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A Framework for Life Cycle Management of Road Pavements in Europe

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Abstract

Sustainability Assessment (SA) is a standardized practice that is rapidly taking up also in the building sector; however, the transport infrastructure sector is still questioning the best way forward to implement it as a regular practice. This work tries to fill this gap by providing a summary of the PavementLCM package, a comprehensive instrument developed for European National Road Authorities (NRAs). The aim of the package is engineering sustainability for road pavement management by including SA, Life Cycle Management (LCM) and circular economy practices while complying with the most recent European standards for the "Sustainability Assessment of Construction Works" (EN 15643, EN 15978 and EN 15804). As a result, the research delivers specific Guidelines to implement LCM as a current practice, as well as suggestions concerning circular economy and durability assessment.

Keywords: *life cycle management; sustainability assessment; road pavements; durability assessment; circular economy; decarbonisation*

1. Introduction

Among the main issues our society is dealing with, the environmental damages due to inattentive policies are one of them and sustainability is becoming a main approach for actual practices. In fact, also at international levels more

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and more attention is paid on it and the European Union is fighting for achieving the so-called "Sustainable Development Goals" until 2030 [United Nation, 2015] and obtaining the climate neutrality until 2050 [EU Commission, 2019]. For this reason, in each field there is a call for action and researchers are trying to implement sustainability in each sector of our society, proposing more environmental, economic and social practices, technologies and materials. It is spreading the need of quantifying how much sustainable a process/product is, thereby the necessity of performing a Sustainability Assessment (SA). Among the available methods, there is the Life Cycle Thinking which looks at the product/process throughout its entire life cycle, from the extraction of raw materials to its end of life, considering installation and maintenance. In this regard, International and European standards (ISO 14040 and 14044 for Life Cycle Assessment (LCA) or EN15978.2011 for the assessment of environmental performance of buildings) are the basis in carrying out this kind of calculation, suggesting how to calculate environmental and economic burdens. These results, analyzed with a Multi-Criteria Decision Making (MCDM), can lead to more robust and consistent decisions: this is what the authors of this work define as Life Cycle Management (LCM).

In civil construction works, for example, a set of EN standards have been already published. It is divided into three levels (framework, works and products) and separated for buildings and civil engineering works. Nevertheless, the methodology is not fully completed and for civil engineering works there is a bigger lack due to the general content. In fact, the standards don't specific how to perform a SA in each sector, as the Federal HighWay Administration (FHWA) framework (2014) does for environmental calculation of road pavements in USA. This gapy was the point of departure for PavementLCM research [Lo Presti et al, 2022 http://pavementlcm.eu]. This project, funded by the Conference of Directors of Roads (CEDR), has tried to comply with most recent European standards for the "Sustainability Assessment of Construction Works" (EN 15643, EN 15978 and 15804) and define a framework for a life cycle-based approach in order to implement LCM practices in road pavements construction and maintenance.

2. Framework

In order to fill the gap in knowledge and provide a complete package of methodologies and tools to help National Road Authorities (NRAs), the research covered three main points: the innovation in Sustainability Assessment (SA), the innovation in Durability Assessment and the progress in terms of implementation of Circular Economy (CE) , as shown in Figure 1.

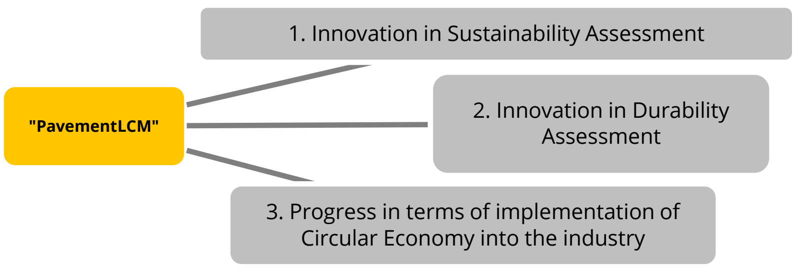

Figure 1 – Methodology used within the "PavementLCM" project

2.1. Innovation in Sustainability Assessment

Actual EN Standards are developed in a strong way for buildings, a bit less for the other construction works, whose road pavements are part. The research was based on the main points:

- Adapting the actual standards for buildings and civil engineering works to road pavements, focusing on the "Framework on specific principles and requirement for civil engineering works (EN 15643-5)", on the buildings' "Calculation methods" (EN 15978:2011) and on the "Core rules for the product category of construction products" (EN15804:2011+A2:2019);
- going deeper in the State-of-the-Art on the subject, including also extra-UE research, such as the Pavement Life Cycle Assessment Framework, published by the FHWA (2015).

