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Systematic decision making methodology on the pavement rehabilitation and upgrading of low volume roads

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Editor	S. Henigman (DDC)
Authors	J. Jamnik (DDC), L. Gáspár (KTI), S. Henigman (DDC), J. Čelko (TUZA), P. Harasim (IBDiM), J. Stryk (CDV), J. Komacka (TUZA)
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TABLE OF CONTENTS

TABLES

FIGURES

PICTURES

APPENDICES

1 QUESTIONNAIRE (WITH INFORMATION FROM SLOVENIA)

2 NATIONAL REPORTS

FOREWORD

This report is the final report of the Work Package 2, Task Group 2.3 in the EU-project SPENS – Sustainable Pavements for European New Member States. The objective of this research project is to develop appropriate tools and procedures for the rapid and cost-effective rehabilitation and maintenance of roads. The overall objective is to search for materials and technologies for road pavement construction and rehabilitation that would behave satisfactorily, have an acceptable environmental impact and be cost-effective.

A consortium of the following partners has conducted the SPENS project.

Partner	Partner acronym	Country
Slovenian National Building and Civil Engineering Institute **Co-ordinator**	ZAG	Slovenia
Institute for Transport Sciences	KTI	Hungary
The Swedish National Road and Transport Research Institute	VTI	Sweden
arsenal research	arsenal	Austria
Transport Research Centre	CDV	Czech Rep.
Road and Bridge Research Institute	IBDiM	Poland
Zilina University	TUZA	Slovakia
Europe's National Road Research Centres with **	FEHRL	Belgium
DDC Consulting & Engineering Ltd.	DDC	Slovenia
Ferriere Nord SpA	FENO	Italy

** TECER- Transport and Road Research Institute (Estonia)
IGH - Civil Engineering Institute of Croatia (Croatia)
IP - The Highway Institute (Serbia)
CRBL - Central Roads and Bridges Laboratory (Bolgaria)

List of participating organizations in Task Group 2.3

- **DDC** - DDC svetovanje inženiring, Družba za svetovanje in inženiring, d.o.o., DDC Consulting & Engineering Ltd, Kotnikova 40, 1000 Ljubljana, SLOVENIA
- **KTI** - Közlekedéstudományi Intézet KHT, Institute of Transport Sciences, Thán Károly u. 3-5 H-1119, Budapest 107, HUNGARY
- **CDV** - Centrum dopravniho výzkumu, Transport Research Centre, Lisenska 33a, 63600, Brno, CZECH REPUBLIC
- **TUZA** - Zilinská univerzita v Ziline, University of Žilina, Univerzitna 8215/1, 01026 Zilina, SLOVAKIA
- **IBDiM** - Instytut Badawczy Dróg i Mostów, Road and Bridge Research Institute, Jagiellonska 80, 03-301, Warsaw, POLAND

The EC, participating partners and national organisation have funded this project, which is gratefully acknowledged.

Members of Work Task listed:

Slovenko Henigman, DDC, Slovenia (Task Group leader)

Julijana Jamnik, DDC, Slovenia

dr. László Gáspár, KTI, Hungary

Josef Stryk, CDV, Czech Republic

dr. Ján Čelko, TUZA, Slovakia

Przemyslaw Harasim, IBDiM, Poland

And other contributors who provided additional input:

Bencze Zsolt, KTI, Hungary

dr. Josef Komacka, TUZA, Slovakia

We thank to the following reviewer:

Dr. Boromisza Tibor Dr. tech. M. Sc. (Civil Eng.),
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We hope that this report will be of great assistance both to the individual and to those responsible for construction and maintenance of flexible roads.

Mojca Ravinkar Turk
Project Co-ordinator

EXECUTIVE SUMMARY

Chapter editor: L Gáspár

Instead of new road constructions, the rehabilitation, the upgrading and the maintenance of highway networks have become a major task in Europe, including its countries in the Eastern part of the Continent. That is why decisions on the actual rehabilitation techniques and their timings are of high economic importance. The sophisticated decision support is desirable in order to avoid the sub-optimum decisions. The scientifically-based decision aid is often lacking, principally for low-volume roads. This report of SPENS Work Task WT 2.3 (Deliverable D13) introduces a systematic decision support methodology for the rehabilitation of low-volume roads with asphalt pavement (below 300 heavy axle loads/day traffic volume), and intended mainly for the some 300 000 km secondary roads in Central and Eastern European countries.

The flowchart-based methodology presents the steps and the yes/no-type branches to be taken during the decision aid. The condition parameters considered were taken in the following order: skid resistance, transverse evenness (rut depth), surface defects, longitudinal evenness, bearing capacity. The actual condition parameter levels are not included in the process, just their classification into “very good”, “good”, “fair”, “poor” or “very poor” categories. The combination of various condition parameter levels can be considered in the methodology. The outputs of the flowchart are suggested optimum rehabilitation or upgrading techniques (e.g. resurfacing, overlaying, strengthening) on network-level.

Geometrical corrections (e.g. pavement widening) are not dealt with. Economic considerations are tackled just superficially.

The report deals first with the condition improving (mainly pavement strengthening) methods as important elements of a maintenance management system. Then the basic principles of pavement deterioration are presented mentioning the typical deterioration trends for various condition parameters. The widely used combined indices are also identified, and the pavement performance model, as the generalized form of deterioration curves typical for a certain road link is defined.

The priority programming methods used in the case of insufficient funds are presented, as well. The realization of maximum benefits or minimum total costs can be targeted in the prioritisation.

A questionnaire was prepared for the SPENS project and was answered by the experts of Slovenia, Hungary, Czech Republic, Slovakia, Poland, Austria and Bulgaria. The information coming from the responses could be readily used in the systematic decision making methodology established for pavement rehabilitation. Similarly, the results of an international literature survey were taken into account.

The final decision making methodology on pavement rehabilitation and upgrading is based upon the Slovenian methodology taking into account other methodologies and allowing room for the implementation of national technical specifications, regarding the intervention levels

and condition classification presented in the final report of COST 354 action. The following road rehabilitation and upgrading techniques are considered: resurfacing (surface dressing, slurry seal, thin overlay), overlaying, strengthening (upgrade by asphalt layers, “sandwich” system, recycling), reconstruction.

The pavement condition evaluation techniques widely used in the new European Union member states and Austria having participated in the questionnaire survey are also introduced. The transverse evenness measuring, the longitudinal evenness measuring, the skid resistance measuring and the bearing capacity measuring devices, as well as the surface defects assessing devices and methods are presented there.

The characteristic pavement rehabilitation methods introduced include the following ones: resurfacing (surface dressing, slurry seal, thin overlay), overlaying (together with local repair), strengthening (together with local repairs), “sandwich” method, recycling and reconstruction. All of these rehabilitation techniques are based on the design methods for new pavement structures.

The selection of the appropriate pavement repair measures depends on traffic and environmental loads, material properties and pavement characteristics. Also rutted pavements need a previous surface repair before selecting the most suitable repair method.

The actual presentation of the flowchart for the decision making of pavement rehabilitation and upgrading is followed by the explanation of its various steps.

Several case studies are presented reflecting typical pavement conditions of the CEEC’s participating in the SPENS project, and providing practical examples for the use of flowchart-based methodology.

The appendices of the report comprise the SPENS-questionnaire filled-in with the information from Slovenia, as well as various national reports related to the decision making processes of the participating countries on road pavement rehabilitation. Some of the methodologies were compiled mainly for high-volume roads, while some of them for the whole highway network.

It is important to emphasize that the adoption of network-level rehabilitation measures using this flowchart-based methodology should be followed by some additional analysis at project-level. This latter investigation is (can be) specific for the country in question and, especially, for the local conditions not considered in the network-level decision making process. The actual condition improving technologies for a given project should be designed considering the most effective and sustainable techniques (e.g. various recycling methodologies).

1 INTRODUCTION

The development of the highway networks in the European countries have been nearly completed, just the construction of new expressway sections can be considered among the duties of the near future, mainly in the Eastern part of the Continent. Instead of new constructions, the rehabilitation, the upgrading and the maintenance of existing road networks have become a major task. That is why decisions on the actual rehabilitation techniques and their timings are of high importance from economic point of view. The sophisticated decision support is (would be) desirable in order to avoid the sub-optimum decisions. In reality, this scientifically based decision aid is very often lacking, principally for low-volume roads. Present report introduces a systematic decision support methodology for the rehabilitation of low-volume roads below 300 heavy axle loads/day traffic volume, and intended mainly for the Central and Eastern European countries (Table 1).

