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Multi-criteria decision making tool for road rehabilitation

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Abstract

The aim of this paper is to present a concept of the multi-criteria decision-making software tool named OptiVote. This application is able to recommend its users the most acceptable method and technological variant for flexible pavement rehabilitation project. The introduction of this article describes several calculation tools from the OptiRec family that allow independently evaluate different methods of rehabilitation. The main part of this paper is formed by a case study presenting a project implementation with three different rehabilitation technologies. Specific parameters such as the emission demands of each technology are being evaluated by the OptiRec calculation tool. Those are the input data for the newly developed multi-criteria decision making application OptiVote. Based on the selected criteria, user receives a clear recommendation, what method and technological variant to choose for a specific project. It is also recommended to combine several user-selected criteria. For example, project price together with the environmental impact in proportion to the user's choice.

Keywords

road; rehabilitation; emissions; 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 calculating tools evaluates available rehabilitation methods. Each of the three methods listed below, including technological variants is represented by one OptiRec software application. OptiVote tool evaluates the output data mainly from three described tools.

Basic methods for asphalt pavement rehabilitation:

Traditional method (mill & replace)

Traditional method with RAP (mill & replace, high volume of RAP)

Cold Recycling

Hot recycling

OptiRec TM

The TM software version primarily handles the rehabilitation of asphalt pavement by the traditional “Mill and replace” technology. It is currently the industry standard and most common method of pavement rehabilitation in the form of milling of required layers of a flexible pavement (most often the surfacing) and replacement thereof by new structural layers. The method is effective, however yet quite demanding particularly when it comes to material resources. As a consequence of cost savings in the field of rehabilitation together with the requirement for environment-friendly technologies, alternatives and equally effective solutions are being sought. E.g. the aforementioned cold recycling, hot recycling in-situ or a combination of both of the two methods available.

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)

OptiRec CR

The OptiRec CR software tool handles primarily pavement reconstructions by detaching and mixing, applying cold recycling approaches, most frequently in-situ. It is also possible to prepare cold recycled material with special mobile mixing plant at a job site or at a dumping ground.

Cold recycling technological variants:

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)

OptiRec HR

The software tool OptiRec HR handles pavement rehabilitation by detaching and mixing, applying hot recycling approaches, most frequently in-situ. Recycling is carried out by a remixer and set of panel-heating machines. The method is suitable particularly for reconstruction of asphalt wearing or binder course, in case that the lower structural layers are not violated. Due to the large size of recycler and heating machines, it is recommended to use the technology for road rehabilitation of larger dimensions and outside of residential areas.

Hot recycling technological 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

OptiVote

The newly developed software application 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 reconstruction technology. OptiVote includes technological options of three basic rehabilitation methods. Project is evaluated and data calculated by software applications OptiRec TM, CR and HR. Therefore it is possible to compare all available technological methods of reconstruction 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. Environmental impact (produced CO2, NOx + HC, CO and PM)
2. Duration of rehabilitation process
3. Price of the rehabilitation

Case study

As an example for the case study, an interurban road that requires rehabilitation of the asphalt pavement by one of the above-depicted technological options 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 during the manufacturing of the materials incorporated (asphalt mixes, hydraulic binders and bituminous binders) and CO2 generated by the machinery during the work completion as such. Apart from CO2, other emissions of greenhouse gas (NOx, volatile hydrocarbons, CO, solid particles) are being assessed as well. For the purposes of demonstrating the calculation tool results, a pavement with the following input parameters was chosen (see Table 1).

Basic parameters

Table 1: Basic parameters of the road

|  |  |
| --- | --- |
| 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 |

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 |
| Water  Cement CEM II 32.5 R  Bitumen emulsion (C60B7)  ACsurf 11+  ACbin 16+  ACsurf 8 | 1,00  1,25  1,00  2,36  2,34  2,32 | 0,0003  980  221  40\*  37,9\*  39,9\* | IVL  IVL  Eurobitume  Benninghofen, OptiRec  Benninghofen, OptiRec  Benninghofen, 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 11  80 mm – ACbin 16  150 mm – Mech. bond gran. mat.  200 mm – Ga (31.5mm) | Cold milling, paving  Cold milling, paving  -  - | 40 mm - ACsurf 11  80 mm – ACbin 16  150 mm – Mech. bond gran. mat.  200 mm – Ga (31.5mm) |

Cold in-place recycling

Table 5: Cold recycling on site – pavement design (Wirtgen 2013)

|  |  |  |
| --- | --- | --- |
| Original structure | Activities | New structure |
| 40 mm - ACsurf 11  80 mm – ACbin 16  150 mm – Mech. bond gran. Mat.  200 mm – Ga (31.5mm) | Cold milling, paving  Cold recycling (in-situ)  Cold recycling (in-situ)  - | 40 mm - ACsurf 11  220 mm – Cold recycled mix  200 mm – Ga (31.5mm) |