- Involving the NRAs in order to understand their needs and facilitate the implementation of a more sustainable approach.

As a result, specific Guidelines for carrying out a SA and analyzing them through a MCDM methods for road pavements were defined, with the aim of leading NRAs to more consistent and robust conclusions.

2.2. Innovation in Durability Assessment

A durability assessment for a new road pavement is typically based on performance tests in the lab on fresh material. To improve the reliability and the usefulness of the assessment we suggest and demonstrate an approach where the lab performance test is supplemented with accelerated load test on fresh and artificially aged material as well as a comprehensive statistical analysis of survival data for the reference materials and the expert opinions valuation of the attained data.

Climate, road building and maintenance practices as well as traffic load spectra differs between different regions in Europe. Hence the actual service life of the reference road materials varies across the regions. Weibull and lognormal distribution can be used to model the lifetime (time to failure) We propose to use both complete observations of service life and sensored observations contain partial information about the survival time though end of live is not observed in the analysis.

We also advise to use Bayesian inference [Van de Schoot et al, 2021; Park et al, 2008] as a tool to account for both the uncertainty demonstrated in the local historical records associated with natural variations in durability of pavements and on the other hand, the estimates of the durability of the new materials that are based on experts' opinion and therefore include epistemic uncertainty associated with the experts' disagreements, the effects of limited sample sizes and local conditions they are familiar with, and their own bias and preconceptions.

2.3. Implementation of Circular Economy

CEcontinuously gaining more and more traction within the sector of built environment, has indirectly pushed the involved stakeholders and National Road Authorities (NRAs) in the sector of pavement engineering and management, towards the realization that more principles of CE should be implemented in the overall life cycle management of road infrastructure assets. To better understand what has been implemented in terms of CE in the road engineering sector the national/regional authority roadmaps towards CE that have been published through the European CE Stakeholder Platform were analyzed. Moreover, a questionnaire about CE and its implementation was distributed to different NRAs across Europe and the results were analyzed. In addition, online research has been conducted via the official websites of the investigated NRAs in order to identify aspects of communication concerning CE. The words "circular economy" and "sustainability" were searched for on the websites and the results were analyzed. When it comes to transport infrastructures and asphalt pavements specifically, it is difficult to encompass and conceptualize in their life cycles all these principles. As a matter of fact, there is a plethora of roadmaps towards CE that have been published attempting to pave the way towards achieving circularity at national level but not a lot of effort has been made to specifically address the sector of road engineering. In this study we have identified what has been published by national and/or regional authorities for the road engineering sector that can be implemented towards more circular operational patterns. [Mantalovas et al. 2020]

3. Results

3.1. PavementLCM Guidelines

On the basis of what explained in European Standards and considering the inputs from State-of-the-Art and workshops with NRAs, the authors defined a step-by-step procedure with the aim of introducing LCM in road pavement field.

The Guidelines are structured on seven points process, developed on the basis of the one proposed by the standards, and they are useful to perform an LCM considering environmental, economic and technical/functional indicators.

The structure is developed as follows, as showed in Figure 2:

- The first five points correspond to the first six proposed in the EN. They are useful to define the purpose and the object of the assessment, the scenarios, the data collection and the calculation of indicators. In details, the attention was focused on the step 2 "Specification of the object of the assessment": at this purpose a specific Framework was developed;
- The sixth step is linked to the decision-making process, specifically introduced in this research and not contained in the EN. It is suggested the use of the PROMETHEE;
- The seventh step, which unifies the EN points 7 and 8, aims at reporting, communicating and validating the results.