The methodology presented was compiled for asphalt pavements since they can be found on the overwhelming share of the low-volume roads in the countries interested.

Table 1 Lengths and percentage of roads below and above 300 heavy axle loads/day in some Central European countries

Country	Motorways + Main roads			Regional roads			Municipality (Local) roads		
	Km	Daily ESAL 100kN > 300 [%]	Daily ESAL 100kN ≤ 300 [%]	Km	Daily ESAL 100kN > 300 [%]	Daily ESAL 100kN ≤ 300 [%]	Km	Daily ESAL 100kN > 300 [%]	Daily ESAL 100kN ≤ 300 [%]
Slovenia	1.417	65	35	4.997	4	96	13.811	N/A	N/A
Slovakia	3.738	93	7	14.144	36	64	25.942	N/A	N/A
Czech Republic	6.805	94	6	48.778	4	96	N/A	N/A	N/A
Hungary	7.601	85	15	20.981	4	96	139.818	N/A	NA
Poland	16.811	61	39	N/A	N/A	N/A	N/A	N/A	N/A

The flowchart based methodology presents the steps and yes/no-type branches to be taken during the decision aid. The condition parameters considered were taken in the following order: skid resistance, transverse evenness (rut depth), surface defects, longitudinal evenness and bearing capacity.

The actual levels of various condition parameters are not included in the process, just their classification into “very good” “good”, “fair”, “poor” or “very poor” categories. The combination of various condition parameters levels can be considered in the methodology. The outputs of the flowchart are suggested optimum rehabilitation or upgrading techniques (e.g. resurfacing, overlaying, strengthening) on network level.

The decision support methodology for low volume roads can be utilized for a road network of much over 300 000 km total length in the Central and Eastern European countries.

Geometrical corrections (e.g. pavement widening) are not dealt with. Economic considerations are tackled only superficially.

Working program

Working program of the task is shown below:

- Compilation procedure for decision making methodology
    - Preparation of Questionnaire
    - National reports
- Pavement condition evaluation for different countries
- Preparation of road rehabilitation and upgrading techniques
    - Resurfacing
    - Overlaying
    - Strengthening (upgrade by asphalt layers, sandwich, recycling)
    - Reconstruction
- Development of Systematic decision making methodology
- Case studies
- Final report

2 PAVEMENT STRENGTHENING METHODS, DETERIORATION AND INTERVENTION URGENCY

Chapter editor: L. Gáspár

2.1 Pavement strengthening methods

Road pavement should be strengthened generally if its bearing capacity becomes weak for its traffic volume. Pavement strengthening should be designed as an element of maintenance management system.

Management information needed:

- assessing current level of road condition,
- determining appropriate levels of investment,
- prioritising capital improvements and investments in maintenance,
- simulating the effects on improvements (e.g. strengthening) on the future condition and performance,
- estimating the cost of strengthening,
- preparing designs that reflect the impact of time on the decisions,
- identification of life cycle cost impact of the strengthening or its eventual delay.

Traffic data needed:

- traffic characteristics (normal, diverted and generated traffic),
- traffic flow (composition, traffic growth),
- axle loading.

Pavement condition data:

- unevenness (longitudinal and transversal),
- surface distress,
- structural (bearing) capacity,
- pavement texture and friction (skid resistance).

Treatment selection: scheduled and condition-responsive methods. Strengthening is among condition-responsive ones.

At project level, typical treatments are:

- full pavement reconstruction,
- mill and replace,
- inlay,
- dense graded asphalt overlay,
- thin overlay,
- single surface dressing,

- fog seal/surface rejuvenation,
- patching,
- crack sealing.

Actual pavement strengthening methods:

- asphalt concrete pavements
  - new asphalt layer(s), max 50 mm thickness for new wearing course (with subsequent shoulder regulation),
  - asphalt concrete layers,
- asphalt macadam pavements
  - new asphalt layer(s), max 50 mm thickness for new wearing course (with subsequent shoulder regulation),
  - new asphalt macadam layer(s),
- cement concrete pavements
  - new asphalt layer(s) of max 50 mm thickness for new wearing course (previous preparation of old cement concrete pavement, and subsequent shoulder regulation),
  - new jointed or continuously reinforced cement concrete layer (previous preparation of old cement concrete pavement, and subsequent shoulder regulation).

Strengthening can be combined with pavement widening if needed.

The design service life of strengthened pavements is typically in the range of 10-30 years.

2.2 Pavement deterioration

The pavement is deteriorated due to the combination of traffic and environmental effects. The actual worsening of pavement condition can be characterised by the level of various condition parameters, namely:

- longitudinal (un)evenness,
- rut depth (transverse unevenness),
- surface defects,
- bearing capacity,
- texture,
- skid resistance,
- rolling noise,
- pavement light reflectivity.

The trend of deterioration is different for various condition parameters, typically, they are as follows:

- unevenness – exponential,
- rut depth – exponential,

- surface defects – quadratic,
- bearing capacity – stochastically exponential,
- texture – linear,
- skid resistance – linear,
- rolling noise – linear,
- light reflectivity – practically unchanged.

Several combined indices are known, among others:

- PSI (Present Serviceability Index),
- PCI (Pavement Condition Index),
- OPI (Overall Pavement Index),
- PQI (Pavement Quality Index),
- RCI (Riding Comfort Index),
- SAI (Structural Adequacy Index),
- SDI (Surface Distress Index).

Deterioration curves can be identified for a given project as a function of time and/or traffic passed for any pavement condition parameter.

The generalized form of deterioration curves – typical for a certain road link comprising many distinct sections having similar pavement structure, subgrade type and/or traffic size – is called (pavement) performance model. The most obvious way for their development is the long-term monitoring of trial sections characteristic for given road links. The models can be used for project and/or network level medium or long-term rehabilitation and maintenance planning.

2.3 Treatment urgency (prioritisation)

Road agencies should establish alternatives and policies for their rehabilitation and maintenance program. Under condition of – very unlikely – sufficient available funds, the realization of maximum benefits or minimum total costs can be targeted.

The length of program period for rehabilitation improvements (e.g. strengthening) allowing also life-cycle economic evaluation is typically min. 20 years. However, the development of 5- or 10-year program is widespread where just the first 2 or 3 years of the program are fixed, and annual or biannual updates are carried out.

Almost every pavement management system incorporates some form of priority programming procedure. The types of priority assessment methods vary from simple subjective ranking to sophisticated mathematical programming. Each has specific features in terms of the pavement rating parameters, type of economic analysis applied etc. Their four major steps: information, identification of needs, priority analysis, and output reports.

Priority programming method can be grouped into one of the classes presented in Table 2.

Table 2 Classes of priority programming methods

Class of method	Advantages and disadvantages
Simple subjective ranking of projects based on judgment	Quick, simple: subject to bias and inconsistency: may be far from optimal
Ranking based on parameters, such as serviceability, deflection, etc.	Simple and easy to use; may be far from optimal
Ranking based on parameters with economic analysis	Reasonably simple; should be closer to optimal
Optimization by mathematical programming model for year-by-year basis	Less simple: may be close to optimal effects of timing not considered
Near optimization using heuristics and marginal cost-effectiveness	Reasonably simple; can be used in a microcomputer environment; close to optimal results
Comprehensive optimization by mathematical programming model taking into account the effects	Most complex; can give optimal program (max. of benefits)

Mathematical programming models can be applied to either single year or multiyear prioritization. Formulations used in these models include several variations of linear programming and dynamic programming.

Near optimization technique, which is much simpler, flexible, and operationally efficient, provides result rather close to actual optimization for all purposes.

The output of the priority programming process presents a useful guide for the engineer to follow, so it provides decision support, no more.

3 COMPILATION PROCEDURE FOR DECISION MAKING METHODOLOGY

Chapter editors: J. Jamnik, S. Henigman

The procedure for the decision making methodology on pavement rehabilitation and upgrading was developed from the actual practice of several CEEC countries (Slovenia, Hungary, Slovakia, Czech Republic and Poland).

Each country

- answered a Questionnaire (Appendix 1) prepared for the SPENS project (main findings presented as a summary in Table 3) an
- prepared their National Report (see Appendix 2) about their decision making methodology.

Also the results of an international literature survey were taken into account.

In mutual agreement among participating countries the final decision making methodology on pavement rehabilitation and upgrading was based upon Slovenian methodology, taking into account of all other methodologies and allowing room for the implementation of national technical specifications, regarding the intervention levels and condition classification (similarly as in the final report of COST 354 action).

