 354. The added value to the state-of-the-art on (cross) asset management would be the framework itself.

The project was split into three work packages based on the major road infrastructure assets: pavements, structures (tunnels and bridges) and equipment. Within each work package, the first task was to acquire information from different countries on the current practice concerning monitoring & measurement, individual & combined performance indicators, as well as asset condition & applied interventions. Using this fragmented knowledge, the second task was to combine it into equations that formulate the relationship between the technical condition of the above-mentioned assets and specific end user service levels (EUSL). These include societal parameters such as safety, traffic flow, or environmental issues.

ASCAM’s structure is briefly illustrated in Figure 1 using the pavement work package as an example; the same outline applies to other asset groups. The outcome of the first task is summarised for the different asset groups in the following subchapters.

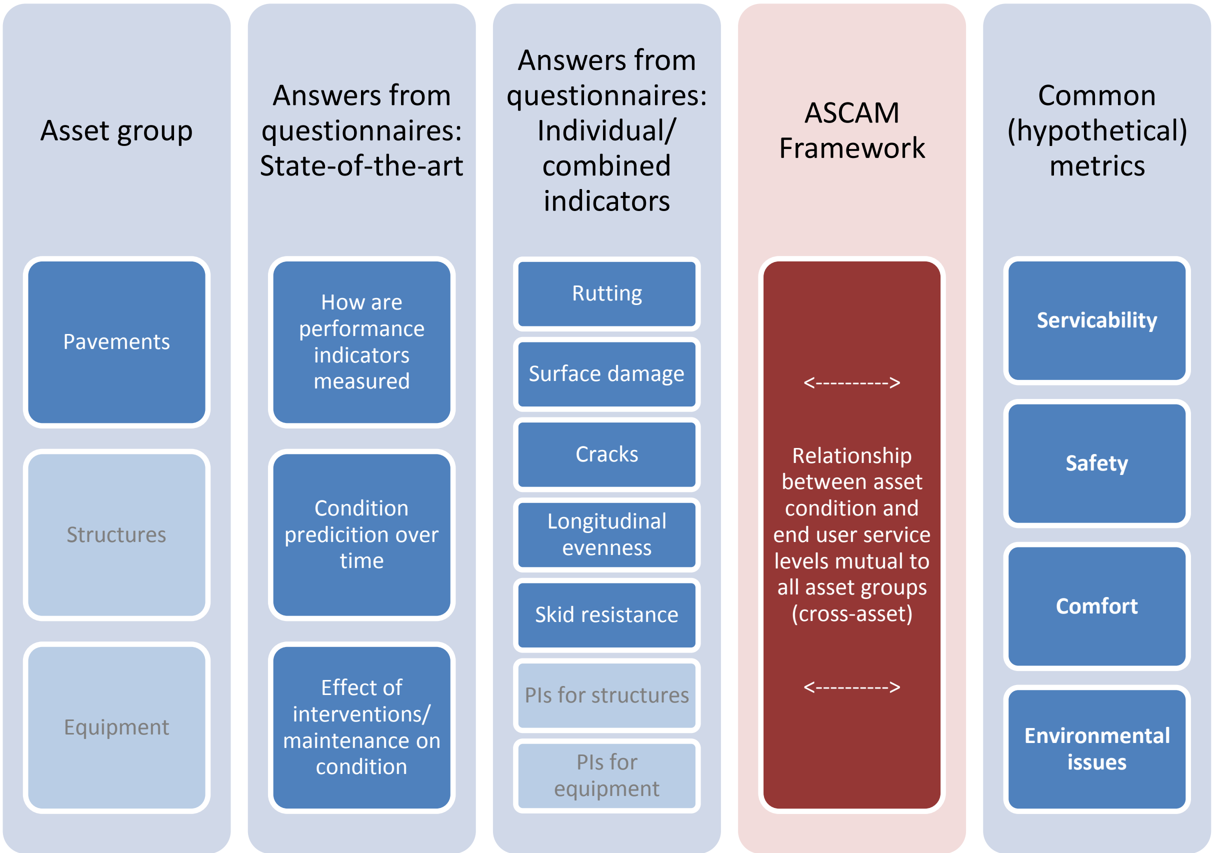


Figure 1: Outline of ASCAM project and structure leading to the framework.

