EUROPEAN COMMISSION
DG RESEARCH

SIXTH FRAMEWORK PROGRAMME

Sustainable Surface Transport

Sustainable Pavements for European New Member States

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

APPENDICES

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APPENDICES

1 QUESTIONNAIRE (WITH INFORMATION FROM SLOVENIA)

SPENS Questionnaire for Work Package 2, Work Tasks 2.1, 2.2 and 2.3

Country:	**Slovenia**
Exact address of the infrastructure owner you are replying for:	**DRSC - Directorate of the Republic of Slovenia for roads, Trzaska 19a, SI - 1000 Ljubljana; DARS - Motorway company in the Republic of Slovenia, Dunajska 7, SI - 1000 Ljubljana**

Respondent

Name:	**Julijana Jamnik**	
Affiliation:	**DDC Consulting & Engineering Ltd**	
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City and ZIP code:	**SI - 1000**	**Ljubljana**
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Fax number:	**++ 386 1 30 68 307**	
E-mail address:	Julijana.Jamnik@DDC.si	

National road network characteristics

Road network length (km)

	Flexible	Semi Rigid	Rigid	Unpaved	Other (please specify)	Total
Motorways and Dual-carriage ways	**0**	**481**	**0**	**0**		**481**
Primary Roads	**923**	**0**	**3**	**0**		**926**
Secondary Roads	**4.451**	**0**	**0**	**396**		**4.847**
Other (please, specify)						**0**
Total	**5.374**	**481**	**3**	**396**		**6.254**

General pavement condition (% of length)

	Very Good	Good	Fair	Poor	Very Poor	Other (please specify)
Motorways and Dual-carriage ways	**77**	**9**	**4**	**4**	**6**	
Primary Roads	**25**	**14**	**14**	**13**	**34**	
Secondary Roads	**25**	**12**	**12**	**11**	**40**	
Other (please, specify)						

Condition is determined by

Criterion, formulae (please, specify)	**Visual pavement condition index**
Other (please, specify)	

Which reference axle load do you apply?

80 kN	No
82 kN	**Yes**
100 kN	No
130 kN	No
Other (please, specify)	

Maximum Traffic Volume and Traffic Loading per day

	Motorways and Dual-carriage ways	Primary Roads	Secondary Roads	Other (please specify)	Average
AADT	**70.000**	**59.385**	**42.000**		**46.728**
ESAL at 80kN ref. load and 4th power/day					
ESAL at 82kN ref. load and 4th power/day	**5.076**	**2.462**	**3.532**		**3.492**
ESAL at 110kN ref. load and 4th power/day					
ESAL at 100kN ref. load and 4th power/day	**2.295**	**1.113**	**1.597**		**1.579**
Other (please, specify)					0

Minimum Traffic Volume and Traffic Loading per day

	Motorways and Dual-carriage ways	Primary Roads	Secondary Roads	Other (please specify)	Average
AADT	**228**	**678**	**30**		**141**
ESAL at 80kN ref. load and 4th power/day					
ESAL at 82kN ref. load and 4th power/day	**18**	**2**	**2**		**3**
ESAL at 110kN ref. load and 4th power/day					
number of ESALs at 100kN ref. load and 4th power per day	**8**	**1**	**1**		**1**
Other (please, specify)					**0**

Average (weighted by the length of the roads) Traffic Volume and Traffic Loading per day

	Motorways and Dual-carriage ways	Primary Roads	Secondary Roads	Other (please specify)	Average
AADT	**23.395**	**8.198**	**2.396**		**4.870**
ESAL at 80kN ref. load and 4th power/day					
ESAL at 82kN ref. load and 4th power/day	**2.290**	**522**	**70**		**308**
ESAL at 110kN ref. load and 4th power/day					
number of ESALs at 100kN ref. load and 4th power per day	**1.035**	**236**	**32**		**139**
Other (please, specify)					0

Traffic information

Maximum permitted axle load on national road network

No. of axles	Maximum axle load (tons)	Axle spacing	Comment
1	11,5		for driving axles on motorways, primary roads
1	10		
2	11,5	< 1m	
2	16	1,0 - 1,3 m	
2	18	1,3 - 1,8 m	
2	11	< 1m	for trailers
2	16	1,0 - 1,3 m	for trailers
2	18	1,3 - 1,8 m	for trailers
2	20	> 1,8 m	for trailers
3	21	< 1,3 m	for trailers
3	24	1,3 - 1,4 m	for trailers

Do you apply axle load restrictions during the thawing period?

Yes

If yes, how do you reduce the following axle loads? (10 t, 8 t, 6 t, other)

Road Category	Allowed Axle Load (tons)
Motorways and Dual Carriageways	**Not applicable**
Primary Roads	**8 t, 6 t**
Secondary Roads	**8 t, 6 t**
Other (please, specify)	

What is the highest allowable gross vehicle mass without special permit on the national road network?

Road Category	Allowed Gross Vehicle Mass (tons)
Motorways and Dual Carriageways	**44**
Primary Roads	**44**
Secondary Roads	**44**
Other (please, specify)	

No. of axles	Allowable Total Mass (tons) motor vehicle + tractor-trailer	Comment
2	18	
3	25	motor vehicles
3	24	trailers
3	28	bus
4	32	
> 4	32	

No. of axles	Allowable Total Mass (tons) group of vehicles	Axle spacing	Comment
up to 3	28		
4	36		2-axle motor vehicle + 2-axle tractor-trailer
4	36	1,3 - 1,8 m	2-axle motor vehicle + 2-axle semi-trailer
4	38	> 1,8 m	2-axle motor vehicle + 2-axle semi-trailer
> 4	40		
> 4	44		special conditions, combined transport (road-railroad)

Collection of traffic information

How do you collect traffic data:

WIM	Counting	Other (please, specify)

How detailed traffic data (how many vehicle classes) do you collect?

	With WIM	With counting	With other device
Number of classes	74	6	0

How many WIM stations do you have?

How many traffic counting stations do you have (periodic and permanent)?

Please provide your typical classification table.

Personal car	Yes
Bus	Yes
Light Truck capacity to 3,5 tons	Yes
Medium Truck capacity 3,5 to 7 tons	Yes
Heavy Truck capacity over 7 tons	Yes
Heavy Truck with Trailers	Yes
Non-classified	No
74 categories based on No. of axles and axle spacings + class Non-classified	Yes

How do you evaluate traffic loading?

From AADT by vehicle types and traffic equivalency factors	Yes
From AADT and % Heavy Vehicles	No
From Weigh-in-motion data	Yes
Other (please, specify)	

Which method do you apply for calculation of aggresivity (influence) of traffic?

Equivalency factors	**Yes**
Other (please, specify)	

If you use the equivalency-factor formula, do you apply:

		Power
The same power for all pavements	**Yes**	**4**
Different powers depending on type of pavement	**No**	Please, specify

If you use the equivalency-factor formula, please specify formula:

Formula	Comment
$FE_{nom} = 10^{-8} * f_0 * (f_k * L_{stat})^4$	**where f_0 = factor of axle distribution (single = 2,212, Tandem = 1,583); where f_k = factor of wheel distribution (single = 1,0, double = 0,9); where L_{stat} = static axle load of individual vehicle in kN**

How do you determine Yearly Traffic Growth (%)?

From traffic studies	**Yes**
Is taken the same for all road categories and vehicle types	**Yes**
Depends on road category	No
Depends on vehicle type	No
Is region dependent	No
Other	Please, specify

How would you classify traffic volume into the following classes?

	(I) - Extreme	(II) - Very high	(III) - High	(IV) - Modest	(V) - Low	(VI) - Very low
AADT	**> 20.000**	**10.000 to 20.000**	**5.000 to 10.000**	**2.000 to 5.000**	**1.000 to 2.000**	**< 1.000**
Other (please, specify)						

How would you classify traffic loading into the following classes?

	(I) - Extreme	(II) - Very High	(III) - High	(IV) - Modest	(V) - Low	(VI) - Very low
ESAL at 80kN/day						
ESAL at 82kN/day	**> 3000**	**800 to 3000**	**300 to 800**	**80 to 300**	**30 to 80**	**to 30**
ESAL at 110kN/day						
Number of ESAL at 100kN ref. load and 4th power/day	**more than 1356**	**362 to 1356**	**136 to 362**	**36 to 136**	**14 to 36**	**less than 14**
Other (please, specify)						

Pavement Condition of existing pavement structures

Bearing Capacity Measurements

Measuring Device

Deflectometer FWD, Deflectograph LaCroix

Other	Please, specify

Do you use GPR (Ground Penetrating Radar)?

No

Classification

Very Good, Good, Fair, Poor, Very Poor

Warning Level, Threshold Level
Other (please, specify)

Classification Criterion

Road Category, Traffic Volume Traffic Load, Driving Speed, Other

Condition Class Limits according to Classification Criterion

		Condition Classification							
	Pavement Condition Classification Criterion	Very Poor	Poor	Fair	Good	Very good	Warning Level	Threshold Level	Other (please, specify)
Deflection (mm/1000)									
E-module (MPa)									
Residual Life Time (years)	**-**	**< 2**	**2 to 5**	**5 to 10**	**10 to 15**	**> 15**			
Other (please, specify)									

Purpose of measurement

Condition monitoring in regular intervals
Occasional research survey
Other (please, specify)

Monitoring level

Project level, Network level

Do you intend to participate in the Harmonisation test (Work Package 2, Work Task 2.2) with bearing capacity measurements on test fields in Vienna 2008?