Pavement condition is characterised (evaluated) by:

- skid resistance,
- transverse evenness (Rut depth),
- surface defects,
- longitudinal evenness (IRI),
- bearing capacity.

The following road rehabilitation and upgrading techniques are proposed:

- resurfacing, including surface dressing, slurry seal and thin overlay,
- overlaying
- strengthening, including upgrade by asphalt layers, “sandwich” system and recycling
- reconstruction.

Table 3 Comparison of the Austrian, Bulgarian, Czech, Hungarian, Polish, Serbian, Slovak and Slovenian answers to the 16 most important questions of the questionnaire

Topic			Country		Austria		Bulgaria		Czech Republic		Hungary
1	Road network length (km)	1.1	Motorways and Dual-carriage ways	1.1	2.080	1.1	-	1.1	568	1.1	804
		1.2	Primary Roads	1.2	10.000	1.2	3.021	1.2	6.107	1.2	7.113
		1.3	Secondary Roads	1.3	23.500	1.3	4.011	1.3	14.614	1.3	23.260
		1.4	Other	1.4	73.000	1.4	11.719	1.4	34.070	1.4	-
		1.5	Total	1.5	108580	1.5	18.751	1.5	55.359	1.5	31.177
2	AADT	2.1	Motorways and Dual-carriage ways	2.1	-	2.1	13.165	2.1	32.000	2.1	32.000
		2.2	Primary Roads	2.2	-	2.2	4.781	2.2	10.000	2.2	10 300
		2.3	Secondary Roads	2.3	-	2.3	1.237	2.3	2.500	2.3	3.100
		2.4	Other	2.4	-	2.4	-	2.4	700	2.4	-
3	Collection of traffic information			3	Counting	3	Counting	3	WIM, Counting	3	WIM,Counting
4	Allowed Gross Vehicle Mass (tons)			4	40	4	-	4	48	4	40
5	Maximum Single Axle Load (tons)			5	11,5	5	11,5	5	11,5	5	11,5
6	Reference Axle Load			6	100 kN	6	115	6	100 kN	6	100 kN
7	The Power of the equivalency-factor formula			7	-	7	-	7	3-10	7	5
8	Sum of the good and very good pavement condition (% of lenght)	8.1	Motorways and Dual-carriage ways	8.1	46	8.1	-	8.1	-	8.1	69
		8.2	Primary Roads	8.2	-	8.2	-	8.2	-	8.2	14
		8.3	Secondary Roads	8.3	-	8.3	-	8.3	-	8.3	8
9	Condition determined by			9	pavement characteristics (Transverse-, Longitudinal Evenness, Skid Resistance, Surface Defects), Structural Characteristics	9		9	Evaluation by longitudinal unevenness and rut depth. 3rd class roads evaluated by Deterioration Index from Visual Inspections.	9	Visual condition evaluation aided by a keyboard-type device
10	Measuring Device	10.1	Bearing capacity	10.1	Deflectometer FWD	10.1	Deflectometer FWD, Deflectograph LaCroix	10.1	Deflectometer FWD	10.1	Deflectometer FWD, Deflectograph LaCroix
		10.2	Transverse Evenness	10.2	Profilometer, 4-m Straight Edge	10.2	Dipstick Road Profiler, 4-m Straight Edge	10.2	2-m Straight Edge, ARAN-Automatic Road Analyzer, ARGUS-Automatic Road Condition Graduating Unit Systém	10.2	3-m Straight Edge (occasionally) , RST Road Survey Tester
		10.3	Longitudinal Evenness	10.3	Profilometer, 4-m Straight Edge	10.3	Profilograph, 4-m Straight Edge, APL	10.3	4-m Straight Edge, ARAN-Automatic Road Analyzer, ARGUS-Automatic Road Condition Graduating Unit System	10.3	Profilograph, 4-m Straight Edge, RST Road Survey Tester
		10.4	Skid Resistance	10.4	RoadSTAR	10.4	Skid Resistance Tester (SRT)	10.4	SCRIM, TRT	10.4	SCRIM, Skid Resistance Tester (SRT)
		10.5	Texture	10.5	Laser	10.5	Sand Patch Test/Volumetric method	10.5	Laser based measurement - ARAN, ARGUS, Sand Patch Test/Volumetric method	10.5	Sand Patch Test
		10.6	Surface Defects	10.6	Video	10.6	Visual inspection, Video Recording	10.6	Visual inspection, Video Recording (ARAN, ARGUS)	10.6	Visual inspection
11	Typical Flexible Pavement Structure	11.1	Surface layer	11.1	SMA-Stone Mastic Asphalt, Asphalt Concrete	11.1	SMA, Dense asphalt, Surface dressing, Microsurfacing, Slury Seal	11.1	SMA-Stone Mastic Asphalt, ACsurf-Asphalt Concrete,	11.1	SMA or AC
		11.2	Binder Course	11.2	Asphalt Concrete	11.2	Dense asphalt	11.2	ACbin-Asphalt Concrete	11.2	
		11.3	Base Course	11.3	unbounded crushed or round stone	11.3	Btumen covered crushed stone	11.3	Asphalt coated agregate	11.3	AC-type
		11.4	Sub-base	11.4	unbounded sub - base according to RVS 03.08.63	11.4	Crushed stone	11.4	Upper and lower sub-base - Crushed Stone or Gravel (mechanically compacted aggregate)	11.4	Bituminous gravel
		11.5	Capping	11.5	-	11.5	-	11.5	Rock Material Resistant to Freezing,	11.5	-
		11.6	Protection layer	11.6	-	11.6	crushed stone	11.6	-	11.6	sand and gravel
		11.7	Stabilized subgrade	11.7	-	11.7	Hidrated lime, cement and chemical additives stabilized soils	11.7	-	11.7	occasionally
12	Typical Semi-Rigid Pavement Structure	12.1	Surface layer	12.1	SMA-Stone Mastic Asphalt, Asphalt Concrete	12.1	SMA, Dense asphalt, Surface dressing, Microsurfacing, Slury Seal	12.1	-	12.1	SMA or AC
		12.2	Binder Course	12.2	Asphalt Concrete	12.2	Dense asphalt	12.2	-	12.2	-
		12.3	Base Course 1	12.3	stabilized base layer	12.3	Cement stabilized crushed stone	12.3	-	12.3	AC-type
		12.4	Base Course 2	12.4	-	12.4	Crushed stone	12.4	-	12.4	cement stabilisation
		12.5	Sub-base	12.5	unbounded sub - base according to RVS 03.08.63	12.5	Crushed stone	12.5	-	12.5	-
		12.6	Capping	12.6	-	12.6	-	12.6	-	12.6	-
		12.7	Protection layer	12.7	-	12.7	crushed stone	12.7	-	12.7	sand and gravel
		12.8	Stabilized subgrade	12.8	-	12.8	Hidrated lime, cement and chemical additives stabilized soils	12.8	-	12.8	occasionally
13	Typical Rigid Pavement Structure	13.1	Surface layer	13.1	concrete pavement according to RVS 8S.06.32	13.1	-	13.1	CC-Cement Concrete,	13.1	jointed cement concrete pavement
		13.2	Base Course 1	13.2	surface treatment	13.2	-	13.2	CC-Cement Concrete,	13.2	AC-type
		13.3	Base Course 2	13.3	-	13.3	-	13.3	-	13.3	cement stabilisation
		13.4	Base Course 3	13.4	-	13.4	-	13.4	-	13.4	-
		13.5	Sub-base	13.5	stabilized or unstabilized sub-base	13.5	-	13.5	Upper and lower sub-base - Crushed Stone or Gravel (mechanically compacted aggregate)	13.5	-
		13.6	Capping	13.6	-	13.6	-	13.6	Rock Material Resistant to Freezing,	13.6	-
		13.7	Protection layer	13.7	-	13.7	-	13.7	-	13.7	sand and gravel
		13.8	Stabilized subgrade	13.8	-	13.8	-	13.8	-	13.8	occasionally
14	Choosing a Treatment Type	14.1	Pavement Condition	14.1	Cracks, Transverse Evenness, Longitudinal Evenness, Skid Resistance, Structure, Theoretical Water Film Thickness	14.1	-	14.1	Yes	14.1	Yes
		14.2	Traffic Loading in Project Period	14.2	Yes	14.2	Yes	14.2	Yes	14.2	Yes
		14.3	Climatic Conditions	14.3	-	14.3	Yes	14.3	-	14.3	Yes
		14.4	Urban Environment Demands	14.4	-	14.4	Yes	14.4	-	14.4	Yes
		14.5	Bearing Capacity of Subbase	14.5	Light Drop Weight Tester	14.5	Yes	14.5	Yes	14.5	Yes
		14.6	Other, please specify	14.6	-	14.6	-	14.6	-	14.6	-
15	Maintanace Treatment Type			15	Resurfacing,Surface Dressing, Overlay < 4 cm, Strengthening, Pavement Reconstruction, Recycling, Mill & Replace of bound courses	15	Resurfacing,Surface Dressing, Overlay < 4 cm, Strengthening, Pavement Reconstruction, Mill & Replace of bound courses	15	Surface Dressing, Overlay < 4 cm, Pavement Reconstruction, Recycling, Mill & Replace of bound courses, Bituminous Overlay > 4cm	15	Resurfacing, Surface Dressing, Overlay < 4 cm, Strengthening, Pavement Reconstruction, Recycling, Mill & Replace of bound courses
16	Pavement Design Procedure	16.1	Theoretical Procedure	16.1	-	16.1	Boussinesque, Westergaard, Software	16.1	Software: BISAR-SPDM, Laypes, Laymed	16.1	ALICE
		16.2	Empirical Procedure	16.2	-	16.2	AASHTO, National Specification	16.2	-	16.2	-
		16.3	Standardized Procedure	16.3	national Standard RVS 03.08.63	16.3	-	16.3	Czech Catalogue	16.3	Hungarian catalogue