2.1 State-of-the-art: Pavement management

From an asset management point of view, the road infrastructure components of greatest interest are those that are key contributors to performance or to the satisfaction of stakeholder needs, as well as the components that are most prone to deterioration or need on-going management, and finally the components that are the most expensive in terms of life cycle costs.

Pavements thus play a major role in any road network and their existing management systems were investigated in one of the ASCAM work packages using questionnaires. These were given to road agencies with the aim of finding out what performance indicators the operators employ to measure the standard of the infrastructure, what interventions they use, and what the benefits of different management strategies are regarding end-user service levels. Overall, the answers together with a literature review delivered an inventory of existing practices amongst NRAs for

- key performance indicators (KPI), combined/single parameters,
- degradation models for KPIs,
- indicators currently used for planning maintenance measures,
- list of existing measures,
- costs of these measures.

Feedback to the questionnaire was received from Austria, Croatia, Slovenia and Sweden. The main conclusion that could be drawn from the answers was that current pavement management systems (PMS) function according to national specifications since there are no European standards. Similarly, the KPIs that are used by NRAs may either be wholly different between neighbouring countries, or since the measuring equipment is not standardized, the measured values are mostly not comparable even for the same technical parameters and/or indices; only some of the measurements are specified in norms EN 13036-1 to EN 13036-8.

The most important results in this work package were the qualitative and quantitative relationships that some countries had established between pavement condition and the necessary intervention, and also the prediction of certain indicators with time i.e. degradation models, which would provide a basis for the ASCAM framework. Likewise, first attempts at quantitatively linking an asset's condition (directly or through combined KPIs) with the abstract concept of end user service levels (safety, emission, comfort) could be obtained from the replies. An example of this is shown in Figure 2 which is a simplified version of the Austrian pavement management system (Weninger-Vycudill et al. 2009).

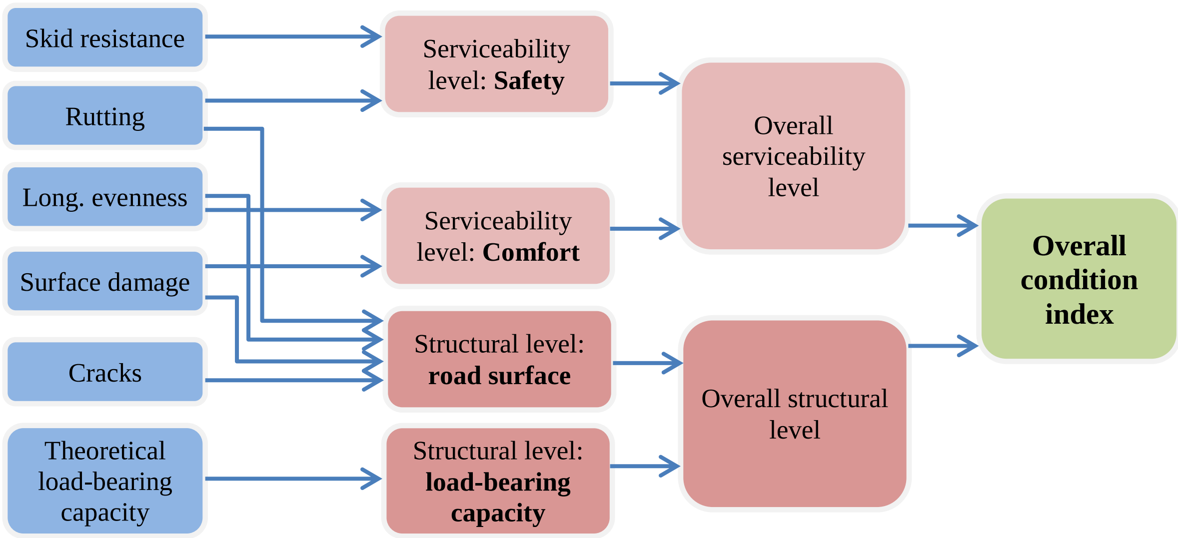


Figure 2: Example of how pavement condition can be linked to the overall performance of the asset and subsequently to a potential EUSL.