Yes

If yes, please answer the next questions:

Device name	**FWD 8002 Dynatest**
Organisation/Person responsible for device	**DDC Cosnulting & Engineering, Mrs. Julijana Jamnik**
Measuring prinicple	**Defelction measurement**
Comments	

Transverse Evenness Measurements

Measuring Device

Profilograph, Profilometer, **4-m Straight Edge,** 3-m Straight Edge, RST Road Survey Tester
Other (please, specify)

Sampling interval: 10 m, **20 m**, 50 m, 100 m, Other - please specify

Classification

Very Good, Good, Fair, Poor, Very Poor
Warning Level, Threshold Level
Other (please, specify)

Classification Criterion

Road Category, **Traffic Volume, Traffic Load, Design Speed,** Other

Condition Class Limits according to Classification Criterion

	Pavement Condition Classification Criterion	Condition Classification Very Poor	Poor	Fair	Good	Very Good	Warning Level	Threshold Level	Other
Rut Depth (mm)	**> Medium Traffic Volume and > Medium Traffic Load**	**> 18**	**14 do 18**	**10 do 14**	**6 do 10**	**< 6**			
Rut Depth (mm)	**<= Medium Traffic Volume and <= Medium Traffic Load**	**> 20**	**16 do 20**	**12 do 16**	**8 do 12**	**< 8**			
Water Depth (mm)	**Driving Speed < 70 km/h**						**8**	**10**	
Water Depth (mm)	**Driving Speed > 70 km/h**						**4**	**6**	
Other (please, specify)									

Purpose of measurement

Condition monitoring in regular intervals
Occasional research survey
Other (please, specify)

Monitoring level

Project level, Network level

Longitudinal Evenness Measurements

Measuring Device

Profilograph, **Profilometer, 4-m Straight Edge**, APL, RST Road Survey Tester
Other (please, specify)

Presentation Length

10 m, 20 m, 25 m, 50 m, **100 m**, 1000 m, Other

Classification

Very Good, Good, Fair, Poor, Very Poor
Warning Level, Threshold Level
Other (please, specify)

Classification Criterion

Road Category, **Traffic Volume, Traffic Load,** Design Speed, Other

Condition Class Limits according to Classification Criterion

		Condition Classification							
	Pavement Condition Classification Criterion	Very Poor	Poor	Fair	Good	Very Good	Warning Level	Threshold Level	Other
IRI (m/km)	**> Medium Traffic Volume and > Medium Traffic Load**	**> 3,1**	**2,2 do 3,1**	**1,5 do 2,2**	**1,2 do 1,5**	**< 1,2**			
IRI (m/km)	**<= Medium Traffic Volume and <= Medium Traffic Load**	**> 4,9**	**4,3 do 4,9**	**3,5 do 4,3**	**2,6 do 3,5**	**< 2,6**			
Evenness 4-m Straight Edge (mm)	**> Medium Traffic Volume and > Medium Traffic Load**	**> 18**	**14 do 18**	**10 do 14**	**6 do 10**	**< 6**			
Evenness 4-m Straight Edge (mm)	**<= Medium Traffic Volume and <= Medium Traffic Load**	**> 20**	**16 do 20**	**12 do 16**	**8 do 12**	**< 8**			
Longitudinal profile variance 30 m									
Longitudinal profile variance 10 m									
Longitudinal profile variance 3 m									
Long Wavelength Index									
Medium Wavelength Index									
Short Wavelength Index									
Other (please, specify)									

Purpose of measurement

Condition monitoring in regular intervals
Occasional research survey
Other (please, specify)

Monitoring level

Project level, **Network level**

Do you intend to participate in the Harmonisation test (Work Package 2, Work Task 2.2) with longitudinal evenness measurements on test fields in Vienna 2008?

Yes

If yes, please answer the next questions:

Device name	Profilometer ZAG
Organisation/Person responsible for device	**ZAG, Mr. Bojan Leben**
Measuring prinicple	**Laser measurement**
Classification according to EN 13036-6 Part 5	**No**
Measured values	True Profile, sampling lenght
	IRI 25m presentation lenght
	IRI 50m presentation lenght
	IRI 100m presentation lenght
	Power spectral density
	Other, please specify
Comments	

Skid Resistance Measurements

Measuring Device

SCRIM, Skid Resistance Tester (SRT)
Other (please, specify)

Classification

Very Good, Good, Fair, Poor, Very Poor
Warning Level, Threshold Level
Other (please, specify)

Classification Criterion

Road Category, **Traffic Volume, Traffic Load, Design/Measuring Speed,** Other

Condition Class Limits according to Classification Criterion

		Condition Classification							
	Pavement Condition Classification Criterion	Very Poor	Poor	Fair	Good	Very Good	Warning Level	Threshold Level	Other
SRT Value	**<= Medium Traffic Volume and <= Medium Traffic Load**						**45 to 55**		
SRT Value	**> Medium Traffic Volume and > Medium Traffic Load**						**50 to 60**		
Horizontal force of measuring wheel									
Side force of measuring wheel	**Measuring Speed 30 km/h**	**< 50**	**50 to 56**	**57 to 61**	**62 to 72**	**> 72**			
Side force of measuring wheel	**Measuring Speed 40 km/h**	**< 46**	**46 to 52**	**53 to 56**	**57 to 67**	**> 67**			
Side force of measuring wheel	**Measuring Speed 50 km/h**	**< 42**	**42 to 48**	**49 to 52**	**53 to 63**	**> 63**			
Side force of measuring wheel	**Measuring Speed 60 km/h**	**< 39**	**39 to 45**	**46 to 48**	**49 to 59**	**> 59**			
Side force of measuring wheel	**Measuring Speed 70 km/h**	**< 36**	**36 to 42**	**43 to 45**	**46 to 56**	**> 56**			
Side force of measuring wheel	**Measuring Speed 80 km/h**	**< 33**	**33 to 39**	**40 to 42**	**43 to 53**	**> 53**			
Side force of measuring wheel	**Measuring Speed 90 km/h**	**<30**	**30 to 36**	**37 to 39**	**40 to 50**	**> 50**			
Other (please, specify)									

Purpose of measurement

Condition monitoring in regular intervals
Occasional research survey
Other (please, specify)

Monitoring level

Project level, Network level

Do you intend to participate in the Harmonisation test (Work Package 2, Work Task 2.2) with skid resistance measurements on test fields in Vienna 2008?

Yes/No

If yes, please answer the next questions:

Device name	SCRIMTEX
Organisation/Person responsible for device	ZAG, Mr. Bojan Leben
Measuring Principle	Sider force coefficent
Slip ratio	
Applied vertical load	
Measuring tyre	
Comments	

Texture Measurements

Measuring Device

Laser based measurement, Sand Patch Test/Volumetric method
Other (please, specify)

Classification

Very Good, Good, Fair, Poor, Very Poor
Warning Level, **Threshold Level**
Other (please, specify)

Classification Criterion

Road Category, Traffic Density, Traffic Load, **Design Speed,** Other

Condition Class Limits according to Classification Criterion

		Condition Classification							
	Pavement Condition Classification Criterion	Very Poor	Poor	Fair	Good	Very Good	Warning Level	Threshold Level	Other
Mean Profile Depth (mm)	**Design Speed 60 km/h**							**0,13**	
Mean Profile Depth (mm)	**Design Speed 70 km/h**							**0,19**	
Mean Profile Depth (mm)	**Design Speed 80 km/h**							**0,25**	
Mean Profile Depth (mm)	**Design Speed 100 km/h**							**0,42**	
Mean Profile Depth (mm)	**Design Speed 120 km/h**							**0,63**	
Mean Texture Depth (mm)	**Design Speed 40 km/h**							**0,22**	
Mean Texture Depth (mm)	**Design Speed 50 km/h**							**0,26**	
Mean Texture Depth (mm)	**Design Speed 60 km/h**							**0,30**	
Mean Texture Depth (mm)	**Design Speed 70 km/h**							**0,35**	
Mean Texture Depth (mm)	**Design Speed 80 km/h**							**0,40**	
Mean Texture Depth (mm)	**Design Speed 100 km/h**							**0,53**	
Mean Texture Depth (mm)	**Design Speed 120 km/h**							**0,70**	
Sensor Measured Texture Depth (mm)									
Other (please, specify)									

Purpose of measurement

Condition monitoring in regular intervals
Occasional research survey
Other (please, specify)

Monitoring level

Project level, Network level

Surface Defects

Measuring Device

Visual inspection, Video Recording (ARAN, Other)
Other (please, specify)

Which Surface Defects do you register with Visual Pavement Condition Survey?

Bleeding	No
Cracking	**Yes**
Joint spalling	No
Corner breaking	No
Punch out	No
Faulting	No
Patching	**Yes**
Potholes	**Yes**
Ravelling	**Yes**
Other (please, specify)	

How do you take into account those Surface Defects?

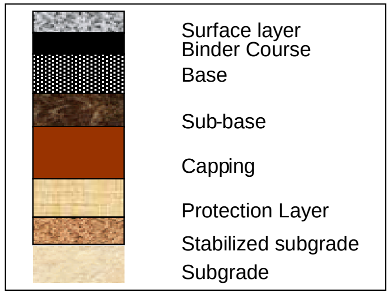
Separately, **All together with Combined Index**
Other (please, specify)

How do you classify individual Surface Defects or Combined Index into Condition Classes?

Yes/No
If yes, how many condition classes?
3, 4, **5,** Other
Other (please, specify)

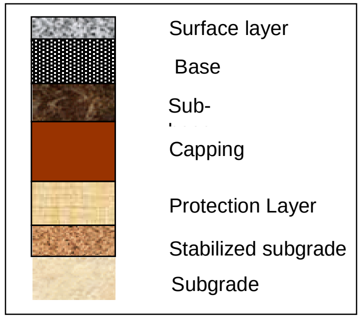
Typical (most common) flexible and semi-rigid pavement structure

Definition of layers



Typical (most common) rigid pavement structure

Definition of layers



Type of pavement structure

- Unbound
- Rigid
- **Semi-Rigid**
- **Flexible**
- Other, please specify

Typical Flexible Pavement Structure (more than one can be defined)

Layer	Material
Surface layer	**SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete**
Binder Course	**AC_{bin}-Asphalt Concrete**
Base Course	**AC_{base}**
Sub-base	**Crushed Stone**
Capping	**Rock Material Resistant to Freezing**
Protection layer	
Stabilized subgrade	
Other, please specify	

Typical Semi-Rigid Pavement Structure (more than one can be defined)

Layer	Material
Surface layer	**SMA-Stone Mastic Asphalt, AC_{surf}-Asphalt Concrete**
Binder Course	**AC_{bin}-Asphalt Concrete**
Base Course 1	**AC_{base}**
Base Course 2	**CS-Cement Stabilization**
Sub-base	**Crushed Stone**
Capping	**Rock Material Resistant to Freezing**
Protection layer	
Stabilized subgrade	
Other, please specify	

Typical Rigid Pavement Structure (more than one can be defined)

Layer	Material
Surface layer	**CC-Cement Concrete**
Base Course 1	**CC-Cement Concrete**
Base Course 2	**AC_{base}**
Base Course 3	**CS - Cement Stabilistation**
Sub-base	**Crushed Stone**
Capping	**Rock Material Resistant to Freezing**
Protection layer	
Stabilized subgrade	
Other, please specify	

Other, please specify

Maintenance Treatments (maintenance means major maintenance, rehabilitation and reconstruction)

Maintenance Treatment Types

- Resurfacing
- **Surface Dressing**
- **Overlay < 4 cm**
- **Strengthening**
  - **Bituminous Overlay**
  - **Sandwich System**
- **Pavement Reconstruction**
- **Recycling**
- **Mill & Replace of bound courses**
- Other

Which Pavement Design Procedure do you use?

- Theoretical Procedure
  - Boussinesque
  - Burmister
  - Odemark
  - Westergaard
  - Software
    - APAS-WIN
    - BISAR-SPDM
    - CIRCLY
    - Other, please specify
  - Other, please specify
- Empirical Procedures
  - **AASHTO**
  - Dormon-Edwards
  - TRRL (Transport and Road Research Laboratory)
  - Other, please specify
- Standardized Procedures (Catalogue of pre-defined typical pavement structures)
  - German catalogue
  - French catalogue
  - Other, please specify

Base and subbase information

Do you perform any field tests on the unbound layers?