Topic			Country		Poland		Serbia		Slovakia		Slovenia
1	Road network length (km)	1.1	Motorways and Dual-carriage ways	1.1	835	1.1		1.1	411	1.1	481
		1.2	Primary Roads	1.2	70	1.2		1.2	3.263	1.2	926
		1.3	Secondary Roads	1.3	17.352	1.3		1.3	3.734	1.3	4.847
		1.4	Other	1.4	-	1.4		1.4	10.401	1.4	-
		1.5	Total	1.5	18.257	1.5		1.5	17.809	1.5	6.254
2	AADT	2.1	Motorways and Dual-carriage ways	2.1	-	2.1	-	2.1	22.500	2.1	23.395
		2.2	Primary Roads	2.2	-	2.2	-	2.2	7.500	2.2	8.198
		2.3	Secondary Roads	2.3	8.298	2.3	-	2.3	3.000	2.3	2.396
		2.4	Other	2.4	-	2.4	-	2.4	1.600	2.4	-
3	Collection of traffic information			3	Counting	3		3	WIM, Counting	3	WIM, Counting
4	Allowed Gross Vehicle Mass (tons)			4	44	4	42	4	44	4	44
5	Maximum Single Axle Load (tons)			5	11,5	5	11,5	5	11,5	5	11,5
6	Reference Axle Load			6	100 kN	6	80 kN, 82 kN	6	100 kN	6	82 kN
7	The Power of the equivalency-factor formula			7	5	7	-	7	3,5	7	4
8	Sum of the good and very good pavement condition (% of lenght)	8.1	Motorways and Dual-carriage ways	8.1	-	8.1		8.1	83	8.1	86
		8.2	Primary Roads	8.2	-	8.2		8.2	36	8.2	39
		8.3	Secondary Roads	8.3	53	8.3		8.3	24	8.3	37
9	Condition determined by			9	SOSN (Pavement Condition Evaluation System, Evaluation by cracks, longitudinal evenness, ruth depth, visual inspection, skid resistance)	9		9	Evaluation by longitudinal unevenness and rut depth. 3rd class roads evaluated by Deterioration Index from Visual Inspections.	9	Visual pavement condition index
10	Measuring Device	10.1	Bearing capacity	10.1	Deflectometer FWD	10.1	Deflectometer FWD, Benkelman beam	10.1	Deflectometer FWD - KUAB	10.1	Deflectometer FWD, Deflectograph LaCroix
		10.2	Transverse Evenness	10.2	Profilograph	10.2		10.2	Profilograph GE	10.2	4-m Straight Edge
		10.3	Longitudinal Evenness	10.3	Profilograph, APL	10.3		10.3	Profilograph GE	10.3	Profilometer, 4-m Straight Edge
		10.4	Skid Resistance	10.4	Skid Resistance Tester (SRT)	10.4		10.4	Skiddometer BV 11	10.4	SCRIM, Skid Resistance Tester (SRT)
		10.5	Texture	10.5	Sand Patch Test	10.5		10.5	Laser based measurement, Sand Patch Test/Volumetric method	10.5	Laser based measurement, Sand Patch Test/Volumetric method
		10.6	Surface Defects	10.6	Visual inspection, Video Recording (ARGUS)	10.6		10.6	Visual inspection, Video Recording - VIDEOCAR	10.6	Visual inspection
11	Typical Flexible Pavement Structure	11.1	Surface layer	11.1	SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete	11.1	SMA, AC	11.1	SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete	11.1	SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete
		11.2	Binder Course	11.2	AC_{bin}-Asphalt Concrete	11.2	-	11.2	AC_{bin}-Asphalt Concrete	11.2	AC_{bin}-Asphalt Concrete
		11.3	Base Course	11.3	AC_{base}	11.3	bitumenious base	11.3	AC_{base}	11.3	AC_{base}
		11.4	Sub-base	11.4	Crushed Stone	11.4	crushed stone, sandy gravel	11.4	Crushed Stone, Gravel	11.4	Crushed Stone
		11.5	Capping	11.5	Rock Material Resistant to Freezing	11.5	-	11.5	Rock Material Resistant to Freezing	11.5	Rock Material Resistant to Freezing
		11.6	Protection layer	11.6	-	11.6	-	11.6	-	11.6	-
		11.7	Stabilized subgrade	11.7	-	11.7	-	11.7	-	11.7	-
12	Typical Semi-Rigid Pavement Structure	12.1	Surface layer	12.1	SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete	12.1	SMA, AC	12.1	SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete	12.1	SMA-Stone Mastic Asphalt, ACsurf-Asphalt Concrete
		12.2	Binder Course	12.2	AC_{bin}-Asphalt Concrete	12.2	-	12.2	AC_{bin}-Asphalt Concrete	12.2	ACbin-Asphalt Concrete
		12.3	Base Course 1	12.3	AC_{base}	12.3	bitumenious base	12.3	AC_{base}	12.3	ACbase
		12.4	Base Course 2	12.4	CS-Cement Stabilization	12.4	cement stabilization	12.4	CS-Cement Stabilization	12.4	CS-Cement Stabilization
		12.5	Sub-base	12.5	Crushed Stone	12.5	crushed stone	12.5	Crushed Stone, Gravel	12.5	Crushed Stone
		12.6	Capping	12.6	Rock Material Resistant to Freezing	12.6	-	12.6	-	12.6	Rock Material Resistant to Freezing
		12.7	Protection layer	12.7	-	12.7	-	12.7	-	12.7	-
		12.8	Stabilized subgrade	12.8	-	12.8	-	12.8	-	12.8	-
13	Typical Rigid Pavement Structure	13.1	Surface layer	13.1	CC-Cement Concrete	13.1	concrete	13.1	CC-Cement Concrete	13.1	CC-Cement Concrete
		13.2	Base Course 1	13.2	CC-Cement Concrete	13.2	cement stabilization	13.2	CC-Cement Concrete	13.2	CC-Cement Concrete
		13.3	Base Course 2	13.3	AC_{base}	13.3	srushed stone	13.3	AC_{base}	13.3	ACbase
		13.4	Base Course 3	13.4	CS - Cement Stabilistation	13.4	-	13.4	CS-Cement Stabilization	13.4	CS - Cement Stabilistation
		13.5	Sub-base	13.5	Crushed Stone	13.5	crushed stone or sandy gravel	13.5	Crushed Stone, Gravel	13.5	Crushed Stone
		13.6	Capping	13.6	Rock Material Resistant to Freezing	13.6	-	13.6	Rock Material Resistant to Freezing	13.6	Rock Material Resistant to Freezing
		13.7	Protection layer	13.7	-	13.7	-	13.7	-	13.7	-
		13.8	Stabilized subgrade	13.8	-	13.8	-	13.8	-	13.8	-
14	Choosing a Treatment Type	14.1	Pavement Condition	14.1	Cracks, Bearing Capacity, Transverse Evenness, Longitudinal Evenness, Skid Resistance, Laboratory tests of existing pavement materials	14.1		14.1	Cracks, Bearing Capacity, Transverse Evenness, Longitudinal Evenness, Skid Resistance, Laboratory tests of existing pavement materials	14.1	Cracks, Bearing Capacity, Transverse Evenness, Longitudinal Evenness, Skid Resistance, Laboratory tests of existing pavement materials
		14.2	Traffic Loading in Project Period	14.2	Yes	14.2		14.2	Yes	14.2	Yes
		14.3	Climatic Conditions	14.3	Frost Depth	14.3		14.3	Freezing Depth	14.3	Frost Depth, Rainfall
		14.4	Urban Environment Demands	14.4	Noise	14.4		14.4	Noise	14.4	Noise
		14.5	Bearing Capacity of Subbase	14.5	CBR	14.5		14.5	-	14.5	CBR
		14.6	Other, please specify	14.6	-	14.6		14.6	backcalculation from FWD measurement	14.6	-
15	Maintanace Treatment Type			15	Surface Dressing, Overlay < 4 cm, Pavement Reconstruction, Recycling, Mill & Replace of bound courses	15	Resurfacing, Strengthening, Pavement Reconstruction, Mill & Replace of bound courses	15	Surface Dressing, Bituminous Overlay, Pavement Reconstruction, Recycling, Mill & Replace of bound courses	15	Surface Dressing, Overlay < 4 cm, Strengthening, Pavement Reconstruction, Recycling, Mill & Replace of bound courses
16	Pavement Design Procedure	16.1	Theoretical Procedure	16.1	Software: BISAR-SPDM	16.1		16.1	Software: Laymed, OPMEKO	16.1	-
		16.2	Empirical Procedure	16.2	AASHTO	16.2		16.2	-	16.2	AASHTO
		16.3	Standardized Procedure	16.3	Polish catalogue	16.3		16.3	Slovak catalogue	16.3	-

