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Multi-criteria Decision Making Tool for Technological Variants of Road Rehabilitation

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Abstract

Following the current trend of increasing buildings density, both residential and industrial, the need to strengthen and improve transport and engineering infrastructure has become essential. Despite the fact that both construction and continuous road and transport network reconstruction are vital elements in meeting the sector`s criteria, numerous bodies, whether it is a state or a regional government, face various obstacles in its implementation. Having said that, it is the aim of this paper to present a valid concept of the multi-criteria decision-making software application called OptiVote. This tool is able to recommend its users the most suitable method and technological option for flexible road rehabilitation project. The first part of this article introduces several calculation tools that allow to independently evaluate different methods of reconstruction. Those are the OptiRec family software tools, solving the traditional way of reconstruction (mill and replace) and the cold and hot recycling. Further on, a description of the wide range of technological alternatives for flexible road rehabilitation follows. The main part of this paper is devoted to a case study presenting a project implementation with three different rehabilitation technologies. Particular parameters such as the emission demands of each technology are being evaluated here by the OptiRec calculation tool. Those are the input data for the newly developed multi-criteria decision making tool OptiVote. Based on the selected criteria, user receives a clear recommendation, what method and technology to choose for a specific reconstruction. It is also possible to combine several user-selected criteria. For instance, price together with the environmental impact in proportion to the given recommendation or the user's choice.

Keywords: Multi-criteria tool; OptiRec; OptiVote; rehabilitation; road

1. Introduction

Each state, county and local government are struggling with on-going construction and rehabilitation of the road transportation network. Both activities are time-consuming, financially and resource-dependant. Its complexity depends on factors such as size and location, with also the available choice of project’s technological solution. Each project can be carried out not only by a basic technological method but also with its technological options.

Road management and maintenance are almost invariably entrusted to government authorities. This body, together with the design engineers take decisions about technological solutions of prepared projects. Based on their experience, knowledge and advice, the preferred solutions usually encompass traditional and time-tested ones. Such approach often brings along the fear of new or less conventional technologies, which may not be ideal. Especially as the choice of less conventional technological solution may be a cheaper alternative with regards to project costs, time and resources. We can therefore assume that a newly developed multi-criteria decision-making tool OptiVote could help change the situation described above. The tool offers a comprehensive solution not only for design engineers, but also to the road authority management.

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2. Available tools

Different financial resources and environmental demands of available road rehabilitation technologies lead to the search of useful tools that would help engineers and authority management in objective comparison of applicable solutions. Required evaluations must always respect the basic parameters of the solved project. OptiRec calculating tools comprehensively evaluates available technological methods. Each of the three methods listed below, including technological modifications represents one OptiRec software application. OptiVote tool evaluates the output data mainly from three described tools.

Basic methods for flexible pavement road rehabilitation:

- Traditional method (mill & replace)
- Cold Recycling
- Hot recycling

2.1. OptiRec TM

The TM software version primarily handles the rehabilitation of flexible pavement by the traditional "Mill and replace" technology. It is currently the industry standard and most common method of pavement reconstruction 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 [1]

2.2. 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 methods:

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
   a. Bitumen emulsion
   b. Bitumen emulsion and cement (lime)
   c. Bitumen emulsion and cement suspension
   d. Foamed bitumen
   e. Foamed bitumen and cement (lime)
   f. Foamed bitumen and cement suspension [1]

2.3. 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 hot recycler (remixer) and a 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

3. Case study

For the case study, a road was chosen that requires reconstruction of the asphalt surfacing by one of the above-depicted technological options. This chapter aims to utilise the OptiRec applications in order to assess the selected reconstruction options. The choices are compared on the basis of the total CO_2 generated during the manufacturing of the materials incorporated (asphalt mixes, hydraulic binders and bituminous binders) and CO_2 produced by the machinery during the work completion as such. Apart from CO_2, other emissions of greenhouse gases (particularly NO_x, volatile hydrocarbons, CO, solid airborne particles) are being assessed as well. For the purposes of demonstrating the calculation tool results, a project with the following input parameters was selected (see Table 1).