Yes

How often you perform field test on the unbound material?

1 (almost) always	**No**
2 occasinally - depends on....	**Yes**
3 almost never - because of ...	**No**
4 other - explain...	

Which field tests do you perform on unbound base or sub-base layers?

	standard used	parameter that you take into account for design
California Bearing Ratio (CBR) - field test		**CBR**
Bearing capacity of soils - static plate loading test (E2)	**national TSC**	**E_2**
Bearing capacity of soils - dynamic plate loading test (Evd)		**E_{vd}**
other...		

Do you make any laboratory tests on the unbound material?

Yes

How often you perform laboratory test on the unbound material?

1 (almost) always	**Yes**
2 occasinally - depends on....	**No**
3 almost never - because of ...	**No**
4 other - explain...	

Which laboratory tests do you perform on unbound base or sub-base layers?

	Do you use European standards?	parameter considered
gradation test- sieve analysis		**Cu, Cc**
optimum desity (Proctor)	**SIST EN 13286-2**	**ρd, Wopt.**
CBR_1	**SIST EN 13286-47**	**CBR_1**
CBR_2	**SIST EN 13286-47**	**CBR_2**
Los Angeles test	**SIST EN 1097-2**	**LA**
Determination of percentage of crushed and broken surfaces in coarse agregate particles	**SIST EN 933-5**	**Ctr,Cr,Ctc,Cc**
Assessment of fines - Methylene blue test	**SIST EN 933-9**	**MB**
Assessment of fines - Sand equivalent test	**SIST EN 933-8**	**SE**
Determination of particle density	**SIST EN 1097-6**	**ρssd**
Water absorption	**SIST EN 1097-6**	**WA**
Test for thermal properties of aggregates - Magnesium sulfate test	**SIST EN 1367-2**	**MS**
Determination of particle shape - shape index	**SIST EN 933-4**	**SI**
other...		

How do you quantify the contribution of individual pavement layers to bearing capacity of pavement structure?

Calculation of Structural Number with Material Equivalency Factors	**Yes**
Other, please specify	

Material Equivalency Factors

Material	Material Equivalency Factors	Other, please specify
SMA - Stone Mastic Asphalt	**0,42**	
AC_{surf} - Asphalt Concrete	**0,42**	
PA - Porous Asphalt	**0,42**	
AC_{bin} - Asphalt Concrete	**0,35**	
AC_{base} - Asphalt Concrete	**0,35**	
Bituminous Stabilization	**0,24**	
Cement Stabilization	**0,20**	
Cement Concrete	**0,60**	
Crushed stone	**0,14**	
Uncrushed stone	**0,11**	
Other, please specify		

How do you decide whether the materials in existing pavement structure are suitable for overlaying or must be removed?

Taking into account the results of Laboratory tests of bound material characteristics from cores, taken from the existing pavement	**Yes**
Taking into account pavement condition measurements and visual inspection	**Yes**
Never remove any layer	No
Always remove wearing course	No
Other, please specify	

What do you take into account when choosing a Treatment Type?

Pavement Condition	**Cracks, Bearing Capacity, Transverse Evenness, Longitudinal Evenness, Skid Resistance, Laboratory tests of existing pavement materials,** Other
Traffic Loading in Project Period	**Yes**
Climatic Conditions	**Frost Depth, Rainfall,** Other
Urban Environment Demands	**Noise,** Drainage System, Other
Bearing Capacity of Subbase	**CBR,** Other
Other, please specify	

2 NATIONAL REPORTS

2.1 Description of the algorithm for defining rehabilitation measures in Slovenia

The definition of the appropriate rehabilitation measures is carried out from the users' point of view, i.e. from the aspect of traffic safety (Figure 1). Therefore, the suitability of pavement surface characteristics vital to the user's safety is verified first.

The approach presented is a network-level one which is followed afterwards on project level by the tests of materials in pavement structures, determination of the causes of the resulting damage and, subsequently, by the pavement design and the selection of suitable materials for rehabilitation. 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 geometrical parameters (e.g. pavement widening) are not a part of this decision making process, neither are the economic considerations (e.g. limited rehabilitation budgets).

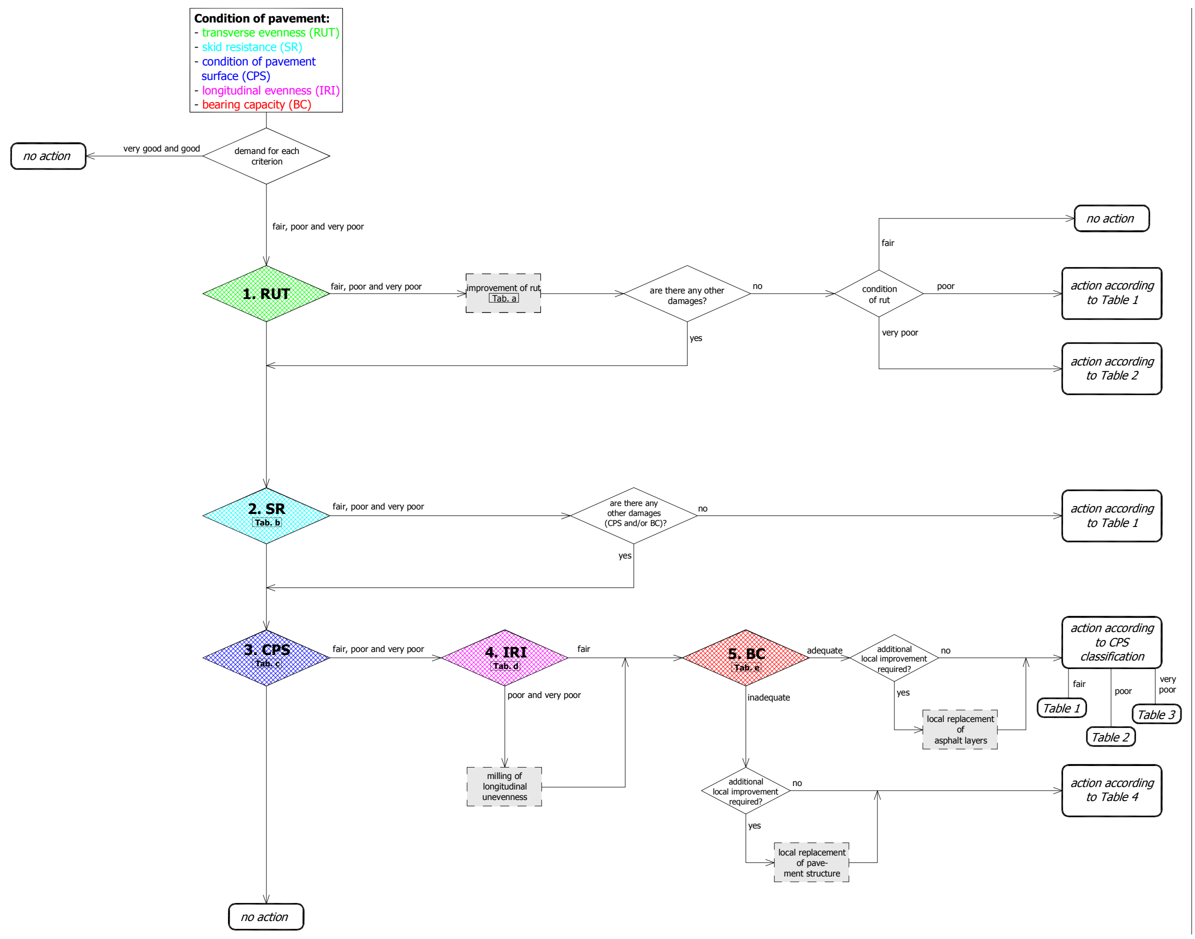


Figure 1: Flow-chart for the decision making of pavement rehabilitation and upgrading in Slovenia

Step 0

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

- current level of pavement condition (assessment of technical parameters: transverse evenness, skid resistance, surface defects, longitudinal evenness, bearing capacity),
- definition of the thresholds for the intervention because of individual technical parameters (according to national technical specifications),
- traffic composition,
- traffic growth,
- axle loading.

Pavement condition is presented with the following technical parameters:

- transverse evenness (rut depth) – RUT,
- pavement surface skid resistance characteristics – SR,
- visual condition of pavement surface – CPS,
- longitudinal evenness – IRI and
- bearing capacity of pavement structure – BC.

Taking into account the national technical specifications and best practice, pavements are divided into 5 condition classes: very good, good, fair, poor and very poor.

If the pavement condition is very good or good in the case of all technical parameters, no measure is taken. However, if, by at least one of the criteria, the pavement condition is fair or poorer, the criterion of transverse evenness - RUT is verified first – Step 1.

Table 1 Pavement Design – overlay for fair condition (damage quotient k_d = 0.9)

Traffic Load		Thickness of existing asphalt layers		Thickness of required overlay							
Class	ESAL in 82 kN/day	a = 0.38		D_{act}	D_{req}	Wearing course a=0.42		Base course a = 0.35		Together	
		d cm	D_{no} cm	(D_{no} x k_d) cm	(D_{no} – D_{ob}) cm	d_1 cm	D_1 cm	d_2 cm	D_2 cm	$d_1 + d_2$ cm	$D_1 + D_2$ cm
- very low	< 30	8	3.04	2.74	0.30	1 SD	-	-	-	1	-
- low	30 – 80	9	3.42	3.08	0.34	1 SD	-	-	-	1	-
- modest	80 – 300	12	4.56	4.10	0.46	1.5 TLD	0.60	-	-	1.5	0.60
- high	300 – 800	15	5.70	5.13	0.57	1.5 TLD	0.60	-	-	1.5	0.60
- very high	800 - 3000	19	7.22	6.50	0.72	2 TLD	0.80	-	-	2	0.80
- extreme	> 3000	21	7.98	7.18	0.80	2 TLD	0.80	-	-	2	0.80

SD surface dressing
TLD thin asphalt layer

Table 2 Pavement Design - overlay for poor condition (damage quotient k_d = 0.6)

Traffic Load		Thickness of asphalt layer		Thickness of required overlay							
Class	ESAL in 82 kN/day	a = 0.38		D_{act}	D_{req}	Wearing course a=0.42		Base course a = 0.35		Together	
		d cm	D_{no} cm	(D_{no} x k_d) cm	(D_{no} - D_{act}) cm	d_1 cm	D_1 cm	d_2 cm	D_2 cm	$d_1 + d_2$ cm	$D_1 + D_2$ cm
- very low	< 30	8	3.04	1.82	1.22	3 AC_{surf}	1.26	-	-	3	1.26
- low	30 – 80	9	3.42	2.05	1.37	4 AC_{surf}	1.68	-	-	4	1.68
- modest	80 – 300	12	4.56	2.74	1.82	4.5 AC_{surf}	1.89	-	-	4.5	1.89
- high	300 – 800	15	5.70	3.42	2.28	3 AC_{surf}	1.26	5 AC_{base}	1.75	8	3.01
- very high	800 - 3000	19	7.22	4.33	2.89	3 AC_{surf}	1.26	5 AC_{base}	1.75	8	3.01
- extreme	> 3000	21	7.98	4.79	3.19	3 AC_{surf}	1.26	6 AC_{base}	2.10	9	3.36