Ultimately, the basis for every PMS is an extensive database. Depending on the quality and amount of data gathered and the suitability of the models used to analyse these data, the economically most effective actions can be taken. A further important aspect of PMS is the network referencing system: road class/number/section/chainage etc. must be taken into account when building a referencing system. There are a lot of important inventory data such as the width of lanes, traffic loads, structures, foot paths, layout, curvatures, crossings etc. The questionnaires also revealed that countries currently build databases in their own specific way.

2.2 State-of-the-art: Structure management

Bridges represent a vital link in any road network. Therefore an increasing number of deteriorating bridges led to the development of a number of Bridge Management Systems (BMS) and life cycle maintenance models (Kaneuji et al. 2006, Airaksinen 2006, BRIME 2000, Noortwijk J.M. et al. 2004).

The heart of any BMS is a database derived from regular inspection and maintenance activities. The integrity of a BMS is directly related to the quality and accuracy of the bridge inventory and physical condition data obtained through field inspections. The database and inventory allow bridge managers to be fully informed about the bridge stock under their control so that they can make informed decisions about future maintenance and repair activities.

The NRAs questioned replied that condition rating of a bridge starts with the identification of defects/damages, its bearing capacity, remaining service life and functionality. Inspections also enable bridge engineers to determine future maintenance requirements. In general, the condition rating can be categorized as an overall bridge rating or an individual component rating. The range of condition states currently used by most operators is a value from 1 to 5. In most BMS, maintenance planning as well as the results of maintenance actions are completely deterministic and the times for maintenance are determined by fixed deterioration levels at which the structural condition is no longer sufficient or the decision is made exclusively by an expert. Some of the possible single key performance indicators for bridges which affect the EUSLs developed in ASCAM are presented in Table 1.

Table 1: ASCAM assessment for structures: Key performance indicators for bridges.

Single key performance indicators for bridges which affect end users		
Service level KPIs	**Environmental KPIs**	**Socio- and Economic KPIs**
Everything that causes any kind of distress to the end user	Everything that effects the environment	Everything that has social and economic influence on the end user
Measureable parameters		
Vibration	Air quality	Influence on the average annual daily traffic
Noise	Damage to surroundings	Economic development of the area
Degradation concrete	Energy consumption	Life cycle cost
Non-measureable parameters		
Psychological indicators of stress	Damage to flora/fauns	Relevant traffic load
	Effects on surface and ground water	Transport cost
	Eutrophication	Travelling time
		Migration (goods, population)
		Investments in maintenance
Psychological indicators of insecurity		Traffic safety
Repair methods → total costs		

2.3 State-of-the-art: Equipment management

The term “road equipment” essentially refers to everything on or close to the road, which is not asphalt or concrete. Important types of equipment are traffic lights, road markings and signs. Other types include post delineators, bollards and game fences. The property they all have in common is that – at least to some degree – their aim is to improve safety, accessibility and comfort for road users.

ASCAM studied six types of equipment (road markings, road studs, delineator posts, fixed signs, variable message signs (VMS) and road lighting) in five countries: Belgium, Croatia, Denmark, Germany and Sweden. In order to fulfil their purpose of improving traffic safety, the important characteristic of equipment turned out to be visibility or legibility: signs must be legible at relevant distances, road lighting is aimed for improving the visibility of the whole road environment and other equipment will improve visual guidance. The questionnaire handed to road operators thus focused on how these equipment types are assessed i.e. how their performance is measured. It also aimed to quantify the state of road equipment in terms of an end user service level (EUSL) and possible costs, which turned out to be very complex because the equipment should simultaneously give improved safety, comfort and accessibility, yet these concepts often counteract e.g. better accessibility means higher speed which leads to worse consequences of an accident.

On the whole, road equipment deteriorates quite slowly and has a life-cycle of around 10 years or more. Hence maintenance measures are usually carried out due to reasons other than wear e.g. a sign may bit hit by a vehicle or covered in graffiti. The exceptions are road markings and road studs which may be exposed to continuous wear from traffic. This can be severe in countries where studded tires are used, requiring maintenance to be performed annually.

