Enhancement of sustainable road design towards compatibility between pavement materials

Ph.D. Larissa Strömberg\textsuperscript{a,b,1}, Prof. Lev Khazanovich\textsuperscript{c} and Prof. Staffan Hintze\textsuperscript{d,e}

\textsuperscript{a}Senior Environmental Advisor, Business Area Infrastructure, NCC Nordic Construction Company, Solna, Sweden

\textsuperscript{b}Affiliated faculty, Department of Civil and Architectural Engineering, KTH Royal Institute of Technology, Stockholm, Sweden

\textsuperscript{c}Anthony Gill Professor, Department of Civil and Environmental Engineering, University of Pittsburgh, USA

\textsuperscript{d}Head of Engineering Development, Business Area Infrastructure, NCC Nordic Construction Company, Solna, Sweden

\textsuperscript{e}Professor, School of Architecture and the Built Environmental, KTH Royal Institute of Technology, Stockholm, Sweden

\textsuperscript{1}For the corresponding author: larissa.stromberg@ncc.se

KEYWORDS: sustainability declaration, LCA, LCCA, EPD, road design.

Conflicts of Interest: None
1. ABSTRACT

The need for correctly made comparisons of different pavement materials, regarding cost-efficiency to reduce the climate impact, is increasing, especially in connection with new types of climate-neutral materials, so that sub-optimizations and oblique competition do not arise. Both the Swedish and USA’s authorities are beginning to demand the Environmental Product Declaration (EPDs) as a certificate of the pavements’ environmental performances from the contractors. There are some methodological difficulties to use the EPDs for comparison of the environmental impacts between different asphalt mixes or between the asphalt- and concrete pavements. This paper has analyzed two new standards which propose to extend the declaration to several aspects of sustainability: technical, environmental and economic performance. In this article, we have investigated if these standards can be used to form a framework to create an extended sustainability declaration of road pavements allowed a multidisciplinary comparison of different materials based on technical performance, Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA).
2. INTRODUCTION

In the next few years in Sweden substantial investments will be made in the mega road projects, such as the West Link in Gothenburg and the Bypass Stockholm. There is a great interest among Swedish public clients such as the Swedish Transport Administration (STA) (1) and municipalities (2) in using new innovative solutions and material choices in these projects in order to build more climate neutral roads. Because of the lack of experience in design and construction of concrete pavements, most roads in Sweden are being built of asphalt. The asphalt pavements are considered a cheaper alternative taking into account the initial investments, but their maintenance might be costly over time. Moreover, an increase in axle weights, changes of the traditional ways of travel, e.g., the use of automated and guided vehicles, and the stricter customer requirements on reducing the climate impact require new approach and the creation of science-based framework to steer the pavement industry towards more climate neutral solutions.

In the European Union and Sweden, there is a strong political drive to develop standards and regulations to reduce the climate impact of the transportation industry. The effect of these standards on reducing the climate impact for pavements is unknown and has not been verified with laboratory or field tests. Assessment of the measures that give the most cost-effective emission reductions is one of more difficult tasks in transitioning the pavement industry to more climate neutral and its complexity has been illustrated by McKinsey (3 & 4) as the global cost curve that shows opportunities and costs of various measures for reducing greenhouse gas emissions. The conclusion is that the world is changing, and the measures we consider expensive today can become relevant in the future through adaptations, innovations, and technological development. Figure 1 has been developed by the International Energy Agency (5) and is based on McKinsey's curve for opportunities and costs for reducing greenhouse gases to show where various instruments have the highest cost-effectiveness.

![Figure 1: Cost-effective use of political and market-driven instruments for reducing greenhouse gases (5).](image-url)
In a perfect world, pricing of carbon dioxide emission would have been enough to transform the industrial processes so that the most cost-effective climate measures are implemented first. In reality, market failures mean that pricing should be accompanied by complementary tools. To the left of the curve in Figure 1 are climate measures that have a "negative price" - that is, they are theoretically profitable to implement. For this reason, research, development, and demonstration are also important components of the policy mix (5). There are various opportunities for investment in the various business sectors, which can to some extent explain why good ideas and cost-effective solutions do not always reach actual measures.

