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road rehabilitation life-cycle calculation tool

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Abstract

The paper presents a new version of OptiVote multi-criteria decision-making tool. This new software modification is able to recommend users the most suitable method and technological variant for flexible pavement rehabilitation project, newly based on life cycle costs criteria.

The introduction describes available calculation tools that allow users independently evaluate different methods of road rehabilitation.

The basic part of this paper is formed by a case study presenting a project implementation with several different rehabilitation technologies used. Specific parameters such as the life cycle costs, price and emission demands are being estimated by the calculation tool. Those are the input data for the newly extended multi-criteria decision making tool OptiVote. User receives a clear recommendation, what method and technological variant to choose for a specific project, based on user-selected criteria. Users can combine several criteria like project life cycle costs, price, together with chosen emissions in proportion to the user's choice.

Keywords

road; rehabilitation; LCC; OptiVote; OptiRec

Introduction

Different financial resources and environmental demands of road rehabilitation technologies that are available lead to the search of useful tools that would help engineers and authority management in objective comparison of possible solutions. OptiRec calculation tools evaluate available flexible pavement rehabilitation methods. Each method is including technological variants and data are calculated by specific version of OptiRec application. OptiVote tool evaluates the output data mainly from OptiRec tools. Basic rehabilitation methods are listed bellow.

Traditional method (mill & replace)

Data from the rehabilitation of asphalt pavement by the traditional “Mill and replace” technology can be calculated by OptiRec TM tool. There are two main traditional method technological variations:

1. Milling of selected layers of the existing structure and paving of new layers, virgin material
2. Milling of selected layers of the existing structure and paving of new layers, virgin material with 20 % and more of RAP added (Snizek 2015)

Cold Recycling

Cold recycling technologies can be performed on-site or in plant. Data from both performances are possible to calculate with the OptiRec CR software tool. Main cold recycling technological variants are:

1. Milling of and mixing the material of existing structure of the selected layers (e.g. re-shaping)
2. Recycling with the application of hydraulic binders (R) – cement or cement suspension
3. Cold recycling (CR) in various variants using bituminous binder or a combination with hydraulic binder
4. Bitumen emulsion
5. Bitumen emulsion and cement (lime)
6. Bitumen emulsion and cement suspension
7. Foamed bitumen
8. Foamed bitumen and cement (lime)
9. Foamed bitumen and cement suspension (Snizek 2015)

Hot recycling

It is possible to calculate hot recycling technological variants by the OptiRec HR tool. There are two main variants:

1. Milling of and mixing the material carried out by in-situ hot remix plus technology
2. Milling of and mixing the material carried out by in-situ hot remix technology

Decision making tool

The newly developed software application OptiVote is a comprehensive tool that could serve to road authorities, engineers and architects. Based on the input parameters of the road section and the following selection of preferred benchmarks, the user gets the best recommendation on pavement rehabilitation technology. OptiVote includes technological options of basic flexibme pavement rehabilitation methods. Project data are calculated by software applications OptiRec TM, CR and HR. Therefore it is possible to compare all available technological methods of rehabilitation according to the selected criteria. For the assessment of combination of selected criteria, a multi-criteria evaluation tool was programmed. The tool allows also set a weight rating among the criteria.

Currently available criteria:

1. Life cycle costs of project
2. Price of the rehabilitation
3. Environmental impact (produced CO2, NOx + HC, CO and PM)

Case study

As an example for the case study, an interurban road that requires rehabilitation of the flexible pavement by one of the above-described technological variant was chosen. The chapter aims to use various OptiRec applications in order to assess the selected rehabilitation options. The comparison is based on the total CO2 produced and other emissions of greenhouse gas (NOx, volatile hydrocarbons, CO, solid particles). Apart from emissions, manufacturing costs and life cycle cost are being assessed as well. For the purposes of OptiVote tool demonstrating, a pavement with the following input parameters was chosen (see Table 1).

