CERCOM - Adoption of the Circular Economy in Road Construction

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ABSTRACT: Implementation of the circular economy and resource efficiency has the potential to significantly contribute to decarbonisation targets, while using fewer natural resources, maintaining or enhancing biodiversity and providing regenerative design for generations to come. The CERCOM project has developed an innovative risk-based framework and management tool to facilitate a step change in the adoption of Resource Efficiency (RE) and Circular Economy (CE) principles in procurement and multi-lifecycle management by National Road Authorities (NRAs) across Europe. To develop the Risk-Based Analysis Framework (RBAF) and establish the system boundaries, risk-based decision analysis was first reviewed to establish current good practice. A review of risk-based approaches from previous research projects was completed. Building on processes developed in previous frameworks, the CERCOM Risk-Based Analysis framework is presented which utilises a weighted sum of the Risk Reduction Index, the Cost Potential Index and the various Key Performance Indicators developed in the work in order to delineate and rank various construction and maintenance activities in terms of circularity and risk. The framework considers technical, economic, environmental and social criteria, as well as RE / CE, to assess the change in risks in moving from a linear to a circular economy. The RBAF allows NRAs to decide on the level and scope of analysis they wish to complete and provides a tool to do so taking account the scale and nature of the project. The result is in an intuitive user-friendly framework for NRAs, providing trust and confidence in output results.

KEY WORDS: Risk analysis; Circular economy; Resource efficiency; Highway maintenance.

1 INTRODUCTION

Implementation of Circular Economy (CE) has the potential to tackle the root causes of global challenges such as climate change, biodiversity loss and pollution whilst at the same time providing regenerative design for generations to come. In the context of road construction and maintenance, several European National Road Authorities (NRAs) are already engaged with the circular agenda. A recent review has reported that while some progress has been achieved by the EU NRAs, particularly regarding maximising recycling and minimising waste, "not all NRAs and/or sector stakeholders seem to be adequately familiar with the Circular Economy concept" [1]. As road infrastructure accounts for an extensive use of resources, NRAs must become more material and energy efficient, moving beyond recycling, to reuse, repair/life extension and minimising use of materials. To make the process truly operable, a quantitative methodology is required which can adequately make the case for CE and Resource Efficiency (RE) in procurement and multi-lifecycle management.

In 2020, the Conference of European Directors of Roads (CEDR) issued a call for research on Resource Efficiency and Circular Economy and commissioned the project, 'Circular Economy in Road Construction & Maintenance' (CERCOM) [2]. CERCOM investigates how the circular economy could work in the context of highway construction and maintenance and what barriers and opportunities exist for its adoption. The aim of CERCOM is to deliver an innovative risk based framework and management tool to facilitate a step change in the adoption of RE & CE principles in procurement and multi-lifecycle management by CEDR NRAs. To develop the Risk-Based Analysis Framework (RBAF) and establish the system boundaries, risk-based decision analysis was first reviewed to establish current good practice.

2 OVERVIEW OF EXISTING RISK ANALYSIS FRAMEWORKS

2.1 *Risk analysis*

Design and maintenance of road networks aims to meet the required performance standards while also limiting the risk to road users and the infrastructure itself. In procurement of any design or maintenance strategy, consideration of risk is paramount in deciding upon the most appropriate solution for the scheme. That is, the solution which maximises safety and ensures the desired level of functionality while minimising cost. With the move towards a circular economy, there is an added objective to ensure RE & CE factors are integrated within this assessment. One of the objectives of CERCOM is to identify the fundamental characteristics of a risk-based framework to make it applicable to NRAs in their procurement processes. Risk management involves gaining an understanding of what may go wrong, the probability of this happening and the associated consequences. The primary source for the current work is ISO 31000:2018 Risk management – Guidelines [2]. The prescribed risk management process involves the systematic application of policies, procedures and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk. This process is illustrated in Figure 1.

The ISO 31000 framework should be considered when developing risk assessment frameworks for any specific need, and as such forms the basis for the development of the CERCOM RBAF. The framework enables rational decisions to be made around the adoption of RE & CE approaches, with the principles of risk assessment at its core.