The need for a theoretical framework for correctly conducted comparisons of various pavement materials in terms of cost-efficiency to reduce the climate impact, is increasing, especially for new types of climate-neutral fuels, machines, and materials, so that sub-optimizations and oblique competition do not arise at various stages of the construction process: in early planning, procurement, detail planning, production, operation, maintenance and recycling.

The new research from Massachusetts Institute of Technology (MIT) (6) has shown that increasing inter-industry competition lowers paving unit prices for both asphalt and concrete – which is likely to result in significant savings for both clients and taxpayers. A wider choice of pavement materials would result in a more fair competition with lower prices and higher climate-efficiency.

The Swedish, Norwegian, and US construction industries have come a long way in terms of the implementation of the EPDs as a measure of the environmental performance. The information in an EPD can be also accepted for use in reporting, marketing, procurement, and development of the product. EN 15804 standard (7) specifies an industry-approved method for the development of an EPD for a construction product. The US has adopted the EN 15804 with some modifications as the international standard, ISO 21930 (8). Both EN 15804 and ISO 21930 describe the calculation method for estimating environmental impact of construction materials.

The analysis (9) has shown that there is no constancy in the requirements for calculation, reporting, optimization and follow-up of the LCA/EPD in the Swedish client’s project specifications.

Moreover, in this Swedish study (9), the analyses have shown that clients’ requirements with the EPDs are integrated with procurement requirements along with the technical ones and calculations of the investment cost for a project. Since neither LCA nor LCCA are a part of the design optimization process, the EPDs are not used in the design process.

According to Mukherjee et al. (10), there have been some challenges in using EPDs to communicate LCA results for the asphalt industry in the US. Some of the challenges include defining system boundaries for different types of asphalt and concrete. Mixes may have different production methods such as production temperatures and additives. The comparison between asphalt and concrete pavements is an even more complex issue that has been discussed by the asphalt and concrete industries for many years.
In the long term, more extensive performance declarations allowing comparison of various pavement materials must be developed. This paper has identified two other standards that can be used to solve the above-mentioned issues with comparison of various material types with the EPDs. In this article, we have investigated if these standards can be used to form a framework to create an extended sustainability declaration of road pavements allowing a multidisciplinary comparison of road pavements based on technical, environmental, and economic performance.

To make the EPDs an effective tool reducing the environmental impact they have to be integrated with pavement design. Current road design and construction practices are specified by national guidelines, but the climate impact reduction goal is set at the global and international levels. The USA, Sweden and Norway have well-established methodologies and software tools for design of asphalt pavements, but Sweden and Norway have no tool for design of concrete pavements. These countries have experimented with LCA/EPD on several infrastructure projects, but the LCA/EPD procedures are not standardized and not completely integrated with pavement design.

There is a strong political drive to reduce the climate impact at the global level in both the EU and US. International collaboration and sharing of innovative solutions for road pavements could support establishment of a fair and transparent competition among producers. This would compensate for the lack of national experience with certain design solutions. There are two main areas urgently requiring international collaboration:

1. Development of framework for a standardized sustainability declaration which would enable a comparison of traditional and innovative alternative pavement materials.
2. Development of an internationally accepted approach to set the initial climate effectiveness targets in the bidding brief and in validating the results meeting these requirements, including technical performance, climate impact reduction goal, and cost efficiency in the design phase.

1. RESEARCH SIGNIFICANCE

The article proposes the framework for a sustainability declaration of road pavements based on the international standards and enhancement of the initial pavement design process and modification of the system boundaries in the LCCA and LCA analyses.