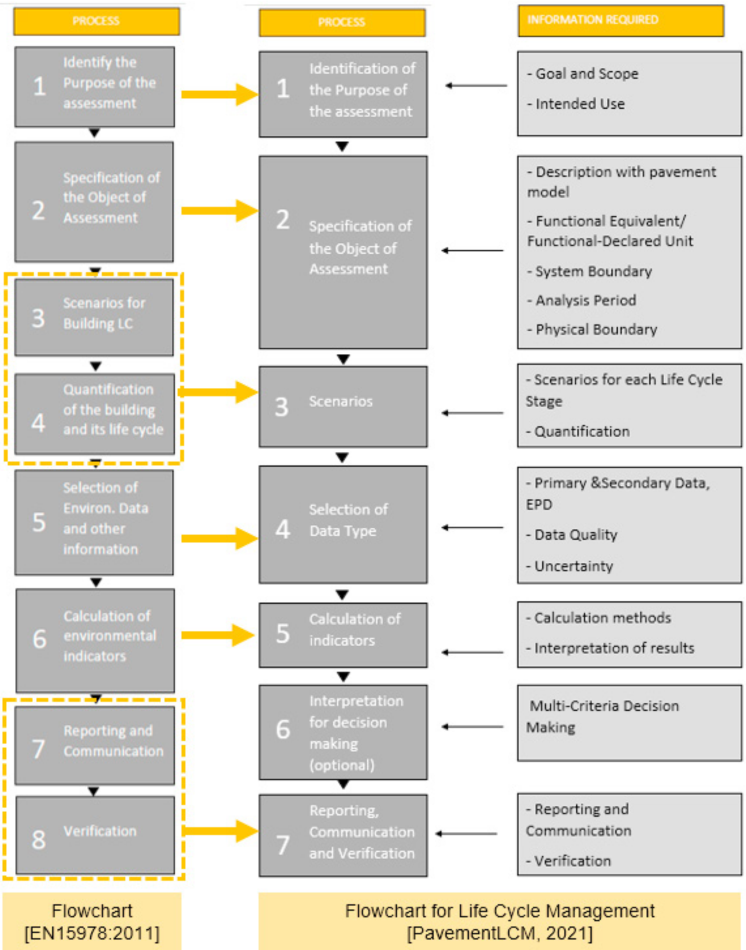

Figure 2 - Comparison between EN15978:2011 and PavementLCM flowcharts

As specified above, a deeper attention was paid to the "specification of the object the assessment" (step 2) through the definition of Framework for road pavements. Two different systems have been identified: pavement materials and pavement activities (Figure 3). The first ones are all the materials used to build, repair and maintain road pavements and its components; the second ones are all the activities aimed at building, repairing and maintaining road pavements or its components. The levels differ in terms of system boundaries (production and/or entire life cycle), analysis period, functional unit or stakeholders involved (producers or contractors and NRAs). The framework, through a literature review and workshops with NRAs, also defined a set of indicators to calculate.

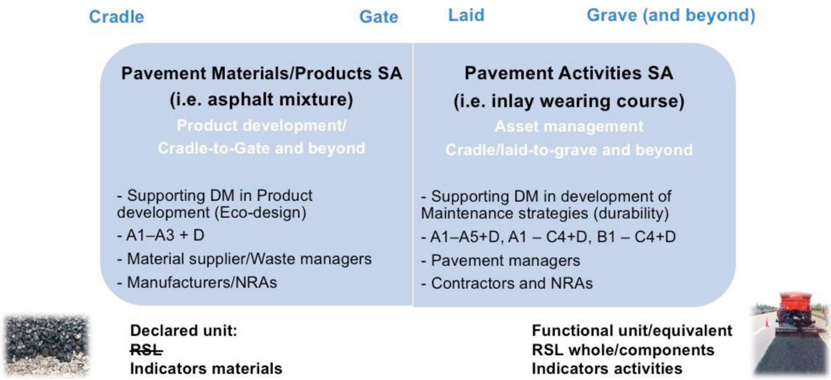

Figure 3 – Pavement materials vs Pavement Activities

3.2. Durability Assessment

To demonstrate the approach for durability assessment of new mixes we used stone mastic asphalt, SMA, and porous asphalt, PA, as reference materials since there is knowledge about their actual performance in different European countries. The reference SMA was compared to three SMA mixes with potentially higher durability and/or including high percentage of reclaimed asphalt (RA) potentially more sustainable asphalt mixes. The reference PA was compared to three PA with strong fibers or polymer modified binder.