4 PAVEMENT CONDITION EVALUATION

Due to increasing traffic size on the roads, up-to-date measurement systems operate at traffic speed (usually 60 – 100 km/h) during measurement. Therefore, no closing of roads or certain lanes becomes necessary. Static or quasi-static measurements have lost their importance over the past years. Their area of application remains the field of acceptance tests on newly built roads before their opening to traffic. Nevertheless, even for this purpose high speed measurements are used today and in the near future, static measurement systems will become obsolete for pavement management purposes.

During the SPENS project, a questionnaire was sent out to the partner countries to collect the different methods and devices that are used for non-destructive testing in the New EU Member states today. Compilation includes also the results from Austria, although it is not a New EU Member State.

4.1 Transverse evenness measurements (Rut depth)

There are two commonly used transverse evenness measuring techniques: 2 m, 3 m or 4 m Straight Edge which represents static means of measurements and fast profilometer laser technique which can function separately or simultaneously with other road condition survey systems (ARAN, ARGUS etc.) - Table 4.

Table 4 Rut depth measuring devices in the countries considered

Country	Measuring Device
Austria	Profilometer, 4-m Straight Edge
Bulgaria	Dipstick Road Profiler, 4-m Straight Edge
Czech Republic	2 m Straight Edge, ARAN-Automatic Road Analyzer, ARGUS-Automatic Road Condition Graduating Unit System
Hungary	3 m Straight Edge (occasionally) , RST Road Survey Tester
Poland	Profilograph
Slovakia	Profilograph GE
Slovenia	4 m Straight Edge

4.2 Longitudinal evenness measurements

For longitudinal evenness, different kinds of profilometers are used. These are usually contactless, laser sensor and/or accelerometer based devices. The 4 m straight edge and the profilograph are also widely used (Table 5).

Table 5 Longitudinal evenness measuring devices in the countries considered

Country	Measuring Device
Austria	Profilometer, 4 m Straight Edge
Bulgaria	Profilograph, 4 m Straight Edge, APL
Czech Republic	4 m Straight Edge, ARAN, ARGUS
Hungary	Profilograph, 4 m Straight Edge (occasionally), RST Road Survey Tester
Poland	Profilograph, APL
Slovakia	Profilograph GE
Slovenia	Profilometer, 4 m Straight Edge

4.3 Skid resistance measurements

A large variety of methods and devices are used for skid resistance measurements. In many countries, the British Pendulum (SRT) test is used. It is at the moment the only internationally standardized procedure (see EN 13036-4) - Table 6.

Table 6 Skid resistance measuring devices in the countries considered

Country	Measuring Device
Austria	RoadSTAR, Griptester, British Pendulum (SRT)
Bulgaria	Skid Resistance Tester (SRT)
Czech Republic	SCRIM, TRT
Hungary	SCRIM, Skid Resistance Tester (SRT)
Poland	Skid Resistance Tester (SRT)
Slovakia	Skiddometer BV 11
Slovenia	SCRIM, British Pendulum (SRT)

4.4 Surface defects assessment

The basic surface defects assessment used in New European Member States is visual inspection. Although some new advanced video recording techniques have become more popular, it still remains the most available for a wide range of practice (Table 7).

Table 7 Surface defect assessing devices in the countries considered

Country	Measuring Device
Austria	Video
Bulgaria	Visual inspection, Video Recording
Czech Republic	Visual inspection, Video Recording (ARAN, ARGUS)
Hungary	Visual inspection
Poland	Visual inspection, Video Recording (ARGUS)
Slovakia	Visual inspection, Video Recording (VIDEOCAR)
Slovenia	Visual inspection

4.5 Bearing capacity measurements

For bearing capacity, every country uses Falling Weight Deflectometers from different manufacturers, mainly Dynatest and KUAB. The Deflectograph LaCroix is also used in some countries (Table 8).

Table 8 Bearing capacity measuring devices in the countries considered

Country	Measuring Device
Austria	Deflectometer FWD
Bulgaria	Deflectometer FWD, Deflectograph LaCroix
Czech Republic	Deflectometer FWD
Hungary	Deflectometer FWD-KUAB, Deflectograph LaCroix (occasionally)
Poland	Deflectometer FWD
Slovakia	Deflectometer FWD - KUAB
Slovenia	Deflectometer FWD, Deflectograph LaCroix

5 ROAD REHABILITATION AND UPGRADING TECHNIQUES

Characteristic pavement rehabilitation methods of damages are the following:

- resurfacing (surface dressing, slurry seal, thin overlay),
- overlaying (including local rehabilitation),
- strengthening (including local rehabilitation),
- "sandwich" method,
- recycling, and
- reconstruction.

All of these rehabilitation techniques are based on the pavement design methods used for new structures.

The selection of the appropriate measure for repairing damage on existing pavements depends on traffic and environmental load, material properties and pavement characteristics.

If a pavement is also damaged by ruts, previous rehabilitation is needed before selecting the appropriate measure.

5.1 Resurfacing (surface dressing, slurry seal, thin overlay)

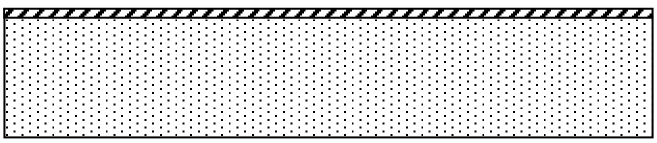
Resurfacing (Figure 1) preserves the assets – pavement structure – and improves the properties of the wearing course.

When resurfacing by

- surface dressing or
- slurry seal or
- thin overlay,

friction characteristics – skid resistance – are improved and the surface of the pavement is sealed.

Figure 1 Scheme of resurfacing



new resurfacing layer

existing pavement structure

All three measures are implemented when the bearing capacity of the pavement structure is fully appropriate, that is the pavement structure is able to withstand traffic loads with its existing layer thicknesses and built-in materials.

If the bearing capacity of the pavement is locally poor, it has to be rehabilitated beforehand.

Resurfacing of the pavement is recommended primarily for roads with low and medium traffic loads.

Example 1 presents a typical example for a pavement suitable for resurfacing (Picture 1).

Example 1: Roadway suitable for rehabilitation with surface dressing

Explanation: The existing wearing course is asphalt concrete AC 8 surf (from a mixture of carbonate grains), its surface is highly slippery. The section has low traffic load. The bearing capacity of the pavement structure is suitable, map cracks appear locally which must be rehabilitated before resurfacing. Hydrological conditions are favourable.