2. EXTENTION OF THE EPD

Within the international standardization community, active work is underway with the development of theoretical foundation for multidisciplinary optimization of sustainability of infrastructure projects. The goal of the ongoing standardization is assessing various design
options (including various material types) in a comparable and fair way. The EPD standard, EN 15804 (7) describes the calculation method for estimating environmental impact of construction materials, e.g., asphalt or concrete, see Figure 2.

We propose the use of the EN 15804 (or its international equivalent ISO 21930) along with two new standards, EN 15643-5 (11) and ISO 15686-5 (12), to develop a standardized declaration of the overall sustainability performance of road pavements. By combining three standards, it would enable establishing of a framework for assessment of multiple aspects of the road pavement’s performance.

The EN 15643–5 (11) has created common system boundaries for methods for assessing sustainability aspects of civil engineering projects. The EN 15643-5 relates environmental, social, and economic performances, as well as technical and functional performances, to each other. According to the EN 15643-5, the EPDs can only be used to compare the environmental impacts between different asphalt mixes or between the asphalt and concrete pavements if the system boundaries for the EPDs include all life cycle stages of the entire road structure and all cross-sections of the road. According to the Standard, sustainability performance assessments must be made for design alternatives with the same functional equivalent and within the same system boundaries, which creates comparability between different material choices. When
choosing a functional equivalent, the Standard refers to the national requirements and guidelines for specific construction types, such as roads, bridges, etc.

The international standard, ISO 15686-5 (12), gives a basic outline of how various sustainability aspects can be integrated into the entire construction process, see Figure 3.

![Figure 3: Performance requirements in the context of the project life cycle according to ISO 15686-5:2017.](image)

The current road design process is geared towards fulfillment of the technical requirements by establishing a final solution fairly early in the planning stage. The "locked" technical solutions are difficult to change later in the detailed design stage, when it is possible to calculate more precisely an LCA/EPD or an LCCA for a whole service life of a pavement. There is a dilemma in complying with existing design guidelines to meet technical requirements while optimizing a road pavement in order to reduce the climate impact, because the climate impact reduction targets are not part of the current design process. The ISO 15686-5 describes an iterative design procedure for a multidisciplinary assessment for early planning, preparation of bidding requirements, design, construction, maintenance, and end of life. Technical, economical, and environmental assessments can be performed in parallel, all based on the same system boundaries, enabling the designer to apply a broader basis for his/her decision taking.

The development of an extended sustainability declaration, including the relevant information on the environmental impact and life-cycle cost associated with a certain road design solution is very time-consuming and costly at the moment, because of the lack of more detailed knowledge of service life, maintenance, recycling potential, etc. For example, currently there is very little information on performance of concrete pavements in Sweden. This impedance can be overcome
by development of a global international database for most frequently used road pavements in Sweden and US, so that clients, contractors, and road owners can easily find comparable data on environmental, economic, and technical performance for alternative road pavements. The proposed database would support a wider choice of the environmentally friendly solutions with lower prices. This would create momentum for developing innovative climate-smart pavements in the EU and US.

In this study, we have analyzed needs and challenges for development of the standardized procedure for road design in Sweden.

3. NEEDS AND CHALLENGES

A. Modification of system boundaries of the used tools and methods. According to the Swedish Transport Administration (STA), the road structure and technical performance are mainly dependent upon traffic, climate zone, and the soil type at the location. There are some main types of road design, see Figure 4.

![Figure 4: Traditional road designs in Sweden.](image)

In Sweden, separate design methods and tools are used to analyze and optimize different performances of pavements, see table 1. The technical design of road pavements complies with the STA's regulations (13) and is carried out in software PMS Objekt (14). LCCA for repairs of existing or planning of new road projects is done using the STA's LCC tool for road superstructure (15). The Swedish industry uses EPDs as a declaration of both asphalt and concrete pavements’ environmental performance. The STA places bidding requirements on
estimation of the environmental impact of asphalt pavements with the LCA tool for asphalt pavement, EKA (16). STA also has the requirement to calculate and report the climate impact of the whole infrastructure project, e.g., a road in the Klimatkalkyl tool (2).