Apart from the typically advanced laboratory characterization of the materials, for example the indirect tensile test to characterize the stiffness, a set of wide-ranging tests were included in the test protocol. These tests included oxidative ageing of the material, dynamic shear modulus test, dynamic shear rheometer tests of the aged and recovered binders and most importantly an accelerated load test performed in a circular road simulator. This last test was performed in three stages, at 35 °C in dry conditions, at around 0 °C with seven freeze-thaw cycles in wet conditions, and finally at 30 °C in dry conditions with a flexible underlayer until failure. SUV tires loaded with 450 kg and with the inflation pressure of 3,5 Bar running at 70 km/h were used in the accelerated load test. Throughout the accelerated load test signs for distress such as rutting, fretting, stone losses, change in texture and friction and cracking was recorded. To estimate the relative service life of the new asphalt mixtures compared to the reference mixes based on the results from the laboratory studies we have to understand the context in which the new mixes are going to be used in, i.e. in which country and which type of road. We also need to have a picture of which type of distresses are common in that context. This information was collected via questionnaire to local experts and is presented in Table 1.

Table 1 - Distress likely to trigger resurfacing of high-volume roads with for SMA16 (or SMA11, or SMA11 10%RA) or PA16.
(++ indicates that the distress is likely cause for resurfacing operations. + indicates that the distress is somewhat likely cause for resurfacing operations.)

	DK	SW 1	SW 2	DE	NO	LT	SW2	SW3	NL	DE
Answers valid for	SMA11	SMA16	SMA16	SMA11	SMA16	SMA11	PA16	PA16	PA16	PA11
Fretting	++	++			+	++	++			
Ravelling	+	++			+	++	++		++	++
Rutting	+	++	++		++			++		
Road wear		++			+		++	++		
Low friction	+			++		++				
Cracking (not specified)		+		++		++				
Transverse cracking										
Longitudinal cracking		+			+	++				
Edge cracking					+	+				
Block cracking						+				
Alligator cracking		+				+				
Other						+			+	

The experts also agreed in the questionnaire that a decrease in traffic volume by 25 % would only increase the expected service life for high volume roads by approximately 10% (5-15 %), instead of 33% which would be expected if service life was only dependent on traffic if the Palmgren-Miner linear damage hypothesis would apply. Thus, it could be concluded that other factors that influences the service life, such as ageing and exposure to wet conditions and freeze-thaw cycles have a substantial influence on the service life.

The outcome of the experimental studies for the SMA materials were classified as performing better or worse than the reference mix in each study using a scale with five levels. The compilations are presented in Table 2, where the reference mix was a SMA 16 70/100 with 6,2% binder. The mix was produced in a plant in Sweden. The aggregate was granite from Styvinge. 0.4% cellulose fibers and 0.3% Wetfix BE was added to the mix. Two SMA 11 mixes were produced in plants in Denmark. The first mixe was a SMA 11 40/60 with 5.8% binder. The aggregate was approximately 70% Hyperit, 20% Labradorit and 10% granite from the RA. 1.5% reactive filler and 1.25% limestone filler was used together with 0.35% Viatorp 66. The second mix was plant produced SMA 11 with 40% RA in the mix. The SMA 8 50/70 with 60% RA in the mix. It was produced in the lab. 54% of the binder in the final mix originated from the RA. To compensate/rejuvenate for the hardened binder in the RA, 0.53% of a VMA additive was used (8.7% of the total binder content).

Table 2: Relative performance of SMA mixes with potentially lower environmental impact compared to the reference SMA16 mix*. The relative performance is indicated with - -, -, =, +, ++ where - - and - indicates much worse and worse, = indicates equal performance and + and ++ indicates better or much better performance. RA – reclaimed asphalt.

	Test	SMA11 10%RA	SMA11 40%RA	SMA8 60% RA
Climate	Water sensitivity	=	=	=
Ageing	Short and long term oven ageing	+ +	+ +	- -
Traffic	ALT (accelerated load test)	= ravelling = rutting = cracking = friction	= ravelling - rutting = cracking = friction	= ravelling - rutting = cracking = friction
Traffic/aging	ALT of aged material	= ravelling = rutting + cracking = friction	= ravelling = rutting + cracking = friction	= ravelling = rutting - cracking = friction
Traffic/climate	ALT: Water sensitivity and freeze-thaw cycles	=	=	- aged material
Traffic	Stiffness modulus / road structure performance	+	=	-
Traffic	Shear modulus / rutting	+ +	=	+

To make the estimations the service lives for the new mixes one needs to compare the relative performance of the new mixes considering the context. In the survey presented in Table 1, there were large differences between different countries regarding the typical distresses that triggers resurfacing. The following example for the situation in Germany may serve as an example: Typically, high-volume roads with SMA are resurfaced because of low friction in cracking and low friction in Germany. Based on the performance regarding cracking and structural performance it is estimated that the SMA11 10% RA have longer (+5%) lifetime, the SMA11 40% RA have the same lifetime, and that SMA8 60% RA have shorter (-10%) lifetime, compared to the reference SMA on high-volume roads.