Table 2 summarises the findings of the equipment work package, showing how the performance of different types of furniture is assessed, what maintenance measures are performed and what the subsequent effect on various EUSLs is. It includes responses from all five countries, where "(yes)" means the measure may occur but only rarely, and it also becomes clear that maintenance of road furniture typically involves replacement of the equipment in question. In most cases replacement restores the EUSL to its initial value. The cost for such measures is very difficult to estimate as there is a large variation between countries, type of roads, and also over time.

Table 2: ASCAM assessment for equipment: Maintenance measures on different types of road furniture and their respective effects on certain end user service levels.

Assessment methods for different furniture						
	Road markings	**Road studs**	**Delineator posts**	**Fixed signs**	**VMS**	**Road lighting**
Visual inspection	yes	yes	yes	yes	yes	yes
Hand-held measurement	yes	no	no (yes)	no (yes)	no	no (yes)
Mobile measurement	yes	no	no	no	no	no
Condition assessment	yes	no	no	no	no	no
KPI	retro-reflectivity	CIL-value	CIL-value	retro-reflect., colour	light intensity	luminance, illuminance
Typical measure	**renew**	**replace**	**replace**	**replace**	**replace**	**Replace/clean**
Aver. cost/km & year (€)*	1000	?	50	700	?	100**
End user service levels						
Maintenance effect on TRAFFIC SAFETY	none	none	none or negative	positive	positive	positive
Maintenance effect on ACCESSIBILITY	positive	positive	positive	positive	positive	positive
Maintenance effect on COMFORT	positive	positive	positive	positive	positive	positive
Maintenance effect on EMISSIONS	none or negative	none	none or negative	none	none	none or negative
Maintenance effect on TRAFFIC NOISE	none or negative	none	none or negative	none	none	none or negative

* Very rough estimates.
** Does not include replacement of bulbs.

For most types of equipment there is a regulation which states a desirable performance level. However, generally this level is not based on the drivers' needs, in other words, the desirable end user service level is not known. Instead, the desirable EUSL may be based on expert opinion or on what manufacturers can achieve. Regarding road equipment, it can therefore be concluded that too little knowledge about an exact (quantifiable) relationship between EUSLs and the performance parameters is currently available among road operators. Hence the framework, as explained later, had to make certain assumptions when it came to predicting the condition of assets in order to make decisions on when to perform interventions.

3 ASCAM FRAMEWORK

Looking at the abovementioned state-of-the-art results of the three work packages, it was possible to split the types of maintenance available for any asset into the following general concepts:

- Corrective maintenance (condition-based)
- Preventive maintenance (time-based)
- Predictive maintenance (estimated condition-based)

In practice, a combination of these three basic maintenance principles is of course the most common approach. Looking at literature and the answers to the questionnaires, no standard cross-asset maintenance concepts could be found in European NRAs. Some separate pavement-, structure- and (sometimes) road equipment-maintenance concepts, tools and methods exist. In some cases road authorities explicitly chose, after a cost benefit analysis, to combine pavement, structures and road equipment maintenance to avoid hindrance. The ASCAM framework, however, explicitly aims at a cross-asset approach and should be able to show the costs and consequences of a combined strategy versus a separate strategy.

To optimize the cost and value of a network, operators have developed strategies for maintenance, combining the above mentioned principles. These strategies depend on the goals, the type of asset, traffic density, failure type, available budget and other relevant aspects. In ASCAM, the consequences of certain interventions on the end users are measured by the EUSLs defined in the project and are not only an index for costs, but also for risk and value. The value of the network is related to stakeholder requirements and the cost stakeholders are willing to bear for getting the required service.