Picture 1 Example of a pavement suitable for rehabilitation by surface dressing

5.2 Overlaying

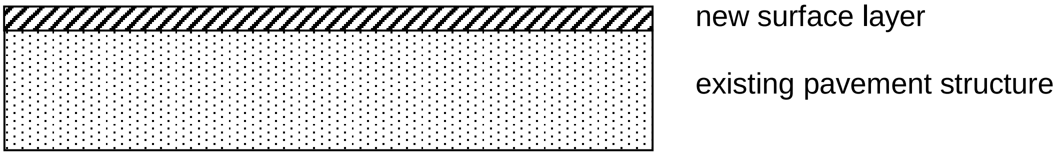
Overlaying (Figure 2) is a method in which a new asphalt surfacing is applied to the existing pavement after the local rehabilitation of severely damaged areas.

Overlay preserves the assets – pavement structure – and improves the properties of the pavement – wearing course.

At the same time, overlay improves the evenness and skidding resistance of the pavement. It can be built using various asphalt mixture types such as:

- Asphalt Concrete – AC surf,
- Stone Mastic Asphalt – SMA,
- Porous asphalts – PA.

Figure 2 Scheme of overlaying



Overlaying (with AC surf, SMA or PA) is suitable for all traffic load categories. Use of SMA reduces noise by at least 2 dB(A) and use of PA reduces noise by 5 to 8 dB(A).

Example 2 presents a typical example for a pavement suitable for overlaying (Picture 2).

Example 2: Pavement suitable for overlaying with asphalt concrete – AC surf

Explanation: Surfacing is a layer of Asphalt Concrete AC 16 s. The mixture AC 16 s contains hard binder BIT 45 which caused characteristic cracks due to hardening of the binder in unfavourable climate (low temperatures). The section has low traffic load. The bearing capacity of the pavement structure is suitable.

Picture 2 Example of a pavement suitable for overlaying with Asphalt Concrete – AC surf

5.3 Strengthening

In a number of cases pavement strengthening requires to various extent previous local rehabilitation. In the majority of cases, local rehabilitation requires the total replacement of the pavement structure by a new one.

The existing pavement structure can be strengthened by:

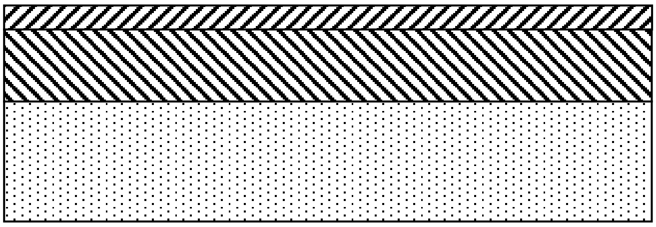
- bound upper base course and wearing course – upgrading by asphalt layers or
- unbound or bound base course(s) and wearing course – “sandwich” system or
- recycling the existing material (foam bitumen, cement, emulsions) and an asphalt upgrade – recycling.

In the case of strengthening of the pavements with heavy traffic loads, it is recommended to use various reinforcement meshes and improved modified binders in the base and wearing courses.

5.3.1 Upgrade by asphalt layers

The existing pavement structure is strengthened by bound upper base course and wearing course (Figure 3).

Figure 3 Scheme of upgrade by asphalt layers



Example 3 presents a typical example of pavement suitable for upgrade by asphalt layers (Picture 3).

Example 3: Roadway suitable for upgrade by asphalt layers

Explanation: The existing pavement structure consists of unbound layers with a total thickness of 60 cm and asphalt layers of 12 cm. The pavement is severely damaged (wide alligator cracks) and with poor localised bearing capacity of the pavement structure is locally poor. The section has a very heavy traffic load.

Before strengthening with base (AC base) and wearing (AC surf) courses, the areas of poor bearing capacity must be appropriately rehabilitated.

Picture 3 Example of pavement suitable for upgrade by asphalt layers

5.3.2 “Sandwich” system

"Sandwich" method comprises rehabilitation using a mixture of unbound grains in the lower layer(s) of upgrade and asphalt mixtures in the upper one(s). In such a case, the base is the existing damaged pavement structure with the bearing capacity of CBR = min. 15%. Upgrade is designed as a new construction.

Assuming that the damage of the existing carriageway results from fatigue and/or deformation of the upper layers of the pavement structure (resulting in very high deflection depending on the forecasted traffic load and/or severe pavement surface deformation forming very high longitudinal and/or transversal unevenness), the favourable condition of the base is a precondition for the upgrade using "sandwich" method.

Strengthening of the pavement structure by using the "sandwich" method is also appropriate when an upgrade using just asphalt layers is not economical.

A reason for deciding on "sandwich" method can also be the inadequate thickness of frost-resistant materials in the existing pavement structure.

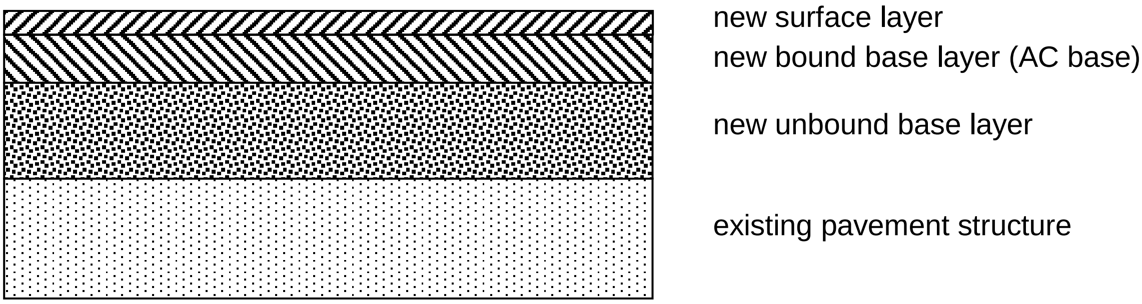
The unbound base layer made of frost resistant crushed rock material must be at least 15 cm thick in the damaged pavement structures with low and medium traffic loads, and in the pavement structures with heavy traffic loads at least 20 cm thick.

The use of "sandwich" method for the rehabilitation of a damaged existing pavement is limited by the eventual constraints of pavement level (e.g. vertical clearance under a bridge).

Existing pavement structures can be strengthened by using “sandwich” method (Figure 4) with:

- unbound base layer,
- bound base layer and/or
- surface layer.

Figure 4 Scheme of “sandwich” system upgrade



Strengthening by applying “sandwich” method is recommended primarily for the rehabilitation of pavements with very low, low and medium traffic loads. Only mixtures of crushed rock grains must be used in the new unbound base layer.

Example 4 presents a typical example of a pavement needing upgrade by “sandwich” method (Picture 4).

Alternatively, we can use the method of recycling the existing material and an asphalt upgrade which improves the existing unbound material using a binder, followed by the upgrade.

Example 4: Roadway suitable for upgrade using “sandwich” / recycling method

Explanation: The existing pavement structure consists of unbound layers with a total thickness of 40 cm and asphalt layers of 6 cm. The pavement is seriously damaged, and the pavement structure has poor bearing capacity in the entire section. Climatic and hydrological conditions are unfavourable. There is no effective drainage. The section has very low traffic volume. The section goes through forest, so the pavement surface level can be raised.

Picture 4 Example of pavement suitable for upgrade by “sandwich” method

5.3.3 Recycling

The use of the recycling method (Picture 5 and Picture 6) on the material of an existing pavement structure requires

- that existing pavement structure has frost-resistant material of sufficient thickness which ensures favourable conditions and appropriate bearing capacity (CBR = min. 10%) of the remaining material or
- climate conditions where frost penetration requires no additional measures.

The assumption for determining pavement structures using recycling of the material of the pavement structure is that roads with low or medium traffic loads have at least 25 cm thick upper layer of material that is by mixing with the appropriate binder suitable for recycling, and for roads with heavy traffic loads such layer should be at least 30 cm thick.

Picture 5 Recycling

Picture 6 Recycling

5.4 Reconstruction

Reconstruction of an existing pavement structure requires in addition to the measures defined for new pavements also the removal of the existing pavement structure to the thickness required by the new surface level of the pavement.

Reconstruction of a pavement structure is to be used if:

- several pavement properties are in very poor condition and
- road elements need improvement at the same time (widening of the carriageway, curve correction, etc.) and
- the damaged existing pavement structure has insufficient thickness of frost-resistant material and/or
- the depth of frost penetration requires thicker upgrade.

And at the same time:

- upgrade is not possible (e.g. due to surface level constraints).

Reconstruction is a measure for the replacement of the existing pavement structure. It is implemented if the bearing capacity of the pavement structure and the quality of its material are inadequate, and so the pavement structure is incapable carrying the actual traffic load.