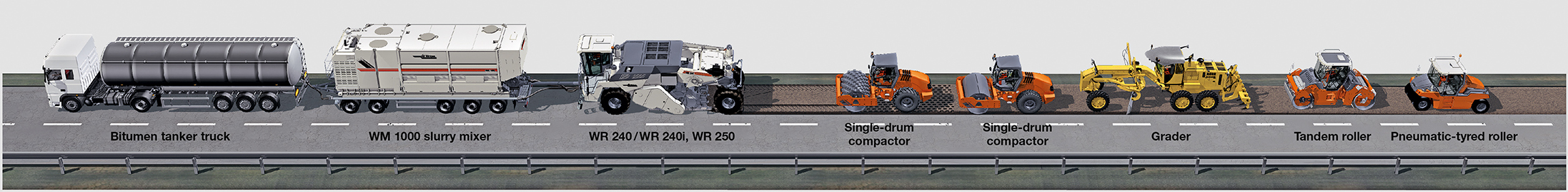


Figure 1: Cold recycling machine set (WIRTGEN GMBH)

Hot in-place recycling

Table 6: Hot recycling in-place – pavement design (Wirtgen 2008)

|  |  |  |
| --- | --- | --- |
| Original structure | Activities | New structure |
| -  40 mm - ACsurf 11  80 mm – ACbin 16  150 mm – Mech. bond gran. mat.  200 mm – Ga (31.5mm) | Paving  Hot recycling (in-situ)  -  -  - | 40 mm - ACsurf 8  50 mm – Hot recycled mix  80 mm – ACbin 16  150 mm – Mech. bond gran.  200 mm – Ga (31.5mm) |

Summary

Tables below contain an overview of possible technological methods with a focus on emission production during the reconstruction process. It means 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. Greenhouse gas emissions released during production of building materials, their use, transportation and incorporating in structures counts to harmful and cause risk to the natural environment.

**Table 7: CO2 production of technological variants – machines, material**

|  |  |  |
| --- | --- | --- |
| Rehabilitation technology | CO2 (t) material | CO2 (t) machines |
| Mill & Fill – traditional method  Cold recycling – bit. emulsion, cement  Hot recycling – remix plus technology | 115,69  150,25  39,88 | 37,43  22,89  64,23 |

**Table 8: Total CO2 production of technological variants**

|  |  |  |
| --- | --- | --- |
| Rehabilitation technology | CO2 (kg/m2) material | CO2 (t) total |
| Mill & Fill – traditional method  Cold recycling – bit. emulsion, cement  Hot recycling – remix plus technology | 0,015  0,017  0,010 | 153,12  173,13  104,10 |
| Data source: Machine producers and European emission standards | | |

**Table 9: Total released emissions on a hypothetical project**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rehabilitation technology | CO2 (t) | NOx + HC (t) | CO (t) | PM (t) |
| Mill & Fill – traditional method  Cold recycling – bit. emulsion, cement  Hot recycling – remix plus technology | 153,12  173,13  104,10 | 35,09  86,05  49,96 | 77,84  83,11  65,80 | 0,85  2,41  2,44 |

The above-calculated values of the pollution load on the natural environment, OptiRec software tools provide also economic calculation, resource and time demands estimation of selected reconstruction options. OptiRec tools constitute the main source of input data for the newly developed 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). The project was evaluated by three different technologies and the most suitable option is recommended according to user-selected preferences.

**Table 10: Multi-criterion evaluation - example. 1**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | CO2 | NOx+HC | CO | PM | Score |
| Weight | 20 | 50 | 10 | 20 | 100 % |
| Mill & Fill – traditional method | 153,12 | 35,09 | 77,84 | 0,85 | 5612,3 |
| Cold recycling – bit. emulsion, cement | 173,13 | 86,05 | 83,11 | 2,41 | 8644,4 |
| Hot recycling – remix plus technology | 104,1 | 49,96 | 65,8 | 2,44 | 5286,8 |

In case the user selects criteria and weights as above (CO2: 20%, NOx + HC: 50%, CO: 10%, PM: 20%), according to the total score, there will be hot recycling method of rehabilitation, eventually traditional recycling technology recommended for the project.

**Table 11: Multi-criterion evaluation - example. 2**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Criteria | CO2 | NOx+HC | CO | PM | Score |
| Weight | 5 | 65 | 25 | 5 | 100 % |
| Mill & Fill – traditional method | 153,12 | 35,09 | 77,84 | 0,85 | 4996,7 |
| Cold recycling – bit. emulsion, cement | 173,13 | 86,05 | 83,11 | 2,41 | 8548,7 |
| Hot recycling – remix plus technology | 104,1 | 49,96 | 65,8 | 2,44 | 5425,1 |

If the user chooses the criteria and weights as in the Table 11 (CO2: 5%, HC + NOx: 65%, CO 25%, PM: 5%), recommended technology would be traditional recycling or hot recycling method of reconstruction.

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 limited number of criteria and technological options of rehabilitation being used. Similarly, it is possible to evaluate other available rehabilitation technologies as well as to combine economical, time demanding and emission criteria.

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 environmental impact (emissions of harmful substances from the implementation - 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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