Basic parameters

Table 1: Pavement parameters

|  |  |
| --- | --- |
| Type of road | Asphalt pavement (interurban) |
| Length of the section | 1 000 m |
| Width of the rehabilitated road | 10 m |
| Rehabilitation depth | 120 mm (Mill & Fill)220 mm (Cold Recycling)50 mm (Hot Recycling) + 40 mm new wearing course  |
| Study period | 5 years, 10 years, 20 years |
| Inflation index (p.a.) | 2 % |

The pavement for reconstruction is a hypothetic example of a road with a low traffic load. The end of the asphalt pavement life is indicated by defects like e.g. moderate deep cracking in the asphalt layers. The road surfacing consists of asphalt concrete of a total thickness of 120 mm. The base layer consists of a mechanically compacted aggregate layer being put on a protective layer from crushed gravel. The total thickness of the road structure is 350 mm.

Table 2: Equivalent CO2 of input materials and mixes

|  |  |  |  |
| --- | --- | --- | --- |
| Mix components | Density (t/m3) | CO2 (kg/t) | Data source |
| WaterCement CEM II 32.5 RBitumen emulsion (C60B7)ACsurf 11+ACbin 16+ACsurf 8 | 1,001,251,002,362,342,32 | 0,000398022140\*37,9\*39,9\* | IVLIVLEurobitumeBenninghofen, OptiRecBenninghofen, OptiRecBenninghofen, OptiRec |

Table 3: Basic fuel data

|  |  |  |  |
| --- | --- | --- | --- |
| Substance | Density (t/m3) | CO2 (kg/l) | Data source |
| Diesel – refining | 0,84 | 0,26 | Afteroilev |
| Diesel – consumption | 0,84 | 2,66 | MZP ČR |

Traditional way of rehabilitation

Table 4: Traditional method – pavement design (Snizek 2014)

|  |  |  |
| --- | --- | --- |
| Original structure | Activities  | New structure |
| 40 mm - ACsurf 1180 mm – ACbin 16150 mm – Mech. bond gran. mat.200 mm – Ga (31.5mm) | Cold milling, pavingCold milling, paving-- | 40 mm - ACsurf 1180 mm – ACbin 16150 mm – Mech. bond gran. mat.200 mm – Ga (31.5mm) |

Table 5: Traditional method – LCC expectations

|  |  |  |
| --- | --- | --- |
| Rehabilitation method(variant) | Lifetime(years) | Minor repairs(year and % of cost) |
| Mill and Fill (incl. material transportation) | 20y | 6y (10%), 13y (20%) |

Expected lifetime: 20 years; Minor repairs (10%) after 6 years, after 12 years

Cold in-place recycling

Table 6: Cold recycling on site – pavement design (Wirtgen 2013)

|  |  |  |
| --- | --- | --- |
| Original structure | Activities  | New structure |
| 40 mm - ACsurf 1180 mm – ACbin 16150 mm – Mech. bond gran. Mat.200 mm – Ga (31.5mm) | Cold milling, pavingCold recycling (in-situ)Cold recycling (in-situ)- | 40 mm - ACsurf 11220 mm – Cold recycled mix200 mm – Ga (31.5mm) |

Table 7: Cold recycling on site – LCC expectations

|  |  |  |
| --- | --- | --- |
| Rehabilitation method(variant) | Lifetime(years) | Minor repairs(year and % of cost) |
| Cold Recycling (milling, recycling ,paving) - cement, bit. emulsion | 13y | 4y (10%), 9y (30%) |



Figure 1: Cold recycling machine set (WIRTGEN GMBH)

Hot in-place recycling

Table 8: Hot recycling in-place – pavement design (Wirtgen 2008)

|  |  |  |
| --- | --- | --- |
| Original structure | Activities  | New structure |
|  - 40 mm - ACsurf 1180 mm – ACbin 16150 mm – Mech. bond gran. mat.200 mm – Ga (31.5mm) | PavingHot recycling (in-situ)--- | 40 mm - ACsurf 850 mm – Hot recycled mix80 mm – ACbin 16150 mm – Mech. bond gran. 200 mm – Ga (31.5mm) |

Table 9: Hot recycling in-place – LCC expectations

|  |  |  |
| --- | --- | --- |
| Rehabilitation method(variant) | Lifetime(years) | Minor repairs(year and % of cost) |
| Remix special technology (Recycling + Virgin layer) - option 2 | 20y | 6y (10%), 13y (10%) |

Summary

 Tables below contain an overview of possible technological methods with a focus life cycle costs, manufacture price and on emission production during the rehabilitation process.