EUSLs determined from the questionnaires include travelling time, vehicle operational costs (fuel), number of accidents, noise, comfort and general safety (e.g. ultimate limit state for bridges). In order to create the framework demonstrator, it was necessary to define a dynamic set of mutual EUSLs together with a decomposition of the road network, which quantifies how the technical performance (skid resistance, reflectivity etc.) of individual components (pavements, lighting etc.) affects the EUSLs. Moreover, the effect of maintenance measures on asset condition needed to be quantified and predicted in order to compare different scenarios over an arbitrary timeframe using mutual metrics. Condition prediction is an essential factor in cost-optimisation, as maintenance based on desired EUSLs will be based on a pro-active approach. Therefore equations or functions for condition prediction must be incorporated into the framework. Seeing as these are only available in very few countries and using very individual sets of data, general assumptions had to be made. Uncertainties in these relationships can be reduced once an NRA has the “true” relations between asset condition vs. EUSL and intervention methods vs. condition and/or condition degradation. At the moment, the implemented time functions linking performance indicators to EUSLs are still hypothetical and aim to serve the demonstration of the functionality of the ASCAM framework.

As an example, the relationship between condition and safety is given in equation (1), where the factor F_{safety} was introduced to account for a potential relation between a component’s condition and the number of accidents on that stretch of road.

$$F_{safety} = a + b(1 - c)^2 \quad (1)$$

Depending on the parameterization for *a* and *b*, F_{safety} can have values between 0.5 (for excellent condition of the object, *c*=1) and 1.5 (for very poor condition of the object, *c*=0). From this, the condition-dependent number of annual accidents N_{acc} and the yearly costs C_{acc} are then calculated according to equations (2) and (3), respectively.

$$N_{acc} = F_{safety} \cdot P_0 \cdot (L \cdot I) \tag{2}$$

$$C_{acc} = C_0 \cdot N_{acc} \tag{3}$$

L corresponds to the length of the investigated road segment [km] and *I* to the traffic intensity [veh/year]. Values for P_0 = 2.10^{-7} [/vehkm] and an estimate for C_0 = 31 kEuro/accident.

The framework is implemented in an ASCAM demonstrator for a hypothetical information set. The demonstrator is a spread sheet-based calculation tool programmed in Excel© and intended as a proof of principle. In the first step of the demonstrator, the user is able to define a stretch of road network composed of various objects found in the database (bridges, equipment, pavements etc.), together with general data concerning traffic intensity, traffic growth or discount rate over the given time period. Several maintenance measures can be selected from a drop-down menu in the next step to compare three different scenarios, see Figure 3.