AC_{surf} asphalt concrete surface course
AC_{base} asphalt concrete base course

Table 3 Pavement Design for very poor condition (damage quotient k_d = 0.4)

Traffic Load		Thickness of existing asphalt layers a = 0,38		Thickness of required overlay							
Class	ESAL at 82 kN/day			D_{act}	D_{req}	Wearing course a=0,42		Bearing course a = 0,35		Together	
		d cm	D_{no} cm	(D_{no} x k_d) cm	(D_{no}– D_{ob}) cm	d_1 cm	D_1 cm	d_2 cm	D_2 cm	$d_1 + d_2$ cm	$D_1 + D_2$ cm
- very low	< 30	8	3,04	1,22	1,82	5 AC_{bs}	1,90	-	-	5	1,90
- low	30 – 80	9	3,42	1,37	2,05	6 AC_{bs}	2,28	-	-	6	2,28
- modest	80 – 300	12	4,56	1,82	2,74	3 AC_{surf}	1,26	5 AC_{base}	1,75	8	3,01
- high	300 – 800	15	5,70	2,28	3,42	3 AC_{surf}	1,26	7 AC_{base}	2,45	10	3,71
- very high	800 - 3000	19	7,22	2,89	4,33	3 AC_{surf}	1,26	9 AC_{base}	3,15	12	4,41
- extreme	> 3000	21	7,98	3,19	4,79	3 AC_{surf}	1,26	11 AC_{base}	3,85	14	5,11

AC_{bs} ……..asphalt concrete base-surface course

Table 4 Pavement strengthening based design on deflection criterion

Traffic Load		Thickness of existing asphalt layers a = 0,38		Value of deflection [mm]															
Class	ESAL at 82 kN/day	d cm	D_{no} cm	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD	Lacroix	FWD
- very low	< 30	8	3,04	1,55	1,10	1,85	1,29	2,15	1,47	2,45	1,65	Recycling or renewal							
- low	30 – 80	9	3,42	1,33	0,96	1,58	1,12	1,88	1,30	2,18	1,49	2,52	1,69						
- modest	80 – 300	12	4,56	1,05	0,78	1,24	0,90	1,48	1,05	1,72	1,21	2,00	1,38	2,34	1,58				
- high	300 – 800	15	5,70	0,86	0,65	1,00	0,74	1,15	0,84	1,33	0,96	1,55	1,10	1,83	1,27	2,12	1,45	2,53	1,70
- very high	800 - 3000	19	7,22	0,62	0,49	0,70	0,54	0,79	0,60	0,88	0,66	1,02	0,76	1,18	0,86	1,38	0,99	1,62	1,14
- extreme	> 3000	21	7,98	0,56	0,44	0,63	0,49	0,69	0,53	0,75	0,58	0,86	0,65	1,01	0,75	1,16	0,85	1,36	0,98
				Required thickness of asphalt layers [cm]															
				4		6		8		10		12		14		16		18	

Step 1 Transverse evenness (rut depth) – RUT

If transverse evenness condition is good or very good, proceed to Step 2.

If the condition of transverse roughness is fair or poorer, first check whether any pavement damage other than ruts is also present:

- if any other damage is also present, proceed to Step 2,
- if there is no other damage, taking into account the rut depth, implement a previous rehabilitation measure according to Table 5 and Figure 2.

Table 5 Previous rehabilitation measures for the improvement of transverse evenness

Condition	Rut depth [mm]	Previous rehabilitation measure
good	< 15	-
fair	15 to 30	Ridge milling along the rut
poor	30 to 60	Milling of the ridge and edges of the rut + levelling out the rut
very poor	> 60	Milling of the ridges and edges of the rut + levelling out the rut

The area around the rut is rehabilitated by milling the ridges along the rut to the level of the non-deformed pavement surface alongside the rut (1 metre width); then, the rut edges are also milled to the bottom of the rut (0.5 metre width).

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), allowing for the lowering of fresh asphalt surface level during compaction.

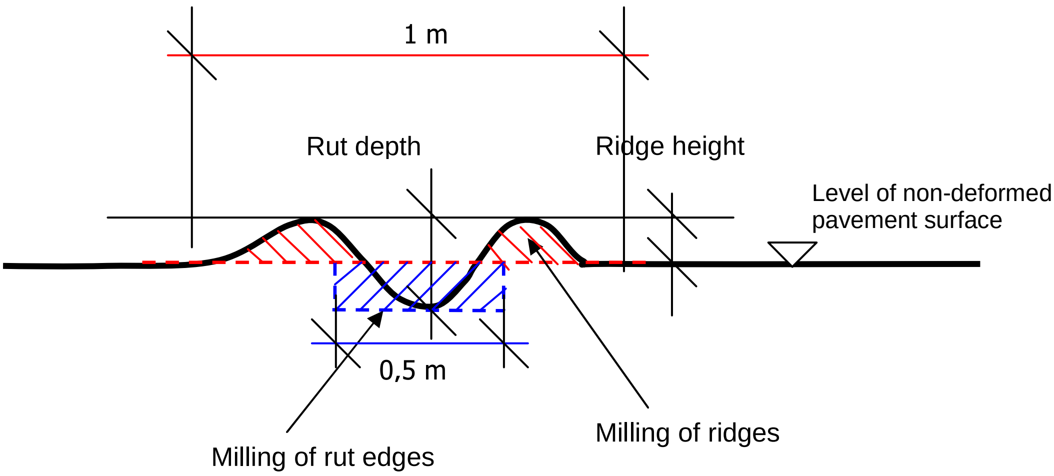


Figure 2: Methods of the previous rehabilitation of a rutted pavement

If the pavement surface is damaged only by ruts, following previous rehabilitation, the pavement is repaired by taking measures for the fair condition from Table 1 or, respectively, upgraded with the measure for the poor condition from Table 2.

In Table 1 and Table 2, the thickness of the required upgrade is determined depending on traffic loads. It is assumed that the existing pavement structure is built in the minimum required thickness for specific traffic load, in accordance with relevant-Slovenian technical regulations. The bearing capacity of the pavement structure, taking into account the pavement condition determined by a visual assessment of cracks, ravelling, patching and potholes, is reduced by the damage quotient k_d, specifically:

$k_d = 0.9$ for the fair condition of the pavement, and

$k_d = 0.6$ for poor pavement condition.

The designations in Tables 1 and 2 denote the following:

a material equivalence factor,

d total thickness of asphalt layers,

D_{act} actual thickness index (Structural number),

D_{req} required thickness index.

D stands for thickness index (Structural Number), and is defined by the following equation:

$$D = d \cdot a \text{ [cm]}$$

Step 2 Skid resistance characteristics – SR

If the condition of skid resistance characteristics is good or very good (according to Table 6), proceed to Step 3.

If the condition of skid resistance characteristics is fair or poorer (according to Table 6), check whether any damage other than poor skid resistance is present on the pavement (verify the pavement surface condition by visual assessment – CPS and the bearing capacity of the pavement structure – BC):

- if other damage is also present, proceed to Step 3,
- if there is no other damage, a measure is taken according to Table 1.

The procedures for determining the skid resistance characteristics of a pavement surface are described in detail in the Slovene technical specification for roads “TSC 06.620: 2003 Pavement surface characteristics – Skid resistance” [18].

Skid resistance and texture depth measurements on the pavement surface can be performed on roads with modern asphalt wearing course or cement-concrete pavement slabs, in particular in the offside (right) rut, which, as a rule, is more loaded than the other one.

In Slovenia, pavement surface skid resistance measurements are performed at an oblique angle to a guided anti-skid measuring wheel, with the measurement device known as the Side-way Force Coefficient Routine Investigation Machine – Texture (SCRIMTEX) [18].

Table 6 Limit ranges of the skid resistance values (friction coefficient, SN) for assessing the condition of an existing pavement as a function of measuring speed

Measuring speed (km/h)	Pavement condition class				
	very poor	poor	fair	good	very good
30	< 50	50 – 56	57 – 61	62 – 72	> 72
40	< 46	46 – 52	53 – 56	57 – 67	> 67
50	< 42	42 – 48	49 – 52	53 – 63	> 63
60	< 39	39 – 45	46 – 48	49 – 59	> 59
70	< 36	36 – 42	43 – 45	46 – 56	> 56
80	< 33	33 – 39	40 – 42	43 – 53	> 53
90	< 30	30 – 36	37 – 39	40 – 50	> 50

Note: 1. SN values are measured by SCRIMTEX.
2. Average SN values of a homogeneous section are used for the assessment.

Step 3 Visual assessment of pavement surface condition - CPS

If the condition of visually assessed pavement surface damages – CPS is good or very good (according to Table 10), no measure is taken.

However, if the condition of the visually assessed pavement surface damages – CPS is fair or poorer (according to Table 10), proceed to Step 4.

In Slovenia, pavement surface damage is described according to the Modified Swiss Index (MSI) methodology, with visual assessment performed, and each of the four damage types evaluated in terms of their intensity and size (area).

In the MSI calculation, the following types of damage are taken into account on asphalt and other paved surfaces:

- cracks,
- ravelling,
- potholes,
- patches.

Damage intensity (S_m) is rated between 0 and 3 in accordance with Table 7.

Table 7 Method of determining damage intensity - S_m

Pavement surface damage	Gravity of damage intensity			
	0	**1**	**2**	**3**
Cracks	none	Narrow or completely sealed	Wide, longitudinal, transverse – over 3 mm wide or poorly sealed	Wide, alligator or partially sealed
Ravelling	none	Single grains ravelling from wearing course	Several grains ravelling	Wearing course peeling off
Potholes	none	Initiating pothole, intensive peeling	Pothole up to 5 cm deep and up to 20 cm in diameter	Pothole over 5 cm deep and over 20 cm in diameter
Patches	none	Patch with even edges	Patch with cut at right angle to the direction of driving, with even edges	Deformed cold patching and uneven patching without even edges

Area affected by defects (A_m) is rated between 0 and 3 (Table 8).

Table 8 Methods of Determining the affected area of damage A_m

	The affected area A_m			
	0	**1**	**2**	**3**
Pavement surface share (%) affected by a specific damage type	0 %	Up to 10%	10 to 50%	Over 50%

MSI is defined as the weighted sum of the product of intensity and the area affected by various pavement damage types.

$$MSI = \sum_m G_m * S_m * A_m$$

G_m ..... weight of individual damage

m ..... r = cracks, o = ravelling, j = potholes, k = patches.