Main reasons for the replacement of existing pavement structures are as follows:

- inadequate drainage,
- inadequate material of unbound base layers,
- inadequate thickness of the unbound base layer (resulting from poorly designed pavement structure – leading to unsuitable frost resistance),
- inadequate bound base and/or surface layers, etc.

When reconstructing (replacing) a structure, after the removal of the entire damaged pavement structure, a new one is constructed on a new foundation (capping layer).

The pavement design procedure to be used for determining the thicknesses of the new pavement structural layers, consider the bearing capacity of the foundation, the foundation traffic load, the climatic and hydrological conditions.

Example 5 presents a typical pavement in need of reconstruction (Picture 7).

Example 5: Pavement needing reconstruction

Explanation: The existing pavement structure consists of unbound layers with a total thickness of 30 cm and asphalt layers of 9 cm. The pavement is severely damaged (alligator cracks and deformations), and the pavement structure has poor bearing capacity in the entire section. Climatic and hydrological conditions are unfavourable. The section has medium traffic load.

The section goes through populated areas (access roads, sidewalks, etc.) so that the pavement surface level cannot be raised.

Picture 7 Pavement needing reconstruction

6 SYSTEMATIC DECISION MAKING METHODOLOGY FOR THE PAVEMENT REHABILITATION AND UPGRADING OF LOW-VOLUME ROADS

Based on the study of national decision methodologies (see Appendix 2), a common proposal for the systematic decision making methodology for pavement rehabilitation and upgrading of low-volume roads was prepared.

It is shown as flowchart and explained in text in the next chapter. Some examples for different pavement conditions are shown in chapter 6.2.

6.1 Introduction of the methodology in flowchart

The approach presented in the flowchart is a network-level approach, which is afterwards usually followed by project level, where tests of the materials in pavement structures are performed, the cause of the resulting damage is determined and, subsequently, pavement design and the selection of the suitable materials for rehabilitation are done. Project level is not included in the decision making process presented.

The procedure is suitable for all traffic categories (from very low to very high traffic loads), but only for flexible pavements. The changes in road geometry (e.g. pavement widening) are not a part of this decision making process, neither are economic considerations (e.g. limited rehabilitation budgets).

Since the road condition measurements (measuring devices), intervention thresholds and condition classification are different in various countries and depend on many factors (traffic classification, road classification etc.), the methodology has been prepared independent on all of those factors. In order to follow the procedure in the flowchart, it is necessary to transform the pavement condition information into condition classes for each pavement parameter according to the actual national best practice and technical specifications.

The flowchart is prepared for 5 condition classes (very good, good, fair, poor and very poor) but can be used also for 3 ones (good, fair and poor), where “very good” and “good” are together in a class “good”, while “poor” and “very poor” together in a class “poor”.

The flowchart can be used even if not all of the pavement characteristics (parameter levels) are known.

Pavement is rehabilitated whenever at least one of the pavement parameters comes to fair or worse condition. The actual rehabilitation technique is selected based on the users’ point of view that is on traffic safety. Therefore, the suitability of the pavement surface characteristics connected with user’s safety is verified first.

Figure 5 presents the flowchart for the decision making of pavement rehabilitation and upgrading.

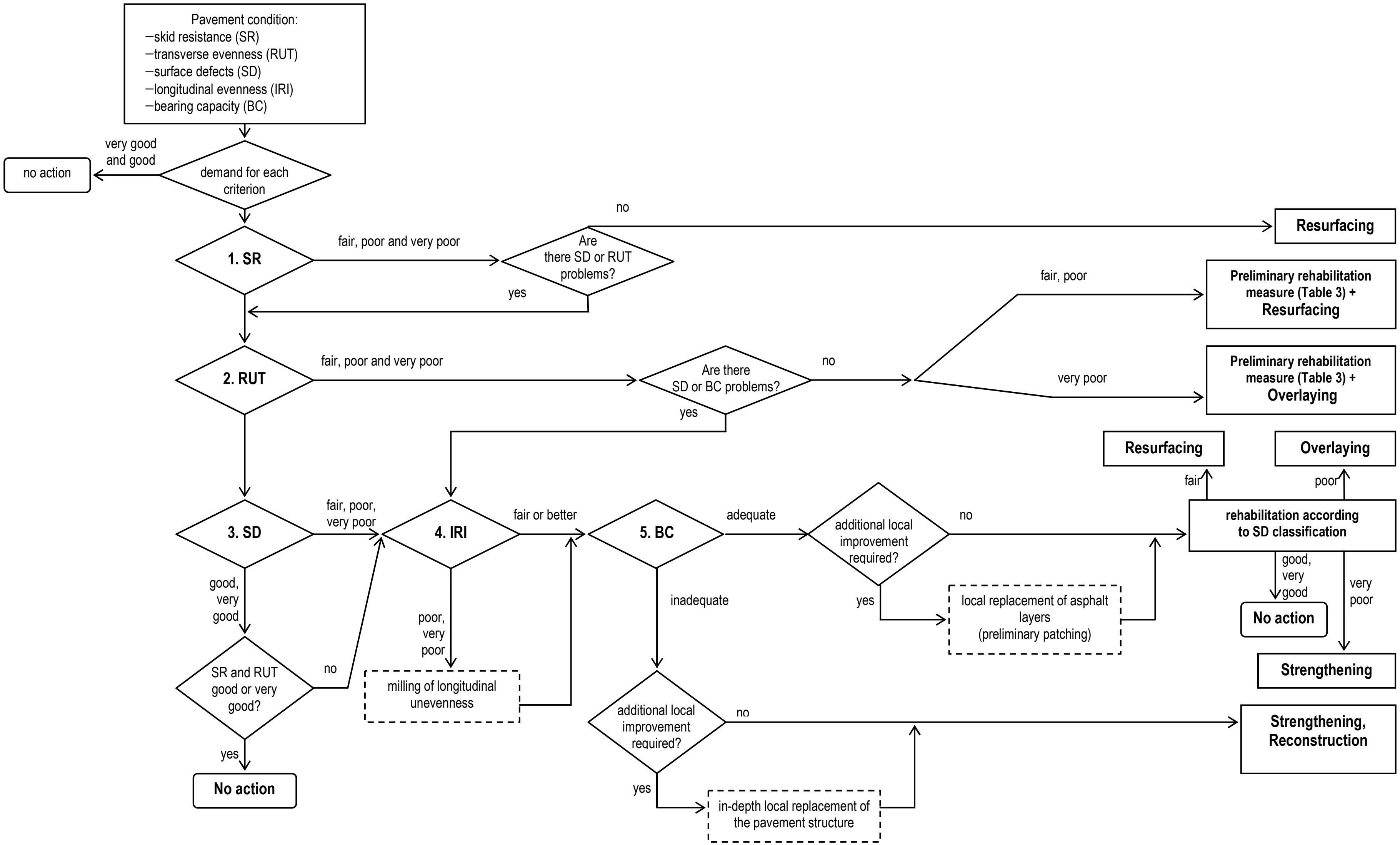


Figure 5 Flowchart for the decision making of pavement rehabilitation and upgrading

Step 0

For the determination of the appropriate rehabilitation measure, the information about the following parameters is needed:

- current pavement condition (skid resistance, transverse evenness, surface defects, longitudinal evenness, bearing capacity),
- definition of the thresholds for intervention in the case of individual pavement properties (according to the still acceptable pavement condition limit in the country),
- classification to 5 or 3 condition classes for every pavement property (according to national technical specifications),
- pavement design procedure for the determination of the thickness of strengthening or reconstruction (axle loading, traffic growth, according to national specifications).

Pavement condition is characterized by the following technical parameters:

- skid resistance characteristics – SR,
- transverse evenness (rut depth) – RUT,
- surface defects – SD,
- longitudinal evenness – IRI and
- bearing capacity – BC.

If all of the technical parameters characterizing pavement condition are very good or good, no measure is taken. However, if, at least one of the criteria of the pavement condition is fair or poorer, the criterion of skid resistance characteristics – SR is to be checked first – Step 1.

Step 1 Skid resistance characteristics – SR

If the condition of skid resistance characteristics is good or very good, proceed to Step 2.

However, if the condition of skid resistance characteristics is fair or poorer, check whether surface defect – SD or transverse evenness - RUT is fair or poorer:

- if either SD or RUT is fair or poorer, proceed to Step 2,
- if there are no SD or RUT problems, resurfacing is applied.

It is assumed here that if the pavement surface does not have any surface defects, the bearing capacity BC is adequate.

Step 2 Transverse evenness (rut depth) – RUT

If the transverse evenness condition is good or very good, proceed to Step 3.