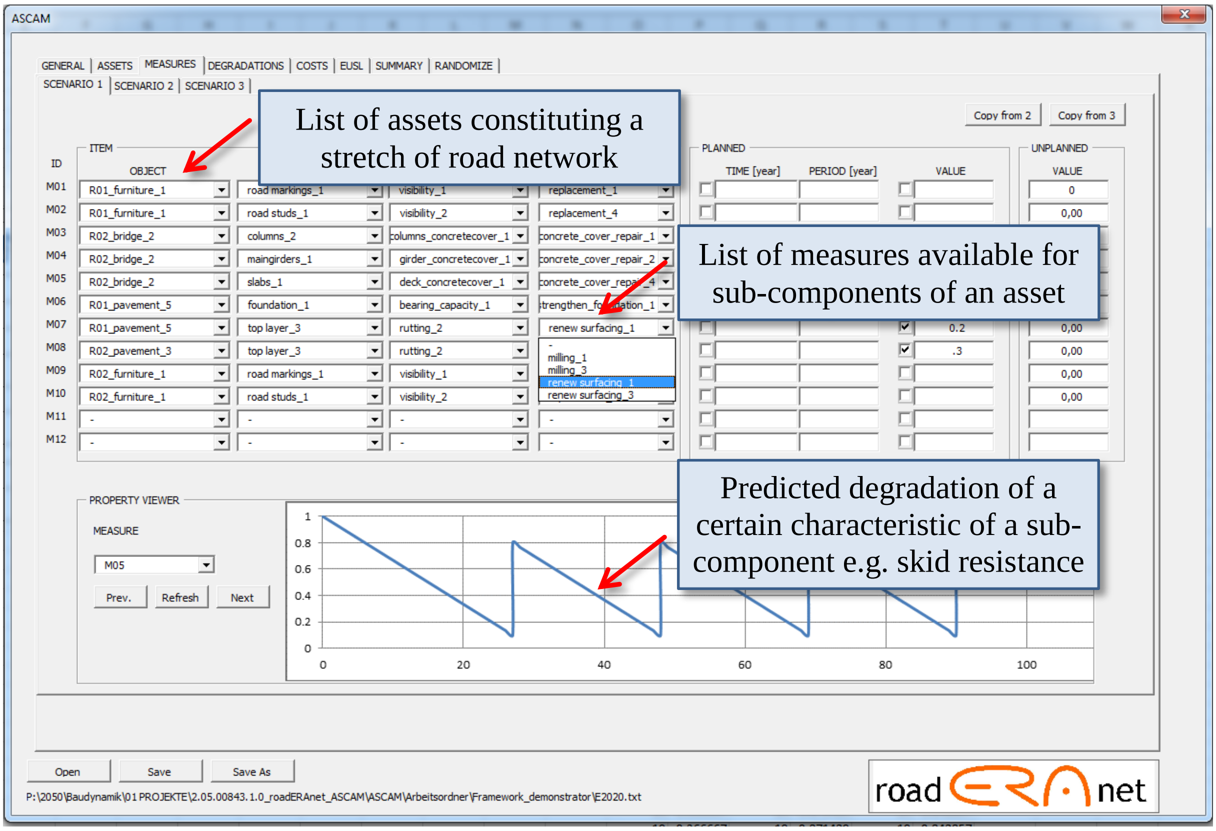


Figure 3: Screenshot of the ASCAM framework's demonstrator, showing dropdown menu of measures that can be applied to selected components.

The inset graph at the bottom of Figure 3 shows the predicted degradation and effect of a measure on an asset's condition e.g. the effect of milling on skid resistance of a pavement, or the effect of road stud replacement on reflectivity of the furniture. The performance of these characteristics is in turn related to EUSLs over time. In an example to show the framework's functionality, the following situation on a 2-lane highway was investigated: The first segment encompassed 0.5 km of pavement, with the sub-components *foundation* and *top layer*, as well as furniture that consisted of the sub-components *road markings* and *road studs*. This was followed by a second segment, also of 0.5 km length, composed of a bridge (sub-components: *columns*, *girders* and *slabs*), pavement (sub-component: *top layer* only) and furniture (sub-components: *road markings* and *road studs*). Three scenarios for the same network were compared:

Scenario 1: corrective maintenance. Interventions were only performed once a threshold level of the component condition was reached e.g. rutting exceeded a certain depth, visibility dropped below the required minimum, in other words, once damage had already occurred.

Scenario 2: preventive maintenance, according to condition level. A threshold value for the characteristics could be defined at which interventions would automatically be performed. This value is arbitrary e.g. when cracks cover 50% of the pavement top layer.

Scenario 3: also preventive maintenance but at fixed time intervals independent of condition. Here, the time can be specified (in years) after which a certain measure should be implemented for the first time, and then at what intervals it should be repeated.

Figure 4 shows an illustration of the EUSLs considered in the ASCAM framework: comfort, accessibility, safety, emission and noise. Similarly to equations (1)-(3), where safety was expressed in terms of costs, the other EUSLs were also expressed as monetary values and their annual development – along with the actual maintenance costs – during these three scenarios is shown over a 40 year time window, considering an annual traffic growth of 2% and a financial discount rate of 1%.

A further functionality of the framework implementation is the illustration of the total costs for certain scenarios, computed by summing up the costs of the EUSLs and the maintenance costs (direct and indirect). The way the relationships are currently defined in the demonstrator considers the findings from the three work packages, yet includes arbitrary assumptions for certain factors/functions in order to create the proof of principle. The calculated total costs in Figure 5 show that corrective maintenance is the most expensive for all EUSLs, especially safety. The two preventive scenarios perform very much alike within the current example. Further optimizations, however, are still possible especially once countries have their own characteristic data available that links asset conditions to the costs of EUSLs e.g. a precise equation to link longitudinal evenness to driving comfort.