Each type of pavement surface damage has a specific weight (Table 9).

Table 9 Weight (G_m) of damage types

Defect type	Weight (G_m)
Cracks	0.4
Wear	0.3
Potholes	0.1
Patches	0.2
Total:	**1.0**

In this way MSI can have values between 0.00 and 9.00. A higher MSI indicates more serious pavement damage. The calculation of MSI for each 50 m long subsection of the network is followed by section homogenisation, integrating remote but similarly damaged 50 metre long sections, with the average MSI value calculated for them.

Classification of pavement surface condition:

Pavement condition classes according to the criterion of pavement surface damage are defined depending on the MSI value (current condition) and traffic load (Table 10).

Table 10 Classification of the condition of the asphalt pavements as a function of MSI values and traffic load

class	Traffic load limit values in ESAL 82 kN	Pavement condition class				
		very good	good	fair	poor	very poor
- extreme	$> 2 \times 10^7$	≤ 0.4	> 0.4–1.2	> 1.2–2.0	> 2.0–2.8	> 2.8
- very high	$> 6 \times 10^6$ do 2×10^7	≤ 0.5	> 0.5–1.3	> 1.3–2.1	> 2.1–2.9	> 2.9
- high	$> 2 \times 10^6$ do 6×10^6	≤ 0.6	> 0.6–1.4	> 1.4–2.2	> 2.2–3.0	> 3.0
- medium	$> 6 \times 10^5$ do 2×10^6	≤ 0.7	> 0.7–1.5	> 1.5–2.3	> 2.3–3.1	> 3.1
- low	$> 2 \times 10^5$ do 6×10^5	≤ 0.8	> 0.8–1.6	> 1.6–2.4	> 2.4–3.2	> 3.2
- very low	$\leq 2 \times 10^5$	≤ 0.9	> 0.9–1.7	> 1.7–2.5	> 2.5–3.3	> 3.3

Step 4 Longitudinal evenness – IRI

If the longitudinal evenness is in fair or better condition (according to Table 11), proceed to Step 5.

If the condition of longitudinal evenness is poor or very poor (according to Table 11), mill the pavement waves and proceed to Step 5.

In Slovenia, measurements of longitudinal evenness is performed by a profile- metre [17] suitable for the measurements at operation speed (driving speed between 40 and 120 km/h during measurement), it has digital recording, records short, medium and long waves (between 0.8 m and 30 m length), has a sampling interval up to 10 cm and distance measuring accuracy up to ± 0.3 %.

The calculation of the IRI (International Roughness Index), a criterion for determining the condition class must proceed according to the algorithm of the World Bank derived for the movement of the quarter-car model on a measured pavement surface. The IRI value must be calculated as the average value of all slopes of longitudinal sections (RS) at specific n spots using the following equation:

$$IRI = \frac{1}{n-1} \sum_{i=2}^{n} RS_i \, .$$

The IRI values are calculated for 100 metre subsections and the whole road section.

Classification of longitudinal evenness condition:

The Slovenian standard “TSC 06.610: 2003 Pavement surface characteristics – Roughness” [17] defines the informative limit values for assessing the quality of a pavement surfaces depending on the value of IRI_{100} and traffic density (load), respectively (Table 11).

Table 11 Limit values of the longitudinal evenness (IRI_{100}) for assessing road pavement quality (in m/km)

Traffic classification	Pavement condition class				
	very good	good	fair	poor	very poor
Medium or higher density (AADT > 2000 vehicles) and medium or high traffic load (> 80 ESAL 82 kN/day)	< 1.2	1.2 to 1.5	1.5 to 2.2	2.2 to 3.1	> 3.1
Lower density (AADT up to 2000 vehicles) and lower traffic load (up to 80 ESAL 82 kN/day	< 2.6	2.6 to 3.5	3.5 to 4.3	4.3 to 4.9	> 4.9

Step 5 Pavement structure bearing capacity – BC

If the bearing capacity of pavement structure is sufficient (deflection is lower than the relevant limit value given in Table h), in addition to any necessary local rehabilitation, rehabilitation of pavement structure is performed according to Tables 1, 2 and 3 (depending on the pavement surface condition – CPS).

In Tables 1, 2 and 3 the thickness of the required upgrade is determined depending on traffic loads. It is assumed the upgrade is carried out in the minimum required thickness for the actual traffic load, in accordance with Slovenian technical regulations.

Pavement structures where the applicable deflection is higher than the limit one (Table 12), need to be reinforced in accordance with Table 4 in addition to any previous in-depth rehabilitations.

The load-bearing capacity of pavement structures in Slovenia is determined based on the results of deflection measurements by:

- Falling Weight Deflectometre or
- Lacroix deflectograph.

The Slovenian Standard “TSC 06.541: 2003 Pavement design, Strengthening design of existing asphalt pavement structures” [16] defines the applicable deflection and limit (action) deflection values, calculated on LaCroix deflection results.

To assess the condition of the pavement structure and determine suitable measures, established deflection measurement procedures must be used to determine the applicable deflection of the pavement surface of a homogenous road section - d_m. In both cases of deflection measurements (LaCroix and FWD), the criterion of bearing capacity is the measured deflection of the pavement structure under an axle load of 100 kN.

Table h defines the limit (action) deflection values of existing asphalt pavements, measured by LaCroix deflectograph or FWD deflectometre.

Table 12 Limit pavement deflection values

Traffic load category	Limit deflection value, d_m (mm) measured by	
	FWD	LaCroix
- extreme	0.36	0.44
- very high	0.40	0.50
- high	0.55	0.72
- medium	0.69	0.92
- low	0.83	1.13
- very low	0.93	1.29

The established relationship between the deflection value measured by FWD deflectometre and LaCroix deflectograph is:

$$d_{Lacroix} = 1{,}4 \cdot d_{FWD}^{1{,}12}$$

d_{FWD} …..the deflection value [mm] under the load plate, measured by with FWD.

2.2 Description of the algorithm for defining rehabilitation measures in Slovakia

(Decision Making Processes in Slovak Pavement Management System)

The Slovak Pavement Management System is a tool for effective budget distribution as a part of road rehabilitation management. The system includes maintenance, repairs and reconstruction of the roads. The decision-making processes are the core of the system. The processes are based on the diagnostics of the pavement surface parameters and bearing capacity. The bearing capacity and calculated residual life are principal pavement characteristics determining a rehabilitation process. The parameters describe surface defects, skid resistance, ruts depth and longitudinal unevenness. These parameters are tested from point of view of serviceability level. The technology of pavement rehabilitation is chosen considering all of these parameters. The most important benefit of PMS is more objective distribution of financial resources for the rehabilitation based on an economic analysis. The cost analysis includes construction and user costs.

The Pavement Management Systems (PMS) are processes for effective maintenance, repairs and renewal of road surfaces and structures. Systems ensure more objective distribution of financial resources used for road maintenance. The Slovak PMS [1] has road network and project levels.

The road network level PMS solves the selection of sections to be rehabilitated, budget requirements, and distribution of financial resources. The diagnostics and evaluation of pavement conditions are basic information for decision-making process.

The project level PMS solves a proposal for maintenance and repairs. It defines requirements for maintenance and repair costs of the selected sections.

Input parameters:

Decision-making processes of both PMS levels use the surface properties and bearing capacity of the pavement as necessary input parameters. The surface properties are described by the following parameters [2]:

1. surface defects,
2. longitudinal unevenness,
3. rut depth – (transversal unevenness),
4. skid resistance,
5. bearing capacity.

Bearing capacity is characterized by the pavement deflection, measured by FWD equipment.

1. Surface defects

Two data collection methods are used in Slovakia for surface defects evaluation. The classical visual inspections collect information about visible failures. The data on cracks, deformation, polishing, bleeding, potholes and ravelling are registered and manually recorded. The Index of Surface Deterioration (ISD) describing ratio of defected area to the total surface area is calculated from data obtained. Evaluation criteria include five quality levels (from excellent to emergency one).

The rapid visual inspection of defects from a moving vehicle is the second method for surface failures collection. The defects are recorded by special computer console. Three types of defects are registered: linear (cracks), point-like (potholes) and area-type (deformation, surface deterioration). Evaluation criteria include three levels of quality (from excellent to emergency one).

Pavement condition evaluation based on surface defects is performed by a special software DEFECTS.

2. Longitudinal unevenness

The PROFILOGRAPH GE measures the longitudinal unevenness during travelling motion by a transversal beam with 15 lasers for the analysis of spatial structure of the surface. *International Roughness Index (IRI)* is calculated, and longitudinal unevenness quality is ranked into one of five classes.

3. Transversal unevenness

The rut depth characterizes the transversal unevenness of pavement. PROFILOGRAPH GE collects data simultaneously with the information on longitudinal unevenness. The quality is evaluated in five-scale classes for longitudinal unevenness. Rut depth is one of components for the ISD calculation in the DEFECTS programme.

4. Skid resistance

Skid resistance describes an interaction between pavement surface and vehicle tyres. Measurements of the SKIDDOMETER BV11 are used for the calculation of the friction coefficient “fp”. The quality evaluation methodology uses three levels of assessment.

The method was developed further last year. Now, the evaluation of skid resistance includes microtexture and macrotexture. The laser analysis of microtexture utilizes the results of SKIDDOMETER, and International Friction Index (IFI) or Skidding Resistance Index (SRI) is calculated. Three assessment levels of quality are used.

5. Bearing capacity

The bearing capacity of pavement is the most important measure of the pavement structure quality. Deflection bowl data measured by FWD KUAB are inputs for the program CANUV determining modulus of pavement layers (backcalculation from deflection bowl data) to calculate residual pavement life and overlay thickness required for the given period [3].

<u>Decision making procedures</u>

Two decision making procedures – prioritizing and optimizing ones – could be used generally. The former one determines pavement rehabilitation technology based on current pavement serviceability and bearing capacity characteristics. Principal point of the optimizing procedure is the determination of optimal time for pavement strengthening. Then a rehabilitation technology is proposed considering the time interval between (frequency of) pavement diagnostic, the optimal time for pavement strengthening and current pavement serviceability state.

<u>Priority procedure</u>

This procedure uses results of evaluation for the pavement serviceability characteristics (evenness, skid resistance, surface defects) but the main criterion is the strengthening layer (overlay) thickness calculated for the required residual life of pavement (Figure 3).

If strengthening thickness (h_z) is not more than 30 mm, the rehabilitation technology proposal takes into account the evaluation results of pavement surface state and pavement unevenness and one of the pavement maintenance technologies is proposed (surface dressing, emulsion microseal, thin asphalt layer etc.).