3.3. Circular Economy

In order to assess the current knowledge of NRAs in terms of implementing circular economy practices, the authors created and distributed questionnaires that also helped to identify NRA's ambitions in this direction. Reviewing the documents collected from the European Circular Economy Stakeholder Platform, it becomes obvious that the principles of CE within the transportation sector are not well established yet and thus contacting various NRAs was enlightening. All the NRAs contacted are aware of the concept of CE and have at least minimum knowledge about what it is that it represents. All the NRAs seem to be familiar with the most commonly known and easily applicable principles of the CE, apart from the NRA that represents Belgium. Austria's and the Netherlands' NRAs seem to be the most informed in terms of CE knowledge, exhibiting the higher number of CE principles that they are familiar with. Among all the NRAs to which the questionnaire was sent, the most commonly known principles of CE are:

- Design out/minimize waste
- Use waste as resource
- Preserve and extend what is already made (usually translated as “preventive maintenance”)

When the NRAs were asked about which principles of the CE are implementing, Belgium, Norway and Lithuania replied that none of them is currently being implemented. However, among the remaining NRAs the most common answers that were received in terms of implemented CE principles are:

- Preserve and extend what is already made
- Design out/minimize waste

More and more NRAs should allocate percentages of their budgets towards the development of circularity metrics and roadmaps/strategies towards the implementation of CE and the assessment of the levels of this implementation. This could help to monitor and evaluate the progress that is being made and finally develop a feasible and spherical framework of how they should actually be implementing CE in asphalt pavements in the best way possible. Moreover, having tabulated the answers provided by the participating NRAs it becomes obvious that there is a conceptual misunderstanding of NRAs when it comes to the business/procurement aspect of circular economy. Most of the replies of all the asked questions were referring to life cycle assessment and EPDs or CO2 foot printing. In reality, when it comes to circular economy and procurement schemes that can comply with it the situation is much more complicated.

4. Conclusions

Sustainability is becoming a keyword in our society, hence it is fundamental to adapt and/or adopt practices which aim at implementing/engineering this “philosophy”. Therefore, starting from the necessity of implementing a more sustainability-driven mindset also in the construction and management of road pavements, this research aimed at three main objectives:

1) Engineering a framework to introduce Life Cycle Management (LCM) in National Road Authorities with a focus on Sustainability Assessment.
2) Detailing a procedure to include road pavement durability assessment in LCM
3) Providing a state-of-the-art and best practices on the implementation of Circular Economy within NRAs

With regards to these objectives this work presented details of the following solutions:

- internationally recognized guidance on LCM for NRA s through a package with State-of-the-art information on the topic; a framework to implement LCM practices amongst the road pavement industry stakeholders and Guidelines to carry out Sustainability Assessment exercises according to the most recent standards on the topic (EN 15643, EN 15978 and 15804);
- a methodology for durability assessment of wearing courses for road pavements as well as datasets for selected green asphalt mixtures, through a coordinated effort comparing conventional asphalt mixes with green ones. To perform these calculations several laboratory tests were used, following three strategic lines: ALT test, lifetime estimations in different case studies of European contests for aged and unaged mixes with empirical-mechanistic design methods and probabilistic modelling of uncertainties. Generally, investigated green mixtures showed to have good performances, also better than conventional mixtures, mostly when the RAP amount is low;
- Sustainability has been formulated in theory and now each industry should pursue path for implementing it. The results of this work have been produced by the authors but also introduced within a forum that for the first time in Europe allows NRAs to discuss and learn about sustainability assessment best practices with other stakeholders as well as with academics and experts from several part of the world. With regards to Circular Economy, NRAs should allocate higher budget percentages towards becoming more familiar with business models and green procurement. Moreover, the collaboration with economists or economic analysts

could be of great help for the NRAs in order for them to formulate a procuring and operating scheme that can fulfil their circular ambitions.

This first theorical part will be followed by the implementation where the authors will be involved in platforms for exchange of knowledge with the NRAs. In fact, every cultural change starts from the intuitions, but it is mandatorily followed by theorization and exchanges with stakeholders.

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