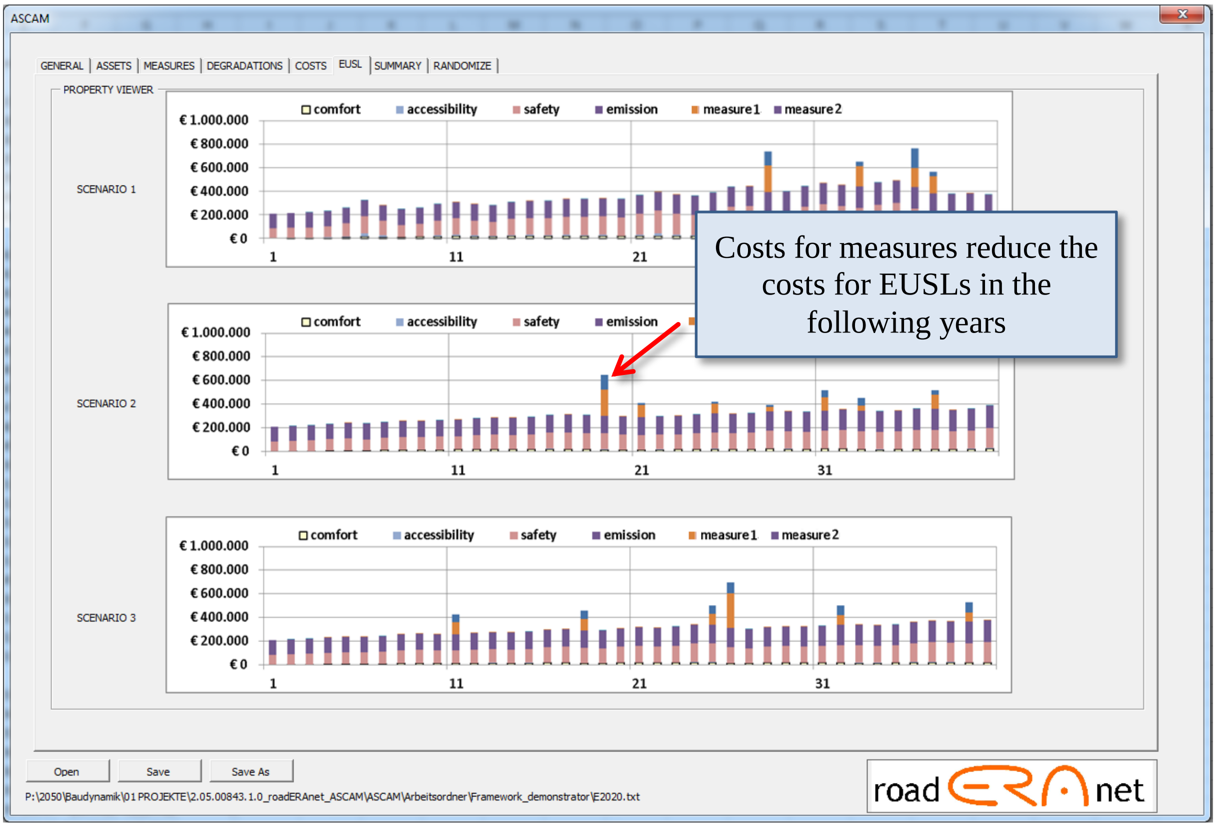
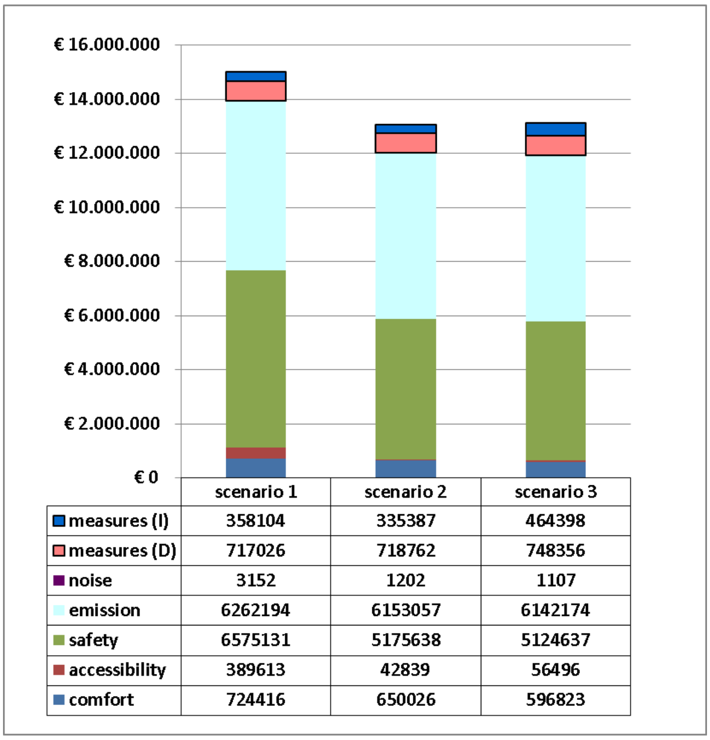