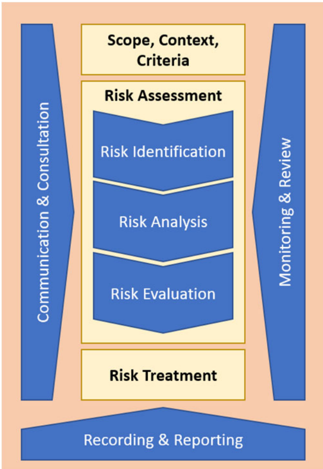

Figure 1. ISO 31000 Risk Management Process [2]

Within the scope of CERCOM, the Scope Context and Criteria, Risk Assessment and Risk Treatment headings of ISO 31000 are integrated directly into the core aspects of the RBAF. The other aspects of Communication and Consultation, Monitoring and Review and Recording and Reporting are continuous processes and occur throughout the procurement process.

The objective of CERCOM is to build upon risk-based assessment frameworks previously developed in the CEDR funded RE-GEN (Risk Assessment of Ageing Infrastructure) project as well as EU framework projects such RAIN (Risk Analysis of Infrastructure Networks) and INFRARISK (Novel Indicators for Identifying Infrastructure at Risk). These previous frameworks for assessment of transport infrastructure were reviewed to facilitate identification of good practice. While numerous examples exist in the literature and were considered as part of the overall review, an overview is provided of these projects based on their relevance to the CERCOM risk-based analysis framework requirements. These can be tailored to suit the CERCOM objectives.

2.2 INFRA-RISK

The INFRARISK project (www.infrarisk-fp7.eu/) aimed to develop reliable stress tests on European critical infrastructure using integrated modelling tools for decision-support. The project intention was to advance decision-making approaches leading to better protection of existing infrastructure while achieving more robust strategies for the planning of new infrastructure. Integrated risk mitigation scenarios and strategies were developed, using local, national and pan-European infrastructure risk analysis methodologies, taking into consideration multiple hazards and risks with cascading impact assessments. An operational framework with cascading hazards, impacts and dependent geospatial vulnerabilities was developed.

To develop the INFRARISK Risk Assessment Framework, a two-phased approach was undertaken. The initial definition of the INFRARISK Risk Assessment Framework had its basis in the global procedure of ISO 31000. This is key to any framework in order to keep the format in line with modern codes of practice. In the preliminary framework, the system boundaries are defined, including the spatial boundaries (e.g., the extent of the transport network to be assessed) and the temporal boundaries (i.e., the time period over which the risk assessment will take place, and the subdivisions of this time period over which the risk will be analysed).

Through engagement within the INFRARISK consortium and discussion on the specific requirements, an updated Risk Assessment Framework was defined by the project, which provided a more flexible and open methodology which could be adapted to not only road and rail infrastructure networks, but all infrastructure networks, allowing for the inclusion of cascading events and interdependencies. The Framework is illustrated in Figure 2.

Figure 2. INFRARISK Final Risk Assessment Framework

In the initiate stage, spatial boundaries and temporal boundaries within the system are considered. This step should also consist of an overview of how the assessment will be carried out, the levels of abstraction and the models and software to be used to determine if the infrastructure related risks are acceptable. Effort should also be made at this stage to define what an acceptable level of risk may be in the context of the organisation. It is important that some thought is put into this before the risk assessment is conducted to provide context to the results.

The Conduct Risk Assessment phase again consists of analysing the system by simulating its behaviour in specific situations and estimating and evaluating the risk. The INFRARISK approach recommends performing the assessment initially at a very high level of abstraction in order initially describe the process, followed by iteratively refining the level of abstraction until it is decided that the level of risk is either acceptable or not. The systems and models can be tested and benchmarked throughout the iteration process, and the level of detail in each model can be enhanced throughout each iteration. This saves time placing needless levels of detail on models that have a comparatively low impact on the risk. This may be a useful step in the CERCOM context as the priorities and capabilities to perform risk analysis incorporating CE and RE aspects may vary significantly between NRAs. The various sub tasks within this stage include (i) set up the risk assessment, (ii) determine approach, (iii) define system, including the definition/determination of the system boundaries, events, scenarios, relationships between events, and models, (iv) estimate risk, and (v) evaluate risk. The INFRARISK framework allowed for the application of various levels of risk assessment, from quantitative to qualitative approaches. The qualitative approach may be demonstrated by a risk matrix, with consideration of likelihood and consequences, but without formal quantification. In the context of the CERCOM approach, the level of complexity in the risk assessment process may be dynamic and vary depending on the requirements of the NRA.