3.2. 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 road intended for reconstruction is a hypothetic example of a road with a minor traffic load. The end of the pavement surfacing life is indicated by defects like e.g. moderate deep cracking in the asphalt layers. The pavement 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 pavement structure is 350 mm.

Table 2. Basic fuel data. [2, 3]

Substance	Density (t/m^3)	CO_2 (kg/l)	Data source
Diesel – refining	0,84	0,26	Afteroilev
Diesel – consumption	0,84	2,66	MŽP ČR

3.3. Traditional way of rehabilitation

Within the framework of the traditional asphalt pavement reconstruction method, the whole thickness of both surfacing asphalt layers is supposed to be milled away. The base layer of the compacted aggregate is retained. A prerequisite for this is sufficient bearing capacity and flatness of the area. The milled material is transported to a dumping ground or a mixing plant (distance of 30 km). Subsequently, a paver lays two new structural asphalt layers ACbin 16 and ACsurf 11. The original vertical alignment of the pavement is retained. With respect to the nature of the reconstruction technology, the OptiRec MF calculation tool is used here.

Table 3. Traditional option for pavement reconstruction – pavement design.

Original pavement structure	Activities during the rehabilitation	New pavement structure
40 mm - ACsurf 11	Cold milling, paving	40 mm - ACsurf 11
80 mm – ACbin 16	Cold milling, paving	80 mm – ACbin 16
150 mm – Mechanically bond granular mat.	-	150 mm – Mechanically bond granular mat.
200 mm – Ga (31.5mm)	-	200 mm – Ga (31.5mm)

Table 4: Total released emissions on a hypothetical project (t). [4]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
MF – traditional method	115,69	37,43	153,12	35,09	77,84	0,85

3.4. Cold in-place recycling

In the case of rehabilitation by application of cold recycling, the chosen technical option is a technology applying cation-active emulsion with residual bitumen content of 2.5 % and additional 1 % cement. A recycler performs in-situ recycling up to the thickness of 220 mm. Only asphalt wearing course must be milled off. The new asphalt layer ACbin 11 of a total thickness 50 mm is paved on the top of the cold recycled and compacted layer.

Table 5: Cold recycling – pavement design.

Original pavement structure	Activities during the rehabilitation	New pavement structure
40 mm - ACsurf 11	Cold milling, paving	40 mm - ACsurf 11
80 mm – ACbin 16	Cold recycling (in-situ)	220 mm – Cold recycled mix
150 mm – mechanically bond granular mat.	Cold recycling (in-situ)	200 mm – Ga (31.5mm)
200 mm – Ga (31.5mm)	-	

Table 6. Total released emissions on a hypothetical project (t). [5]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
CR – bitumen emulsion, cement	150,25	22,89	173,13	86,05	83,11	2,41

3.5. Hot in-place recycling

When rehabilitating pavement structure by hot recycling - remix plus variant, existing wearing course is heated up into the depth of 50 mm. Subsequently, new aggregate and bitumen is added and mixed with existing material (hot recycling). The new wearing course ACsurf 8 of a total thickness of 40 mm is laid on the top of hot recycled layer.

Table 7. Hot recycling – pavement design. [6]

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

Table 8. Total released emissions on a hypothetical project (t). [6]

Used technology for rehabilitation	CO_2 (t) Material	CO_2 (t) Machines	CO_2 (t) Total	NOx + HC (t) Total	CO (t) Total	PM (t) Total
HR – remix plus technology	39,88	64,23	104,10	49,96	65,80	2,44

3.6. Summary

The table below contains an overview of applicable technological variants with a close focus on emission production during the rehabilitation process. This means the total quantity of CO_2, NO_x, volatile hydrocarbons, CO and solid particle matters generated during manufacturing of the materials are incorporated as well as the emissions resulting from the operation of construction machinery during the actual reconstruction. Greenhouse gas emissions released during production of building materials, their use, transport and fitting in structures counts to harmful and cause risk to the natural environment.