Figure 4: Screenshot of the ASCAM framework's demonstrator, showing the development of EUSLs over time depending on the type and timing of maintenance interventions.



	scenario 1	scenario 2	scenario 3
measures (I)	358104	335387	464398
measures (D)	717026	718762	748356
noise	3152	1202	1107
emission	6262194	6153057	6142174
safety	6575131	5175638	5124637
accessibility	389613	42839	56496
comfort	724416	650026	596823

Figure 5: Screenshot of the ASCAM framework's demonstrator, showing the total costs produced by different maintenance scenarios.

4 PROCROSS

In contrast to ASCAM's bottom-up approach, which relies on the technical assessment of individual assets, the top-down approach investigated in the project PROCROSS is a form of resource allocation based on central decisions which deal with infrastructure purely on a network level. The motivation behind this project is the same as for ASCAM, namely that the upkeep of existing assets in Europe consumes a considerable part of road operators' budgets compared to the amount spent on network expansion, hence significant savings can be achieved if road infrastructure is treated collectively rather than on an asset by asset basis.

The decisions involved in a top-down approach require a comprehensive understanding of the overall state of the network and are highly dependent on how road agencies themselves are structured e.g. asset groups may be handled by separate departments who compete for budgetary resources, or some countries manage infrastructure on a regional basis, where sub-assets within the same area are treated collectively. The essence in PROCROSS's top-down approach is that decisions are made in the pursuit of a strategic target on network-level, rather than dealing with technical details surrounding the individual assets.

To achieve this, the stakeholders in whose interest the infrastructure should be maintained were categorised into the following groups: Users, owners, operators, neighbours, financing body and society. The aim of PROCROSS is to understand stakeholders' expectations and perceptions in the road transport system. This provides input for road administrations to establish service levels and, finally, to effectively incorporate them within the cross-asset management process to meet financial, environmental and social requirements. PROCROSS decided to group the stakeholder requirements into the following groups: safety, costs, environment, customer satisfaction (incl. availability). These groups are very similar to the EUSLs in ASCAM, but the difference between the projects is that the decision on what assets to invest in is looked at from a strategic level in PROCROSS (to satisfy stakeholders), while in ASCAM investments are allocated according to technical performances (upkeep of asset conditions). Work on PROCROSS is currently still on-going; the project finishes at the end of 2012.

5 CONCLUSIONS

Long-term planning or anticipation of the timing and volume of investments along a stretch of road is in the interest of both, road administrations and users, and would contribute to optimised life-cycle costs of European roads, by ensuring a safe and sustainable network.

ASCAM aimed to show how costs and consequences of maintenance interventions can be quantified over a certain timeframe using predictions of the lifespan of objects. By comparing various maintenance scenarios, an optimum solution could be found by using predictions concerning the number and costs of interventions as well as their consequences on so-called end user service levels, a common metric that permits a holistic, cross-asset calculation. These mutual EUSLs such as safety, comfort or emissions should allow policy makers and maintenance operators to overcome boundaries between their specific fields of knowledge and communicate on the same level when it comes to planning road infrastructure investments.

The principles of the framework were implemented in a spread sheet-based demonstrator for a hypothetical road network. The example stretch of road was used in the ASCAM project to assess the appropriateness of the concept and to illustrate the functionality of the framework's idea on an understandable level. At the time this paper was submitted, the framework was currently in its evaluation phase and various European road operators were asked for feedback on the applicability/usability of the demonstrator in their particular agency.

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