Table 1: Existing Swedish tools for optimizing various performance aspects of road pavements.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Tools</th>
<th>Purpose and optimization area</th>
<th>System boundaries</th>
<th>EPD modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>STA</td>
<td>PMS Objekt</td>
<td>Technical design and optimization of asphalt road structures.</td>
<td>The whole road structure (superstructure+substructure)</td>
<td>Partial A-B</td>
</tr>
<tr>
<td>STA</td>
<td>PMSV3</td>
<td>Gathering statistical/empirical/modelling data on pavements’ service lives.</td>
<td>Non-standardized</td>
<td>Partial C</td>
</tr>
<tr>
<td>STA</td>
<td>LCC tool for road superstructure</td>
<td>LCC for roads, optimization of initial and maintenance costs.</td>
<td>Only superstructure</td>
<td>Partial A-C</td>
</tr>
<tr>
<td>STA</td>
<td>EKA tool</td>
<td>LCA for asphalt pavements, optimization of the climate impact</td>
<td>Only superstructure</td>
<td>Partial A1-A3</td>
</tr>
<tr>
<td>STA</td>
<td>Klimatkalkyl tool</td>
<td>LCA for infrastructure projects, reporting/optimization of the climate impact</td>
<td>The whole road structure</td>
<td>Partial A1-A3</td>
</tr>
<tr>
<td>EPD systemet</td>
<td>EPD</td>
<td>EPD for asphalt, EPD for concrete, EPD for road etc. Only reporting.</td>
<td>One asphalt or concrete layer or the whole road structure</td>
<td>A-D (Compulsory A1-A3)</td>
</tr>
</tbody>
</table>

In both Scandinavia and the USA, EPDs are currently limited to the assessment of environmental impact of the pavement manufacturing (modules A1 to A3). Therefore, the current implementation of the EPD system is limited to comparison of the same type of the pavements, e.g., the same asphalt mix from different producers (10, 17). A more comprehensive EPD that includes the other EPD modules such as the service stage (module B) and the end-of-life stage (module C) requires more specific data on the future maintenance and repair scenarios. The lack of data prevents the wider use of EPDs as a certificate of environmental performance in infrastructure projects in Sweden (18,19,20).

In the absence of the reliable product-specific data on the potential maintenance intervals and expected service life, declaration of the other modules within an EPD can be done based on a functional equivalent, according to the reviewed standards. The functional equivalent must reflect the entire road’s life cycle and should be used to define the relevant comparable service life scenarios for a certain road project. Service life scenarios are based on the client’s project brief, national guidelines, and EPD-system’s rules for the infrastructure projects. Subsequently, alternative materials for a road pavement can be compared based on this project-specific equivalent.

For development of the project-specific equivalent, the future scenarios on the transport options between the production plant and construction site (module A4), paving technology (module
A5), operation and maintenance scenarios (module B), demolition and recycling of pavement (module C), and reuse of the recycled pavement in new projects (module D) must be specified. Functional equivalent depends on client’s specific brief and targets and can address performance requirements derived from various stakeholders' fields of interest. It is expected that the European standard being developed by CEN / TC 227 / WG6 will define the reference scenarios for modules A4-D as a common ground for further comparability for all life cycle stages of asphalt pavements (21). Currently, in Europe there is no similar standardization project for developing reference scenarios for concrete pavements.

In Sweden, the main obstacle for the development of the comparability equivalent is a lack of service life data on concrete pavements. This leads to a lack of ability to present information to enable project stakeholders to understand the interrelationship between costs (over the whole life cycle), environmental impact, and design quality when comparing alternative pavement types.