The Conduct Intervention Programme stage consists of developing measures to reduce the risk to an acceptable level and optimising to choose the most advantageous action or combination of actions. While the INFRARISK approach to risk analysis is more complex than what is required for NRAs to adopt CE & RE solutions in the procurement process, there are certain aspects of the tools and framework that will prove to be of benefit for the CERCOM RBAF.

2.3 RAIN

The RAIN project (http://rain-project.eu/) aimed to develop an analysis framework that identified critical infrastructure components impacted by extreme weather events and minimised the impact of these events on the EU infrastructure network. The project had a core focus on land-based infrastructure with a much wider consideration of the ancillary infrastructure network in order to identify cascading and inter-related infrastructure issues. A core component of the research considered the implications of climate change and the subsequent impacts that this may have on an already ageing and vulnerable infrastructure system.

The RAIN project is a particularly useful source for the development of the CERCOM approach in the development of quantitative tools which can be used for Risk analysis. The framework developed was fully probabilistic, with not only the hazards and impacts being modelled probabilistically, but also the consequences and "utility" of the associated impacts. As per the INFRARISK approach, while the methodology is complex and not directly applicable to the CERCOM objectives, many of the tools developed may be transferrable.

The framework consisted of 5 steps, globally divided into two phases; the inference phase and the decision phase. The first step of the inference phase, enumeration, consists of listing of all possible states that the infrastructure may be as well as all the possible actions that can be taken to manage these states This phase may be considered part of the "scope context and criteria" stage of the ISO 31000 risk management process.

The second step in the inference phase is the quantification phase. In this step, the hazards and associated vulnerabilities of the infrastructure are modelled in order to describe the likelihood of each state occurring. The quantification of the likeliness of the possible states of the system under consideration gives us the state probability distributions. The quantification step also contains the quantification of consequences of each state. This state consequence quantification is often based on historic data as well as estimates from key stakeholders.

The final step in the inference phase is the construction of the outcome probability distribution. This involves multiplication of the consequences and likelihoods at each state in the system. The risk is represented by a random variable representing the fact that the final risk is an uncertain value.

The first step in the decision phase is the construction of the "Utility" distribution. This is a distribution which describes the practicalities of a strategy in the context of the availability of budget to implement it. Choosing the action which optimizes the risk 'position' on this basis is therefore the final step in the process. This level of probabilistic utility estimation is not required for CERCOM, where deterministic outcomes of RBAF are preferable in order to be usable in the procurement process of most NRAs.

However, there may be scope to include a flexible approach whereby probabilistic tools may be employed where data is available.

2.4 Re-Gen

The primary objective of the Re-Gen project (Risk Assessment of Aging Infrastructure Networks - www.re-gen.net) was to provide Road Owners/Managers with best practice tools and methodologies for risk assessment of critical infrastructure elements such as bridges, retaining structures and steep embankments. The Re-Gen project sought to adopt a network-wide probabilistic risk-based approach to optimize lifecycle performance of the infrastructure, within the context of evolving traffic demands and climate change effects. The Re-Gen project therefore suggested using quantitative risk assessment tools (e.g. fault tree or BBNs) to model the risk of road infrastructure in respect of climate change and long-term traffic growth. If historical data is not available to perform such analysis, Re-Gen recommended that application of structured expert judgment to provide quantitative data.