If the condition of transverse evenness is fair or poorer, first check the surface defects SD and bearing capacity BC of the pavement:

- if there are SD or BC problems (fair or poorer condition), proceed to Step 4,
- if there is neither SD nor BC problems (good or very good condition), implement

a previous rehabilitation measure according to

- o Table 9 + resurfacing if the transverse evenness – RUT is fair or poor,

a previous rehabilitation measure according to

- o Table 9 + overlaying if the transverse evenness – RUT is very poor.

Table 9 Previous rehabilitation measures for the improvement of transverse evenness

Condition	Previous rehabilitation measure
good	-
fair	ridge milling along the rut
poor	milling of ridge and edges of the rut + levelling out the rut
very poor	milling of ridges and edges of the rut + levelling out the rut

The levelling of ruts is performed by incorporating asphalt mixtures for bituminous concrete wearing courses (or wearing courses which skeletal composition is comprised of discontinued bituminous concrete or stone mastic asphalt), where a level reduction of freshly laid layers during compaction has to be allowed.

If the pavement surface is damaged only by ruts, followed by previous rehabilitation, the pavement is levelled in the case of poor condition by resurfacing or, respectively, upgraded with overlay for very poor condition.

Step 3 Surface defects - SD

Check the condition of the visually assessed pavement surface defects – SD.

If the condition of the surface defects (SD) of the pavement is good or very good, check the condition of SR and RUT. If they are both either very good or good, end the procedure; no rehabilitation action is needed. If SR or RUT is fair of poorer, proceed to Step 4.

If the condition of surface defects (SD) on the pavement is fair or poorer, proceed to Step 4.

Step 4 Longitudinal evenness – IRI

If the longitudinal evenness IRI is in a fair or a better condition, proceed to Step 5.

If the condition of the longitudinal evenness IRI is poor or very poor, mill longitudinal unevenness, and proceed to Step 5.

Step 5 Pavement structure bearing capacity – BC

If the bearing capacity is adequate (deflection is lower than the limit one), in addition to any necessary local rehabilitation, the rehabilitation of pavement structure is to be carried out by resurfacing, overlaying or strengthening, depending on the actual surface defects – SD. If SD condition is fair, resurfacing should be built; if the condition is poor, overlay should be selected, and if the SD condition is very poor, strengthening should be done in a calculated thickness, based on pavement design procedure.

If the bearing capacity of the pavement structure is inadequate, the strengthening (in addition to any previous in-depth local rehabilitation) or reconstruction should be carried out in a calculated thickness, based on pavement design procedure.

6.2 Case studies

In the following chapters, some case studies are presented with the description of the pavement condition. The proposed methodology for the pavement rehabilitation and upgrading of low-volume roads is used to define the proper rehabilitation measure (technique).

6.2.1 Case study No 1

The pavement condition is described as follows (Picture 8):

- pavement type (AC or asphalt macadam),
- skid resistance characteristics show very poor condition,
- transverse evenness (rut depth) is in the class “good”,
- surface defects show fair condition,
- longitudinal evenness – IRI is in good condition,
- bearing capacity is adequate.

Picture 8 Pavement condition, case study No 1

According to the flowchart the skid resistance characteristics SR is checked first (Step 1). It is in very poor condition, therefore we check whether there are surface defects SD or RUT problems. Because SD is in fair condition, we proceed to Step 2, and check the transverse evenness (RUT). It is in good condition so we proceed to Step 3, and check the surface defects SD condition. It is in the class “fair” that is why we proceed to Step 4, and check longitudinal evenness IRI. Longitudinal evenness is good, so we proceed to Step 5, and check bearing capacity BC which is adequate. We check if additional local improvement is required, and since there are alligator cracks appearing locally we decide to replace locally the asphalt wearing course (previous patching).

Now we have to choose the rehabilitation measure according to SD classification which is fair, and the result is Resurfacing (with some previous patching).

6.2.2 Case study No 2

The pavement condition is described as follows (Picture 9):

- skid resistance characteristics show very poor condition,
- transverse evenness (rut depth) is in the class “poor”,
- surface defects show very poor condition,
- longitudinal evenness – IRI is in very poor condition,
- bearing capacity is inadequate.

Picture 9 Pavement condition, case study No 2

According to the flowchart, the skid resistance characteristics SR is checked first (Step 1). It is in very poor condition, and therefore we check the condition of the pavement regarding surface defects SD and RUT. Because SD and RUT are in very poor and poor condition respectively, we proceed to Step 2, and check the transverse evenness RUT. It is poor, and we have to check if there are surface defects SD or bearing capacity BC problems. Since there are, we proceed to Step 4, and check longitudinal evenness IRI. Longitudinal evenness IRI is very poor, so we have to mill longitudinal unevenness, and proceed to Step 5 to check the bearing capacity BC which is inadequate. We check if additional local improvement is required, and since there are alligator cracks and pavement deformations, we decide to make some in-depth local replacements of the whole pavement structure.

The rehabilitation measure is Strengthening (in-depth local replacement of the whole pavement structure) because there are no constraints for rising the level of the pavement. Even the upgrade by with “Sandwich” pavement structure is possible. The thicknesses of the layers depend on pavement design results.

6.2.3 Case study No 3

The pavement condition is described as follows (Picture 10):

- pavement type: asphalt macadam,
- skid resistance (SR) characteristics show very poor condition,
- transverse evenness (RUT) is in the class "poor",
- surface defects (SD) show poor condition,
- longitudinal evenness (IRI) is in fair condition,
- bearing capacity (BC) is inadequate.

Picture 10 Pavement condition, case study No 3

According to the flowchart, the skid resistance characteristics SR is checked first (Step 1). Since it is in a very poor condition, it is checked whether there are surface defects SD or RUT problems. SD and RUT are poor, that is why we proceed to step 2, and check transverse evenness (RUT). Actually, it is in the class "poor", so it is checked whether there are SD or BC problems. The answer is yes, that is why Step 4 follows where the longitudinal evenness is investigated which is in a fair condition. So, Step 5 is taken, and bearing capacity is checked which happens to be inadequate. This case additional local improvements (in-depth local replacements of the pavement structure) are required because of the depressions on the pavement surface.

The output of the survey in the flowchart is Strengthening with local improvements, Reconstruction is not needed yet.

6.2.4 Case study No 4

The pavement condition is described as follows (Picture 11):

- pavement type (Asphalt concrete)
- skid resistance characteristics show good condition,
- transverse evenness (rut depth) is in class fair,
- surface defects show very good condition,
- longitudinal evenness – IRI is in fair condition,
- bearing capacity is inadequate.

Picture 11 Pavement condition, case study No 4

According to the flowchart, the skid resistance characteristics SR is checked first (Step 1). It is in good condition, and therefore we proceed to Step 2, and check the transverse evenness (RUT). It is in fair condition, so we have to check if there are SD or BC problems. Because there are (BC is inadequate), we proceed to Step 4, and check the longitudinal evenness IRI. Longitudinal evenness is fair, so we proceed to Step 5, and check bearing capacity BC which is inadequate. We check if additional local improvement is required, and since there are local alligator cracks, we decide to make some in-depth local replacements of the whole pavement structure.

Now we have to choose the rehabilitation measure that, according to the flowchart is Strengthening (with some in-depth local replacements of the whole pavement structure) or Reconstruction.

6.2.5 Case study No 5

The pavement condition is described as follows (Picture 12):

- pavement type (Asphalt concrete)
- skid resistance characteristics show fair condition,
- transverse evenness (rut depth) is in the class “poor”,
- surface defects show very poor condition,
- longitudinal evenness – IRI is in fair condition,
- bearing capacity is adequate.

Picture 12 Pavement condition, case study No 5

According to the flowchart, the skid resistance characteristics SR is checked first (Step 1). It is in fair condition, and therefore we check the condition of the pavement regarding surface defects SD and transverse evenness RUT. Because SD is in very poor condition, and transverse evenness RUT is poor, we proceed to Step 2, and check the transverse evenness RUT. It is poor, and we have to check if there are either surface defects SD or bearing capacity BC problems. Since there are (SD is very poor), we proceed to Step 4, and check longitudinal evenness IRI. Longitudinal evenness IRI is fair, so we proceed to Step 5 to check the bearing capacity BC, which is adequate. We check if additional local improvement is required and since there are many potholes, alligator cracks and deformations, we decide to make some local replacements of asphalt layers (previous patching).

Now we have to choose the rehabilitation measure according to SD classification which is very poor, and the result is Strengthening (with some previous patching).

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