B. Gathering performance data. An expected service life and maintenance cost significantly affect the LCA and LCCA of the designed road. A concrete road has a longer service life before maintenance operations have to be carried out. This means that fewer maintenance measures are needed, requiring fewer traffic disruptions and lower costs. Maintenance of a concrete pavement is usually carried out every 15-20 years, while the interval for asphalt rehabilitation is 6-10 years (22).

Swedish National Road and Transport Research Institute (VTI) (22) has produced a draft maintenance database with empirical measurements of road status for different types of road pavements in Sweden. The most recent updates to the database were made in 2013. The STA uses an internal database with information on road monitoring, PMSV3 (23). The latest database is not linked to the design of new roads but is used for planning of road maintenance. The format of reported road status data, maintenance needs, etc. is not standardized.

In the United States, a tool for road design, MnPave (24) and MnPave Rigid (25), have been developed and recently implemented by the Minnesota Department of Transportation. The tool enables the design of both asphalt and concrete road structures and their comparison for choosing the most optimal pavement material. Empirical data on road maintenance is stored directly in the tool and is used for planning repairs of existing roads and building new ones.

A study from MIT (26) proposes a systematic approach to documenting the technical and climate performance of pavement networks at the US state-level. The first step evaluates network status, such as the current conditions, road mileage and surface type. The next step involves gathering network performance data, such as international roughness index, thickness, lane number, and traffic volume. Then, these data are entered into a modeling tool to estimate the future road conditions and fuel consumption of vehicles from pavement surface roughness and deflection. To predict future climate impact associated with various road preservation and repair measures, researchers apply their method to a case study of Missouri’s road network over a 50-year analysis period using various maintenance strategies.

We propose use of the outputs from this study and the above-mentioned projects to create a standardized parameter set which will describe various performance aspects of the road.
pavements. The standardized parameter set then be used to create a standardized declaration of the overall performance of road solution. The lack of local data on performance for certain types of materials, e.g., when the Swedish-specific information is not available, it is proposed to fill in the short-term gaps in data with the information on pavement design and performance of the pavements in the climate conditions similar to Swedish.

4. CONCLUSIONS

In this article, we have analyzed current needs and challenges for development of the standardized sustainability declaration for road design in Sweden. According to the analyzed standards, comparison of various pavements must be made on the basis of the same functional equivalent and within the same system boundaries, which creates comparability of various material choices. When choosing a functional equivalent, the standard refers to the national technical requirements and guidelines for specific construction types, e.g., roads. International collaboration and sharing of service life data are essential for compensation of the lack of local experience with certain design solutions. The proposed sustainability declarations of the road pavements can be implemented as a global international database for most frequently used road pavements, both in Sweden and USA. When the Swedish-specific information is not available, it is proposed to fill in the short-term gaps in data with the information on pavement design and performance of the US pavements in the climate conditions similar to Swedish.

5. ACKNOWLEDGEMENTS

The Swedish Construction Industry Development Fund (SBUF) is acknowledged for funding of the project Adaptation of road design to LCC and LCCA (project ID: 13722). The authors would like to thank Sweden’s Innovation Agency (Vinnova) through Strategic Innovation Program InfraSweden2030 and the companies and organizations that funded and participated in the project: clients (Swedish Transport Administration, Swedavia, Finnish Transport Infrastructure Agency), contractors (NCC, Svevia, Peab and Skanska), and academia (KTH Royal Institute of Technology, University of Pittsburgh and University of Illinois at Urbana-Champaign). Our special thanks to Department of Civil and Architectural Engineering, KTH Royal Institute of Technology for academic and scientific guidance when carrying out the project and writing the article.

6. REFERENCES

8 ISO 21930:2017 (2017) Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.
15 STA (2017) Support with LCC for planning and design of roads and railways (in Swedish), version 1.1, Publisher: Swedish Transport Administration.
23 STA (2018) User manual PMSV3- Information about roads, Publisher: Swedish Transport Administration.
25 Tompkins D (2018) MnPAVE-Rigid 2.0, Research project final report, Publisher: Minnesota Department of Transportation.