The Re-Gen project provided guidance on deterministic calculation of failure consequences, considering both direct and indirect costs, including rehabilitation costs C_{Reb}, vehicle detour / running costs C_{Run}, travel time costs C_{Trav} based on the average person wage and Accident costs C_{Acc}. The risk is then computed according to Equation 1:

$$R = P_f \times (C_{Reb} + \dot{C}_{Run} + C_{Trav} + C_{Acc}) \quad (1)$$

Where P_f is the probability of a specific failure state occurring, computed from the fault tree analysis. The Re-Gen project also proposed risk optimization techniques which are of particular relevance to the CERCOM approach. To make effective decisions, the risk framework must be able to identify the action (or combinations of actions over time) which both minimise the risk and the required resources. Re-Gen proposed Multi-Attribute Optimization for this task. An example was provided of potential interventions to prevent a risk (R) of bridge failure. It was assumed that after the implementation of the i_{th} intervention the value of the residual risk would be R_i. As such, a Risk Reduction Index (RRI) can be defined for each intervention as [4]:

$$RRI_i = \frac{R - R_i}{R} \quad (2)$$

The RRI lies in the interval 0.0 – 1.0 for feasible interventions. The cost of each intervention can be estimated as C_i and includes but is not limited to the cost of materials and labour. Having the total budget allocated for risk optimization B, a Cost Potential Index (CPI) can be defined for each intervention as [4]:

$$CPI_i = \frac{C_i}{B} \quad (3)$$

Finally, the Net Risk Reduction Gain ($NRRG$) of the i_{th} intervention is defined in this work as:

$$NRRG_i = w_1 \times RRI_i + w_2 \times CPI_i \quad (4)$$

Where w_1 and w_2 are weighting factors, reflecting the preference of decision makers to either reduce the risk or to expend less money on interventions. It should be noted that w_1 + w_2 = 1.0, and *CPI* is considered negative in Equation (4), reducing the *NRRG* brought about by the intervention. The optimal intervention strategy is the one which maximizes the sum of $NRRG_i$; that is, the net gain of risk reduction should be the greatest after the application of the optimal intervention strategy under the constraint of the limited available budget.

Although the framework developed in Re-Gen had a different aim to the CERCOM project, the tools are a good starting point for evaluating risk while prioritising RE and CE uptake by NRAs in the procurement of road construction and/or maintenance activities. The flexibility to perform quantitative or qualitative risk assessment also lends itself well to NRAs, while the multi-attribute optimization appears to be an excellent tool for building the prioritisation of environmental goals, RE and CE approaches.

3 CERCOM FRAMEWORK

3.1 Framework Overview

The aim of the CERCOM framework is to facilitate procurement of circular solutions for road construction and maintenance while assessing the risk of doing so. In order to develop the basis of the framework, the system boundaries and general context were first established.

The CERCOM framework considers technical, economic, environmental and social criteria, as well as RE / CE, to assess the change in risks in moving from a linear to a circular economy. The framework is applicable to all road infrastructure elements under the maintenance remit (e.g., road pavements, bridges, retaining walls, cuttings and embankments and roadside infrastructure). The framework is adaptable to new construction and maintenance methodologies, lending itself to, for example, the evaluation of novel "green", circular and bio-based maintenance solutions, and has a means by which the RE and CE ranking of different solutions can be considered.

The RBAF framework is outlined in Figure 3. It is reflective of the universally accepted ISO 31000 approach, with the "Scope, Context, Criteria", "Risk Assessment" and "Risk Treatment" integral within the 5 steps of the framework.

Figure 3. CERCOM Risk-Based Analysis Framework

3.2 Establish context

This step involves a description of the primary goals of the assessment, the hazards involved, the potential actions to reduce risk, the consequences to be considered and how the hazards and consequences will be calculated. A qualitative approach to defining the context is advised within the framework. Expert judgement should be used to establish the nature of the assessment, the hazards, the actions which may be taken, the level of the analysis and the means of assessing RE / CE approaches (i.e., as KPIs or through quantitative cost representation).