If pavement bearing capacity is not sufficient for the required residual life of pavement (h_z > 30 mm) there are two possibilities. Total pavement reconstruction is proposed (h_z > 100 mm) or if the calculated h_z value is between 40 mm and 100 mm, its final value of h_z depends on the pavement surface state classification based on surface defects and transversal unevenness.

When the possible rehabilitation technologies are known, economic analysis has to be done. The special software SEH PS [45] developed at Civil Engineering Faculty, TU Zilina analyses on economical effectiveness of the proposed rehabilitation technologies. SEH PS calculates Internal Rate of Return (IRR) on the basis of construction costs of the rehabilitation technology and the related user costs. Cost analysis needs the following information types:

- pavement surface properties,
- traffic loading,
- structural parameters of the road,
- cost for vehicle repairs and maintenance,
- tyre wear costs,~~,~~
- fuel and lubricants costs,
- life cycle of technology,
- other transport costs.

The procedure of user costs determination comprises the modelling of the travel speed depending on pavement serviceability characteristics. The coefficients of HDM-3 and HDM-4 models are used for the evaluation of the effect of the operational capability to user costs.

Final decision about rehabilitation technology depends on the calculated value of Internal Rate of Return (IRR). This value is the main criterion for ranking (prioritizing) road sections for rehabilitation.

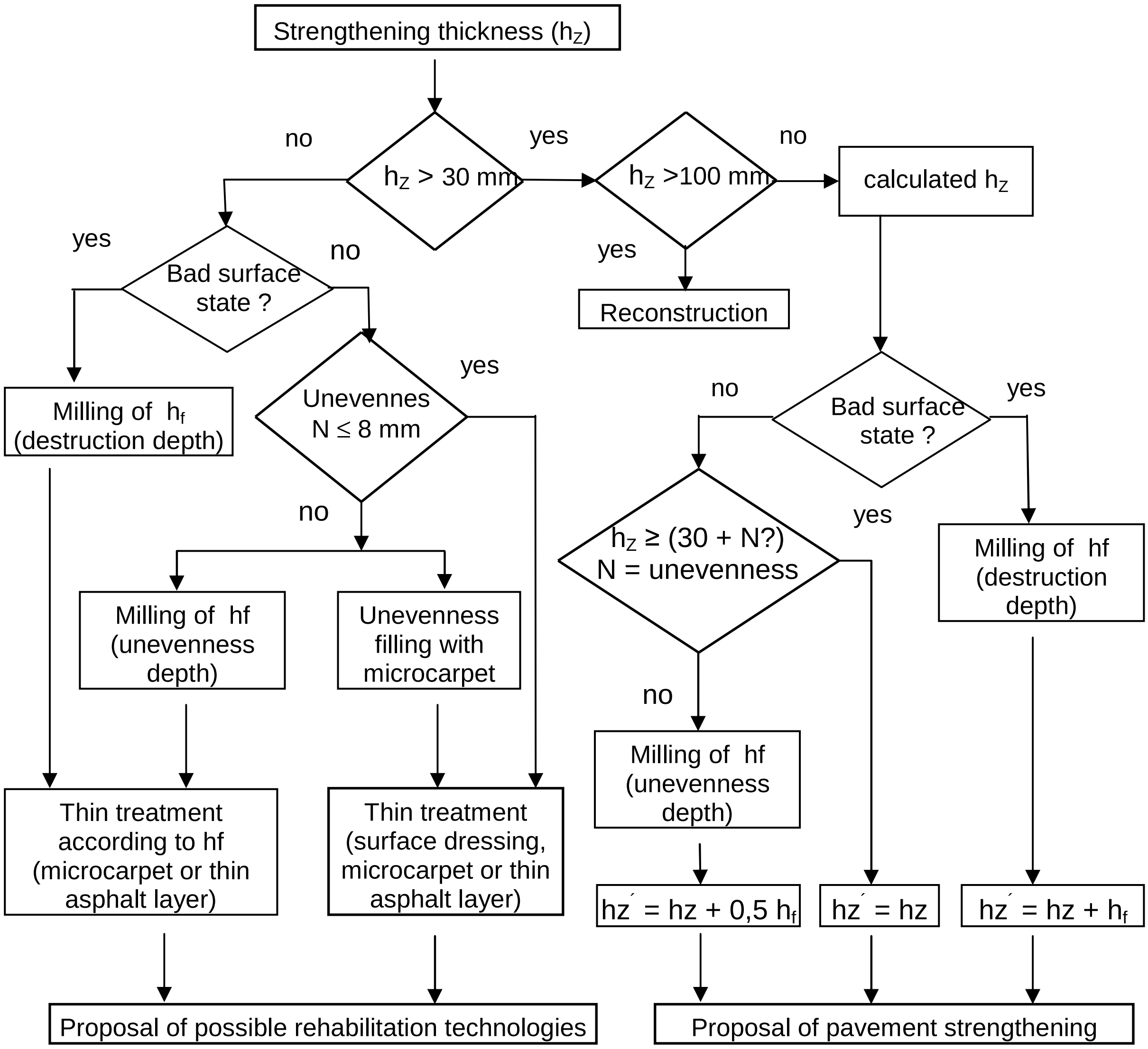


Figure 3: Decision making procedure for of priority ranking

<u>Optimizing procedure</u>

The optimizing procedure of the time of rehabilitation (Figure 4) needs, besides the described parameters the deterioration models of all parameters. The deterioration models can be developed using long-term monitoring data of trial sections and laboratory measuring results. The quality of these models is a basic assumption for the accuracy of optimizing process precision.

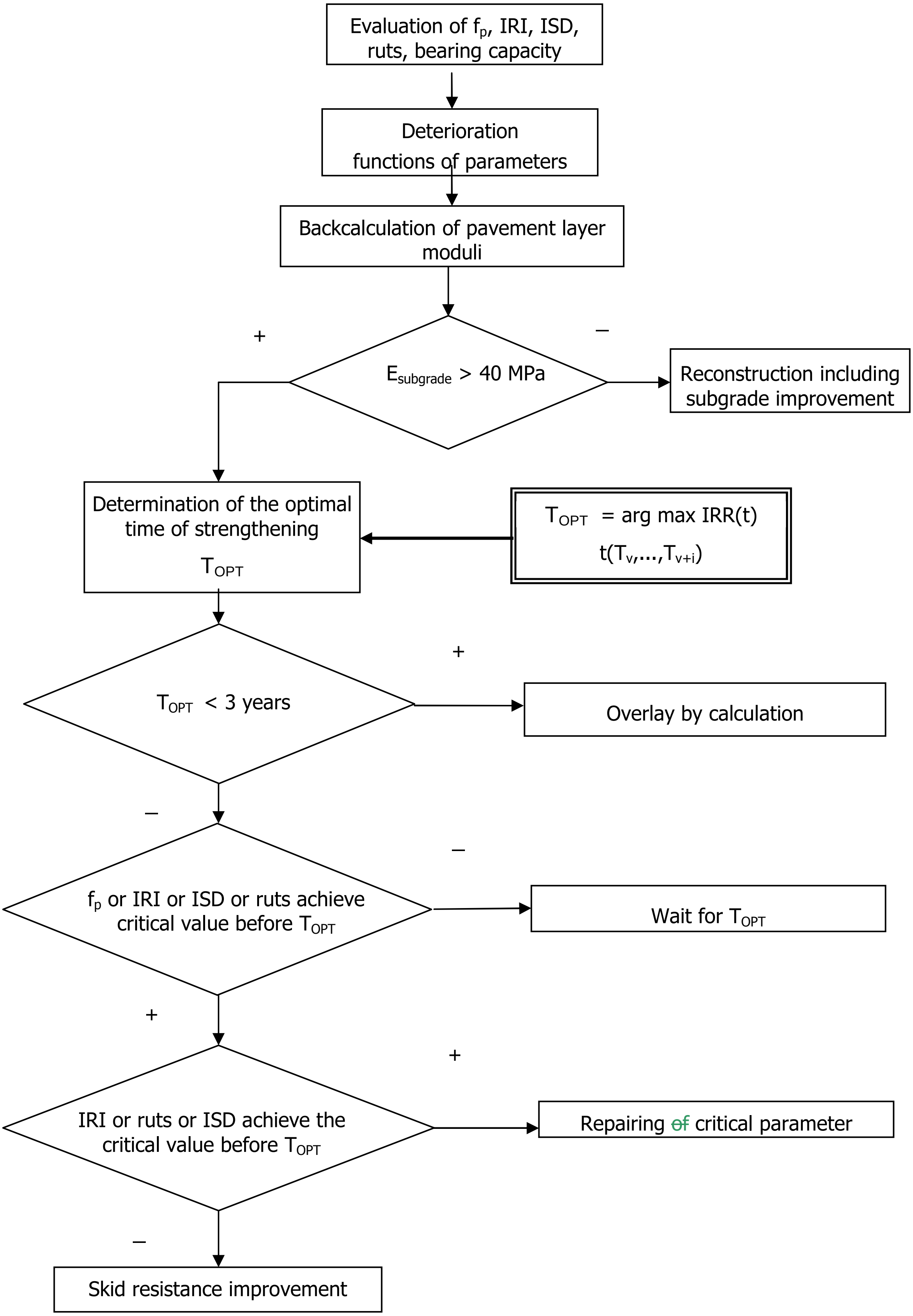


Figure 4: Decision making procedure for the process of optimization

The Pavement Management System is a very strong tool for the objective distribution of the funds for road pavements rehabilitation. The decision-making procedures allow optimizing costs on the basis of surface and structural properties of pavements considering deterioration processes and technological options.

The priority procedure is used in Slovak PMS for the ranking of sections for rehabilitation every year. The optimizing procedure is more complicated. However, it allows optimal distribution of rehabilitation budget in the case of budget constraints from the point of view of long-term analysis.

2.3 Description of the algorithm for defining rehabilitation measures in Czech Republic

National methodology on the systematic decision making for low-volume road rehabilitation

Situation

There is no special technical specification for the evaluation and treatment of low-volume roads, except for forestry and agricultural roads. But there are two categories of roads – category A for motorway and primary roads and category B for secondary and other roads.

The main specification for the rehabilitation of asphalt roads is a technical standard of Ministry of Transport of the Czech Republic “TP 87: Maintenance and repair design of flexible pavements (1997)”. Currently this specification is under revision. Actual basic information is introduced in the technical specification “TP 170: Design of roads (2004)” [6].

Two basic types of PMS

There are two Pavement management systems in use. Big PMS (multi-parametric) is used for the roads of category A and Small PMS (single or dual parametric) for the roads of category B. Schematic representation of progress of rehabilitation planning is mentioned at Figure 5.