Table 9. Total released emissions on a hypothetical project – comparison (t). [4], [5], [6]

Rehabilitation technology	CO_2 (t)	NOx + HC (t)	CO (t)	PM (t)
Mill & Fill – traditional method	153,12	35,09	77,84	0,85
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41
Hot recycling – remix plus technology	104,10	49,96	65,80	2,44

Like the above-calculated values of the pollution load on the natural environment, OptiRec software tools provide also economic calculation, time and resource demands estimation of selected reconstruction options. Tools OptiRec thus constitutes the main source of input data for the newly developed OptiVote tool.

4. Decision tool

4.1. OptiVote

The newly developed assessment tool is a comprehensive tool aimed at road authorities and project architects. Based on the given parameters of the road and the subsequent election of preferred benchmarks such as impact on the environment or project cost, the user gets the best recommendation on pavement rehabilitation technology. The tool includes technological options of three basic reconstruction methods. Input data are calculated by software application OptiRec TM, CR and HR, eventually OptiRoad tool. Therefore it is possible to compare all available technological options of rehabilitation according to the selected criteria. In case they are combined together (multi-criteria evaluation), it is necessary to also set a weight rating among the criteria.

4.2. Evaluation criteria

The following criteria are divided according to their source, which provides input values for the multi-criteria evaluation:

- **Values from OptiRec:** 1 / environmental impact (produced CO_2, NO_x + HC, CO and PM); 2 / economic demands (cost of reconstruction); 3 / time demands (time of reconstruction); 4 / resources demands (material, mechanization, manpower - the quantity);
- **Values from OptiRoad:** 1/ life cycle costs; 2/ schedule or intensity of reconstructions throughout the life cycle
- **Values from other sources:** 1 / local availability of technology and resources; 2 / demands on the climatic conditions during reconstruction; 3 / impact on the environment during reconstruction (odour, noise, ...); 4 / applicability of the technology in various widths and inclinations of the road; 5 / technology trends that are used in the world; 6 / quality of the finished surface for vehicle (grip, noise, ...); 7 / safety in terms of operation; 8 / technology proneness to risk in terms of quality maintenance

4.3. Case study

The use of the OptiVote tool is presented on a case study where the main objective is to select the most suitable rehabilitation of asphalt pavement. This should be done according to the environmental impact (emissions generated during implementation and material manufacturing). The project is evaluated by three different technologies and the best option is recommended according to user-selected preferences.

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

Criteria	CO_2	NO_x+HC	CO	PM	Score
Weight	10	60	20	10	100 %
Mill & Fill – traditional method	153,12	35,09	77,84	0,85	5201,9
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41	8580,6
Hot recycling – remix plus technology	104,1	49,96	65,8	2,44	5379,0

Depending on the user selected criteria and weights from the above (CO_2: 10%, NO_x + HC: 60%, CO: 20%, PM: 10%), the total score decides on the best suited rehabilitation method, whether it is a traditional method of rehabilitation, eventually hot recycling technology recommended for the project.

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

Criteria	CO_2	NO_x+HC	CO	PM	Score
Weight	60	30	5	5	100 %
Mill & Fill – traditional method	153,12	35,09	77,84	0,85	10633,35
Cold recycling – bitumen emulsion, cement	173,13	86,05	83,11	2,41	13396,90
Hot recycling – remix plus technology	104,1	49,96	65,8	2,44	8086,00

If the user chooses the criteria and weights as in the Table 11 (CO_2: 60%, HC + NO_x: 30%, CO 5%, PM: 5%), recommended technology would be hot recycling or traditional method of reconstruction.

4.4. Summary

The case study above presents the way the tool OptiVote evaluates output data from OptiRec software tools. As an example for the illustration, there are only a limited number of criteria and technological options of rehabilitation being used. In a similar way, 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 presents an effective tool in finding suitable technological methods for road reconstruction. The assessment principle is presented on evaluation of selected technologies, according to the environmental impact (emissions of harmful substances from the implementation - CO_2, NO_x, 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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