3.3 Likelihood

Likelihoods are considered quantitatively within the RBAF, quantifying as accurately as possible, the probability of failure, or the probability of exceedance of a given damage state for given scenarios of hazard and action. This can be used to quantify possible increased risks associated with moving from linear to more circular materials and practices. An example may include quantifying the probability of a certain level of pavement wear for different products proposed as part of a resurfacing regime. By quantifying the probabilities associated with traditional methods and more innovative methods, the various risks associated with moving towards a circular economy can be assessed and optimized as part of the framework. It is important to highlight that the framework does not replace or override these minimum safety requirements set out in design standards, but rather, it aims to use the performance level associated with different methods to compare, rank, and optimize viable options. Probabilistic modelling can utilize Event Trees, Decision Trees and Bayesian Network Modelling to consider the complex interdependencies between different network elements. For NRAs who may not possess the level of data required to perform quantitative probabilistic modelling, Event Trees are also a useful tool to contextualize the problem and describe the processes leading to failure. Expert judgement can then be used rather than probabilistic modelling to input the likelihoods where required.

3.4 Evaluate consequences

Consequences evaluated in a risk assessment are directly related to the specific failure states considered in evaluating likelihood. Probabilities and consequences are combined as part of the final optimization step of the process to calculate the Risk associated with a proposed construction or maintenance scenario. Consequences should be considered quantitatively and expressed in monetary terms where possible.

3.5 Establish additional KPIs

Additional KPIs are established for the scheme in question and their values are quantified for each potential strategy. KPIs should be as orthogonal as possible to avoid double counting and should be determined in a collaborative way among all stakeholders. A range of scores are proposed for each KPI and values are assigned for each strategy. Weights are used to assign relative importance in the "Optimize" step. KPIs have a value between 0.0 and 1.0, with 0.0 having the lowest benefit on CE / RE and 1.0 having the highest benefit. Within the framework, these additional KPIs are divided into 3 categories, RE & CE, Environmental and Social. The framework is flexible to include as many KPIs as necessary in order to capture individual NRA requirements. A ranked interpolation approach of quantifying each KPI provides a robust and stable means to evaluate various RE / CE factors in an intuitive way, and is outlined as follows:

1. Determine the number of ranks required to quantify the KPI;
2. Set the minimum rank to a value of 0.0, and the maximum rank to a value of 1.0;
3. Determine the mathematical relationship between each KPI rank;
4. Score the KPI for the scenario being evaluated and interpolate according to ranked relationship.

In the simplest case, a linear relationship may be assumed between the first and final rank. Where a more complex response is required, a multi-linear or quadratic relationship may be established between different KPI ranks. This type of model may be developed, for example, where the benefit of increasing the rank raises the RE / CE, environmental or social value exponentially. In this case, linear interpolation should be carried out between each rank, as illustrated in Figure 4. An example of how ranks may be structured to reward innovation is outlined as follows:

- Rank 1 = minimum acceptable performance, KPI 0;
- Rank 2 = industry norm, established practice but not always applied, KPI 0.15;
- Rank 3 = industry leading performance, uncommon, KPI 0.6;
- Rank 4 = medium term goal, KPI 1.0.

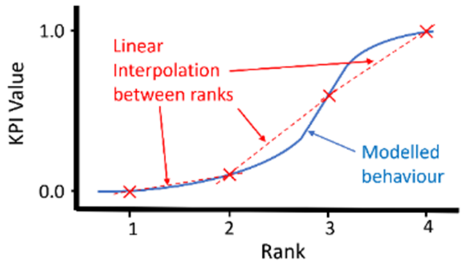

Figure 4. Interpolating KPI values

3.6 Optimize

To allow performance, cost, resource efficiency, environmental and social factors to be considered and integrated into a single index for optimization purposes, the Net Risk Reduction Gain (*NRRG*) is incorporated into the RBAF (Equation 5). This weighted sum involves calculation of the risk, costs and all KPIs to provide a means of scoring the various potential maintenance strategies. All weights assigned must sum to 1.0. For each potential action, the Risk associated with each strategy is calculated and used to generate the Risk Reduction Index (*RRI*), outlined in Equation 6. In terms of cost, the calculation of the Cost Potential Index (*CPI*) provides flexibility within the framework to allow NRAs to vary the level of complexity involved in the calculation of costs associated with each proposed strategy (Equation 7).