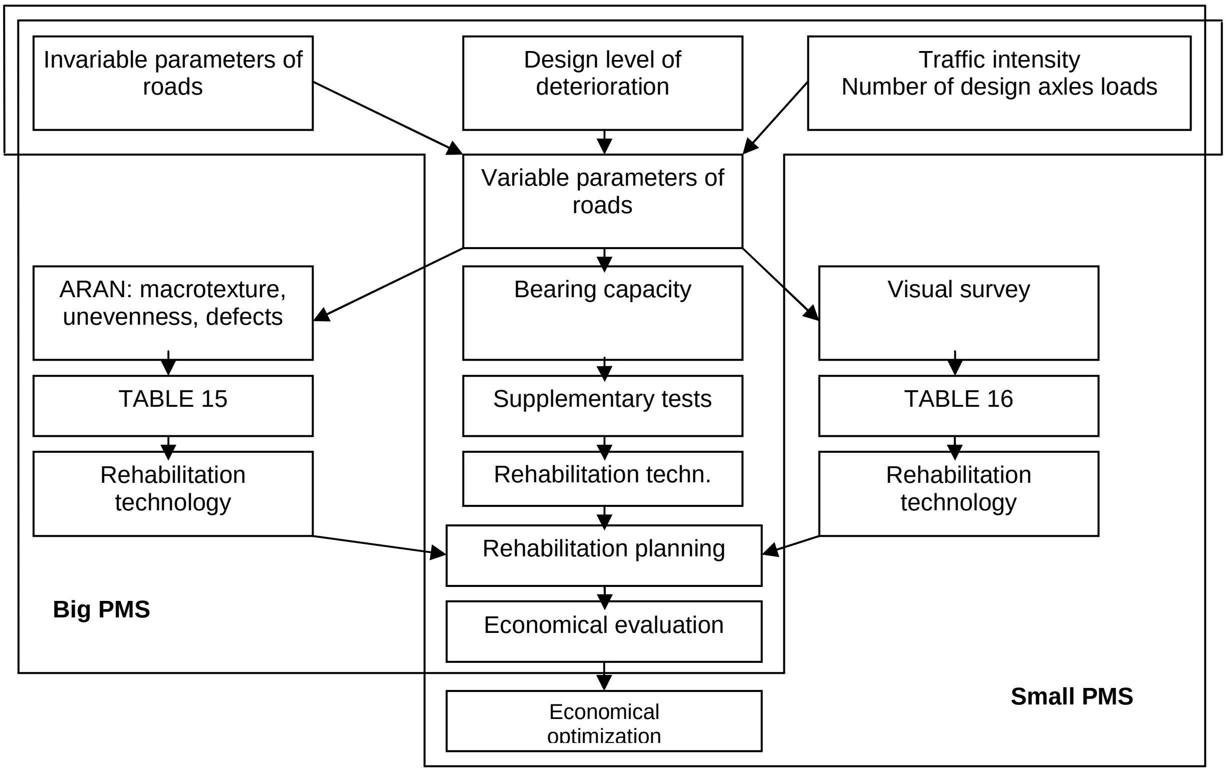


Figure 5: Rehabilitation planning procedure in small and big PMS [8]

Steps of rehabilitation planning

The decision scheme on rehabilitation is introduced in Figure 6.

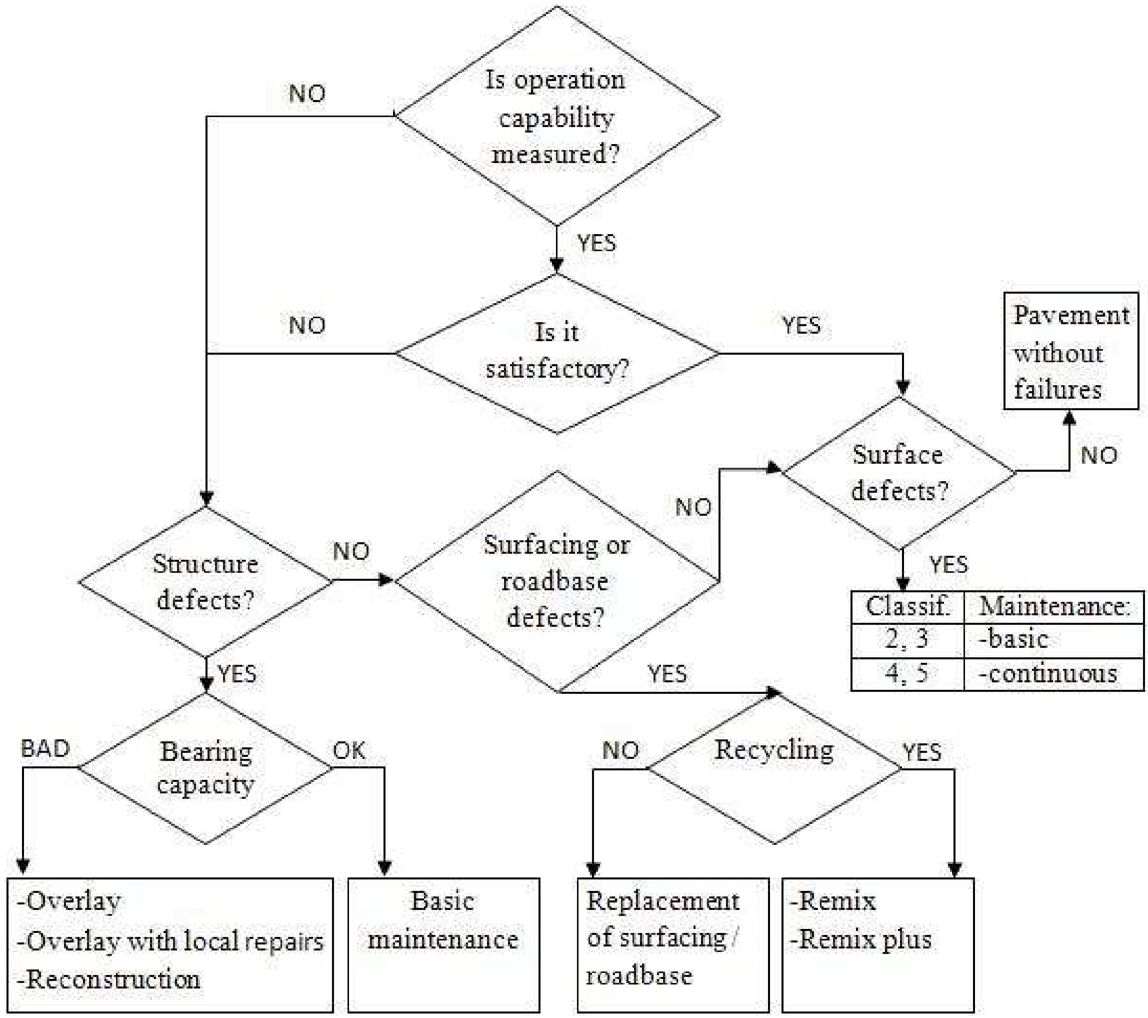


Figure 6: Rehabilitation decision scheme [8]

Operation ability is expressed by the values of skid resistance, longitudinal and transversal unevenness. It can be characterized also by type, location and area of distresses.

Rehabilitation planning is based on the following steps:

- acquire basic information on the pavement (structure of layers, etc.),

Table 13 Design level of deterioration [6]

Design level of deterioration	Road category (ČSN 73 6101)	Estimated traffic intensity (No. of heavy vehicles) (ČSN 73 6114)	Estimated area of distresses at the end of life cycle (%)
D0	motorway, primary roads	S, I, II, III	< 1
D1	secondary roads, parking areas	III, IV, V and VI	< 5
D2	local roads, parking areas	V, VI	< 25
	temporary and purpose-build roads	From IV to VI	

- Determine traffic intensity of road (Table 14).

Table 14 Traffic intensity as a function of the daily number of heavy vehicles TNV [6]

Traffic intensity	TNV_k
S	> 7 500
I	3 501 – 7 500
II	1 501 – 3 500
III	501 – 1 500
IV	101 – 500
V	15 – 100
VI	< 15

TNV_k - average daily number of heavy vehicles on all traffic lanes during the design period (25 years)

- use the results of operation ability measurements and those of visual survey,
- classify the pavement condition according to Table 15
- decide about rehabilitation method or the need for bearing capacity evaluation and for supplementary tests; they are needed in the case of construction defects or in the case of a proposal for continuous repair,
- calculate the remaining life of pavement based on bearing capacity measurement, design level of deterioration, design period, traffic intensity, climatic conditions and subgrade characteristics,
- carry out supplementary tests, evaluate longitudinal and transversal gradient, the thicknesses, types and quality of pavement construction layers, drainage condition, eventual infiltration of subbase layers by subgrade, material, etc.,
- select a suitable and realistic rehabilitation technology,
- perform an economical evaluation of the rehabilitation technological variants,

Table 15 Classification of pavements as a function of the parameters measured and road category [8]

Condition parameters	1 very good		2 good		3 satisfactory		4 bad		5 emergency	
	A	B	A	B	A	B	A	B	A	B
microtexture Pendulum test – PTV	≥70	≥60	69-60	59-50	59-50	49-40	49-40	39-30	≤39	≤29
macrotexture volumetric patch test – MTD	≥0,75	≥0,65	0,74-0,60	0,64-0,50	0,59-0,50	0,49-0,38	0,49-0,38	0,37-0,28	≤0,37	≤0,28
macrotexture ARAN: laser camera – MPD	≥0,90	≥0,80	0,89-0,75	0,79-0,65	0,74-0,65	0,64-0,55	0,64-0,55	0,54-0,45	≤0,54	≤0,44
Skid resistance TRT vehicle (60 km/h) - f_p	≥0,60	≥0,56	0,59-0,54	0,55-0,50	0,53-0,44	0,49-0,40	0,43-0,35	0,39-0,33	≤0,34	≤0,32
Rut depth h (mm)	<6,0	<8,0	6,0-10,0	8,0-14,0	11,0-15,0	15,0-24,0	16,0-22,0	25,0-36,0	>22,0	>36,0
Longitudinal uneven-ness ARAN IRI (m/km)	<1,9	<3,3	1,9-3,3	3,3-5,0	3,4-5,0	5,1-8,0	5,1-8,0	8,1-14,0	>8,0	>14,0
Bearing capacity Residual life t_z (years)	>20		15-20		10-15		5-10		<5	

Table 15 is actualised as a part of TP 87 revision in 2009.

Table 16 Classification of pavements as a function of damaged surface area (%) and the design level of deterioration [8]

Condition parameters	1 very good	2 good				3 satis-factory	4 bad				5 emer-gency
Design level of deterioration	D0-D2	D0	D1	D2a	D2b	D0-D2	D0	D1	D2a	D2b	D0-D2
Roughness loss	0	0	0	1	5		5	10	25	50	
Unevenness > 20 mm	0	0	0	1	3		1	3	10	25	
Bleeding - asphalt binder loss	0	10	10	25	25		50	50	100	100	
Deep corrosion	0	0	0	1	2		1	3	5	10	
Potholes	0	0	0	0	0		0	1	2	3	
Patching	0	0	0	3	5		2	5	10	25	
Microseal corrosion	0	10	10	25	25		50	50	100	100	
Loss of aggregate from surface dressing	0	5	5	10	10		15	15	25	25	
Narrow and wide cracks	0	0	0	1	2		1	2	3	5	
Block cracking	0	0	0	1	2		1	2	3	5	
Alligator cracking	0	0	1	2	3		3	5	10	25	
Construction defects	0	0	0	0	1		0	3	5	15	
Pavement rupture	0	0	0	0	0		0	0	1	3	

Note: There were some changes in the level of deterioration categorization in accordance with TP 170. [6] Categories 1, 2 and 4 are mentioned as examples. Table 16 is actualised as a part of TP 87 [8] revision in 2009.