**Table 10: Life cycle costs and manufacture price of hypothetical project**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rehabilitation technology | Manufacture price [€] | LCC 5y [€] | LCC 10y [€] | LCC 20y [€] |
| Mill & Fill – traditional methodCold recycling – bit. emulsion, cementHot recycling – remix plus technology | 44 69830 62697 032 | 44 69833 94197 032 | 49 73244 921107 959 | 127 71588 828264 696 |

The total quantity of CO2, NOx, volatile hydrocarbons, CO and solid particle matters produced during manufacturing of the materials are incorporated as well as the emissions resulting from the operation of construction machinery during the rehabilitation.

**Table 11: Total released emissions on a hypothetical project**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rehabilitation technology | CO2 (t)  | NOx + HC (t) | CO (t) | PM (t) |
| Mill & Fill – traditional methodCold recycling – bit. emulsion, cementHot recycling – remix plus technology | 153,12173,13104,10 | 35,0986,0549,96 | 77,8483,1165,80 | 0,852,412,44 |

 OptiRec software tools provide the economic calculation of manufacturing price and life cycle costs as well as calculation of values of the pollution load on the natural environment. OptiRec tools are the main source of input data for the new version of OptiVote tool.

Decision making tool

 Using OptiVote tool is shown on the case study where the objective is to select the optimal rehabilitation method of asphalt pavement. This should be done according to the environmental impact (emissions generated during implementation and material production), manufacturing price and life cycle costs. Three different technologies for the project were evaluated and the most suitable option according to user-selected criteria was recommended.

**Table 12: Multi-criteria evaluation - example. 1 – LCC 10y**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria | CO2 | NOx+HC | CO | PM | Price [€] | LCC [€] | Score |
| Weight | 20 | 20 | 10 | 10 | 10 | 30 | 100 % |
| Mill & Fill – traditional method | 153,12 | 35,09 | 77,84 | 0,85 | 44 698 | 49 732 | 1 943 489  |
| Cold recycling – bit. emulsion, cement | 173,13 | 86,05 | 83,11 | 2,41 | 30 626 | 44 921 | 1 659 940  |
| Hot recycling – remix plus technology | 104,10 | 49,96 | 65,80 | 2,44 | 97 032 | 107 959 | 4 212 868 |

 In case the user selects criteria and weights as above (CO2: 20%, NOx + HC: 20%, CO: 10%, PM: 10%, Price: 10%, LCC: 30%), according to the total score, there would be cold recycling method of rehabilitation, eventually traditional recycling technology recommended for the project.

**Table 13: Multi-criteria evaluation - example. 2 – LCC 20y**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria | CO2 | NOx+HC | CO | PM | Price [€] | LCC [€] | Score |
| Weight | 5 | 5 | 5 | 5 | 30 | 50 | 100 % |
| Mill & Fill – traditional method | 153,12 | 35,09 | 77,84 | 0,85 | 44 698 | 49 732 | 7 728 047 |
| Cold recycling – bit. emulsion, cement | 173,13 | 86,05 | 83,11 | 2,41 | 30 626 | 44 921 | 5 361 624 |
| Hot recycling – remix plus technology | 104,10 | 49,96 | 65,80 | 2,44 | 97 032 | 107 959 | 16 146 883 |

 If the user chooses the criteria and weights as in the Table 13 (CO2: 5%, NOx + HC: 5%, CO: 5%, PM: 5%, Price: 30%, LCC: 50%), recommended technology would be again cold recycling or traditional method of rehabilitation.

 The case study above presents the way the tool multi criteria decision-making tool OptiVote evaluates output data from OptiRec software tools. For the illustration, there are only a small number of criteria and technological options of rehabilitation being used. Similarly, it is possible to evaluate other available rehabilitation technologies.

Conclusion

 The multi-criteria assessment tool OptiVote introduces an effective tool in finding suitable technological variant for road rehabilitation. The principle of assessment is presented on evaluation of selected methods, according to the economical (manufacturing price, life cycle costs) and environmental impact (emissions of CO2, NOx, volatile hydrocarbons, CO and particulate airborne substances). The tool is used inter alia to support efficient way of investment and to introduce a more gentle approach to construction to the environment. Supported are both traditional methods as well as recycling technologies of reconstruction.

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