$$NRRG_i = w_1 \times RRI_i + w_2 \times CPI_i + w_3 \times KPI_{1,i} + w_4 \times KPI_{2,i} + \cdots \quad (5)$$

$$RRI_i = \frac{R - R_i}{R} \quad (6)$$

$$CPI_i = \frac{B - C_i}{B} \quad (7)$$

R = Risk associated with the “Do Nothing” option;
R_i = Risk associated with maintenance / construction option i;
B = Budget available for maintenance / construction activity;
C_i = Cost associated with maintenance / construction option i;
$KPI_{3,4,5\ldots,i}$ = Values of each KPI associated with maintenance / construction option i;
$w_{1,2,3\ldots}$ = Values of weights for each KPI. Note that all weights must sum to 1.0

The developed additional KPIs should ensure that contractors can be rewarded for producing a scheme that will be long lasting, cost effective to maintain, use limited amounts of raw materials, designed for multiple lifecycles and/or can be readily repaired for (multi) life extension. The intention is to add components to the scheme design considering reuse, recycling, demountability, etc. pointing towards closing the loop. The KPIs should also be sympathetic to the various maturity levels across NRAs. For example, staff in NRAs may have zero/low or medium levels of awareness of RE & CE. Another example is that the supply chain may have zero engagement between stakeholders, may just recognise the need for engagement or may be actively engaged.

The high-level indicators provide a means to rank strategies taking account of resource efficiency, environmental and social factors within the framework, while allowing for quantification of risk and multiple lifecycle performance. While performance and cost are encompassed within the *RRI* and *CPI*, further KPIs are required for RE & CE, environment and social considerations. It should be again noted that all weights will sum to 1.0, and the KPIs should be expressed in the interval of 0.0-1.0, with 1.0 being the maximum possible value achievable within each KPI. The minimum requirements of each KPI (as defined within the objectives and codified norms of the NRA) should be sustained for each option considered.

This approach allows for maintenance and construction costs and/or Whole Life Costing/multi-LCA to be incorporated. KPIs are utilized within the calculation of *NRRG* to integrate critical resource efficiency, environmental and social factors.

4 SAMPLE APPLICATION

A sample application of a resurfacing scheme for a section of road was considered to demonstrate the application of this framework and assess the stability and robustness. A brief outline of the example is summarized below. As well as the “do nothing” scenario as reference, 3 maintenance options were examined.

- Option 1 - Use of **standard asphalt** surface course with minimum recycled content in line with NRA requirements. This can be further recycled as a surface course at the end of its life, or downcycled into binder / base course.
- Option 2 - Use of asphalt containing **high-recycled content** surface course.
- Option 3 - The use of asphalt containing 10% **crushed glass** and 20% reclaimed aggregate, jointly replacing 30% of the aggregate within the surface course.

The goal is to assess the relative risks associated with adopting the more resource-efficient maintenance scenarios through the application of the developed framework. To assess the possible risks associated with more innovative approaches, a probability of early failure is assigned to each option based on empirical evidence, as outlined in Figure 5. To calculate the risk, the probability of failure is multiplied by consequences which are defined in terms of cost. For this example, the consequence of a failure event is the emergency rehabilitation cost and is assumed to be equal for all 3 options. The *RRI* (Equation 6) is then generated for each scenario.

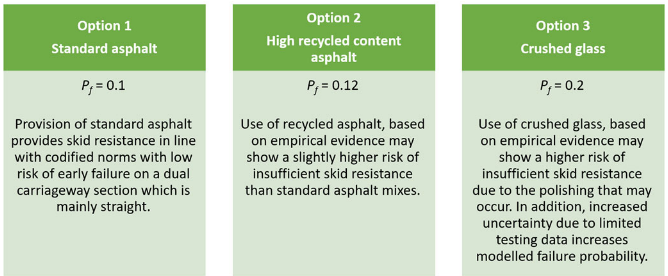

Figure 5. Probability of failure event for each option.

To calculate the *CPI* (Equation 7) for this sample application, it is assumed that the cost of carrying out maintenance options 1, 2 and 3 are €8 million, €7.5 million and €8.5 million, respectively (from an available maintenance budget of €20 million).

As the CERCOM project progresses, multi-Life Cycle Analysis will be integrated into the approach to directly take account of reuse, residual value and disposal of materials. This level of analysis may not be required for some NRAs or for certain schemes, so a more simplistic means to consider residual value of materials is suggested through the integration of an additional cost KPI (KPI_{RV}), which is assigned for each of the 3 scenarios in this example.

Option 1 is assigned KPI_{RV}= 0.5, assuming that materials are fit for re-use with extensive processing required. Option 2 would be similar to Option 1 in terms of residual value, but would require slightly more processing for reuse. As such, a value of KPI_{RV}= 0.45 is assumed. Option 3 is assigned KPI_{RV}= 0.25, assuming that crushed glass would limit the options available for subsequent reuse in surface course material.

For the current example, the following KPIs are also included in the analysis to account for circularity, resource efficiency and environmental factors, Energy Use (KPI_E), Recycled Content (KPI_{RC}) and Carbon Cost (KPI_{CC}). Based on data available, the construction Energy Use of dual carriageways vary from 5.6-12.6 TJ/km. For maintenance Option 1, the construction costs are assumed equal to 10 TJ/km. For Option 2, the construction material energy would be lower due to the lack of production and treating of raw material. For the purpose of this study, 1,200 TJ is assumed. For Option 3, an intermediate case of 1,400 TJ is assumed. Interpolating between upper and lower bounds yields values of KPI_E equal to 0.38, 0.63 and 0.45 for options 1, 2 and 3, respectively.

A recycled content of 20%, 60% and 30% is taken for the scenarios considered, yielding values of KPI_{RC} of 0.2, 0.6 and 0.3 for maintenance options 1, 2 and 3, respectively. For Carbon Content, based on empirical evidence associated with the maintenance scenarios considered and appropriate upper and lower bounds, values of KPI_{CC} of 0.62, 0.71 and 0.65 are interpolated for options 1, 2 and 3, respectively.

The *NRRG* (Equation 5) is calculated for each scenario using a weighted sum of all KPIs, the results are outlined in Table 1. For this example, the technical performance (*RRI*) is assigned twice the weight of each of the other KPIs. NRAs can alter weights to rank priorities when evaluating options. The results show that the option with high recycled content is considered the optimal maintenance scenario with the highest *NRRG*.

Table 1. *NRRG* for each maintenance option.

KPI		Standard asphalt	High recycled content	Crushed glass	KPI Weight
Risk Reduction Index		0.90	0.88	0.80	0.3
Cost	- Cost Potential Index	0.60	0.63	0.58	0.14
	- Residual Value	0.50	0.45	0.25	0.14
RE	- Energy Use	0.38	0.63	0.45	0.14
	- Recycled content	0.20	0.60	0.30	0.14
Environment	- Carbon Cost	0.62	0.71	0.65	0.14
Weighted Sum = NRRG:		**0.59**	**0.69**	**0.55**	1.00

Several sensitivity studies were carried out to check the robustness of the analysis and provide confidence in the basis for the risk-based analysis framework. The ranked interpolation method to quantify KPIs provides a robust and stable means of integrating quantitative measures of RE & CE into the analysis for the evaluation of construction and maintenance scenarios. This results in an intuitive user-friendly framework for NRAs, providing trust and confidence in output results.

5 CONCLUSIONS

The intrinsic value of road materials needs to be protected and if possible enhanced [5]. Climate change has led to the need to reassess road maintenance strategies. This RBAF achieves the objective to provide NRAs with a user-friendly tool that can be used in procurement of maintenance and construction schemes and adapted to suit the scope of the scheme and requirements of NRAs. It aims to support innovative use of new materials and methods to promote CE & RE while effectively managing associated risks. Crucially, the RBAF also has the scope to provide increased functionality as more data becomes available in terms of new materials and approaches. The framework is constructed in such a way as to allow NRAs on different stages of the journey towards circularity to progress over time, building on successful strategies and engaging with more circular approaches.

ACKNOWLEDGMENTS

This work was part of the CERCOM project, which is a CEDR project funded through the Call 2020 Resource Efficiency and Circular Economy.

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