- adjust rehabilitation plans to the available resources; optimisation in accordance with social requirements, accident statistics, political, administrative, economic and other viewpoints.

These steps are taken realised in small and big PMS by using softwares. Homogenous road sections are selected considering the statistically important differences in pavement conditions.

The basic types of rehabilitation are:

- routine maintenance - repair of local surface distresses, crack and joint repair, surface dressing in small areas,
- continuous maintenance - surface dressing, micro-surfacing, thin asphalt layers,
- renewal - overlay, replacement of wearing course and lower layers, hot recycling (Remix and Remix Plus), profile adjustment, cold recycling, widening of roads, local repairs,
- reconstruction - replacement of all construction layers with eventual subbase rehabilitation, partial replacement of construction layers, local reconstruction.

Bearing capacity measurements and evaluation

The main reason of bearing capacity measurements is to evaluate the residual life of pavements. It can be estimated also based on visual surveys. Three different equipment types are used for bearing capacity measurement in the Czech Republic. These are Benkelman beam, deflectograph and FWDs of different producers. There is no official standard how to calculate overlay thickness based on bearing capacity results. Each provider approved by Czech Ministry of Transport is allowed to carry out backcalculation and determine the pavement residual life by a software used with its own equipment. The harmonization tests of such equipments are organised every 3 (5) years in accordance with the technical standard of the Ministry of Transport of Czech Republic “TP 163: Conditions for the application and control of the equipment used for the measurements of road pavement deflection” [11].

Mainly FWD is used for the bearing capacity measurements of low-volume roads. For the calculation of elasticity modulus, the standard programs like Layped, Dg-laymed, etc. are utilized.

Case study – Systematic decision making process for low-volume road rehabilitation

In case of a low volume road the process consists of the following steps (example from prepared revision of Technical Standard of Ministry of Transport of the Czech Republic TP 87 – Maintenance and rehabilitation of flexible pavements):

1. Road categorization:
   - historically build road, thickness of the asphalt pavement layers is at least 50 mm,
   - road with: 5,5 – 6 m,
   - road category: III (secondary road),
   - design level of deterioration: D2 (< 5 % area of distresses at the end of life cycle – 25 years),
   - traffic intensity: V (15 – 100 TNVk - averaged daily intensity of heavy vehicles for all traffic lanes through a design period),
   - climatic condition: frost index = 480 °C.

2. Visual survey (Table 17):
   - determination of area of surface and structure defects (based on inspection walk),
   - dividing road (lanes) into homogenous sections, see table below:
     - section 1 – surface defects on small areas,
     - section 2 – surface defects on continuous long sections,
     - section 3 – structure defects on continuous long sections.

Table 17 Visual survey

Distress	Area of distresses (m^2) / affected area (%)		
	section 1	section 2	section 3
Length of section /m	200	200	800
Narrow cracks	3 / 0,2	3 / 0,2	-
Deep corrosion	6 / 0,5	573 / 43,5	132 / 12,9
Potholes	2 / 0,15	5 / 0,4	7 / 0,7
Block cracking	-	-	401 / 49,3
Areal deformation	6 / 0,5	9 / 0,7	320 / 32,4
Classification	2 - good	5 - emergency	5 - emergency

3. Cores or dug pits:

Five dug pits were realised for section 3. Thicknesses of road layers, composition of different layers, quality of subgrade and effectiveness of drainage system were specified on the base of them.

It was found out that subbase course aggregate penetrates the subgrade, the soil is very close to plasticity limit and the surface drainage is not working very well in section number 3.

The main source of problem was water infiltrating the pavement structure. As a result the bearing capacity of subgrade was lowered and caused pavement areal deformations.

4. Bearing capacity (FWD):

Bearing capacity measurements were not proposed in this case.

5. Proposed treatments (Table 18):

The width of the road will be unified to 6 meters. The proposed treatments for each section are mentioned in table below. For section 1 and 2 the solution is based only on visual survey results. In case of section 3 there was taken into account also results of dug pits.

Table 18 Proposed treatments

Proposed treatments		
section 1	section 2	section 3
crack sealing, pothole and drop reparation, basic maintenance – surface dressing	pothole and drop reparation, continuous maintenance – one layer surface dressing 8/11	milling up to 50 mm, realization of longitudinal drainage, new subbase layers and laying of two asphalt layers 60 mm (16) and 50 mm (11)

The proposed solution removes the cause of problems, they are in accordance with TP 170 requirements (Road Pavement Design specification) and it was verified by calculation in software LAYEPS.

2.4 Description of the algorithm for defining rehabilitation measures in Hungary

In Hungary, the Road Technical Directives UT 2-1.202:2005 “Design of Road Pavement Structures and Overlay Design with Asphalt Surfacing” [20] deal with the specification of the overlay design of flexible pavement structures.

It emphasizes that the overlay design should be started by the measurement of the bearing capacity of existing pavement structure, the investigation of the actual layer composition and the condition of pavement surface.

The knowledge of the bearing capacity and the traffic size of existing pavement structure is not sufficient for the overlay design. Also the reasons of pavement defects have to be revealed in order to perform the strengthening design of the existing pavement structure. This investigation should not be older than 3 years, and it should have the following elements:

- detailed visual and/or measuring investigation of pavement surface defects,
- evaluation of the condition of drainage system,
- measurement of longitudinal and cross sections,
- determination of pavement structure composition (by core samples or GPR),
- preliminary investigation of the materials of pavement structural layers (e.g. susceptibility to plastic deformation),
- investigation of the uppermost layer of subgrade,
- bearing capacity measurements (Benkelman beam or LaCroix deflectograph measuring results).

Overlay design methodologies:

a.) Design based on static deflection measuring results

If the flexible pavement structure has unbound or bituminous bound base course, its overlay design can be performed using the design diagrams (Figure 7 and Figure 8) based on the two-layered flexible mechanical model and static deflection values.

The standard deflection value can be calculated by the following equation:

$$S=C.S_o,$$

where S_o measured static deflection value,
S corrected deflection value,
C correction factor.

$$C=C_k.C_e.C_T.C_o,$$

where C_K correction factor for wheel load (50/P, where P is the actual wheel load in kN),
C_e seasonal correction factor,

C_t temperature correction factor (1.3–0.015T, where T is the temperature of pavement surface during measurement),

C_o comparison correction factor (coming from the Hungarian standard MSZ 2509-4).

Seasonal factors can be calculated by the procedure in the Hungarian Standard MSZ 2509-4 [21] or using the values in Table 19.

Table 19 Seasonal correction factor (Ce) values

Soil groups	Deflection measurement in				
	April	May	June-July	August - September	October - November
I–II.	1.0	1.0	1.0	1.0	1.0
III.			1.1	1.1	1.2
IV–V.		1.1	1.3 (1.4)	1.5 (1.6)	1.5 (1.6)
VI–IX.	1.1	1.0	1.1 (1.2)	1.2 (1.4)	1.3 (1.5)

Notes:

- soils in groups I–II are granular, in groups III–V intermediate and in groups VI–IX cohesive ones,
- the values in brackets refer to wet regions where the total thickness of asphalt layers in the pavement structure does not exceed 100 mm.

Using deflection values, road sections with homogeneous bearing capacity can be determined. The variation coefficient of deflection values in a homogeneous section can not be higher than 0.50. (Outliers are excluded of the calculation, however, their reasons should be identified).

The S_m standard deflection of a homogenous section can be calculated, using the following equations:

$$S_m = \bar{s} + u.s(s),$$

$$\bar{s} = \frac{\sum s}{n},$$

$$s(s) = \sqrt{\frac{\sum (s_i - \bar{s})^2}{n-1}}$$

where S_m standard deflection of the homogeneous section,

s_i deflection value in the measuring point i,

s mean deflection value of the homogenous section,

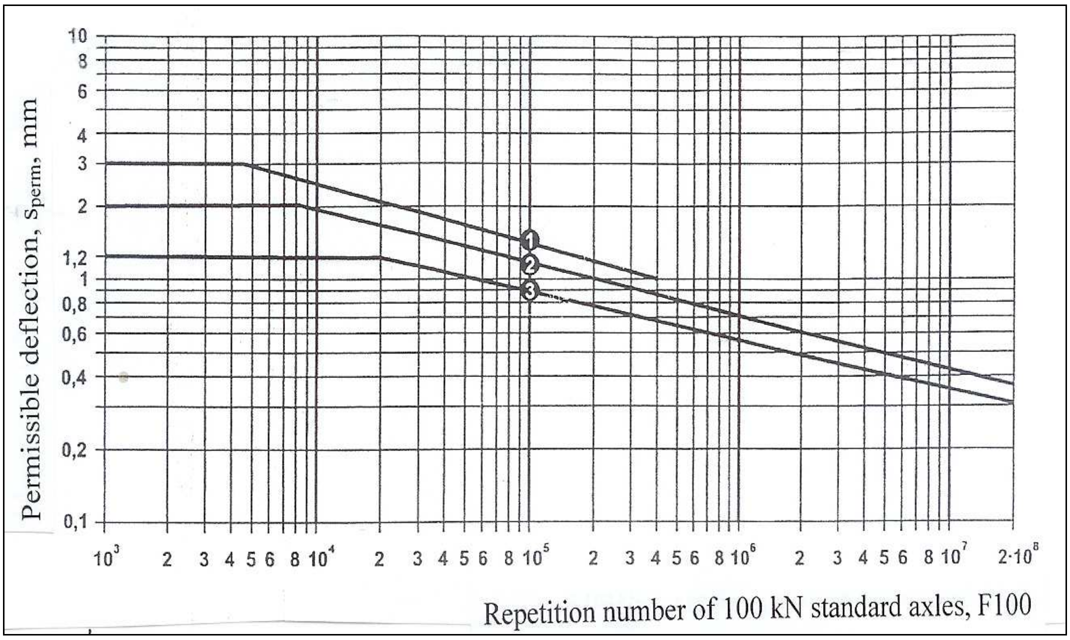
n number of deflection measurements on the homogeneous section,

s(s) experimental standard deviation of the deflection on the homogeneous section, u   probability multiplication factor (u = 1.28 for low traffic volume with 90 % probability level; u = 1.64 for high traffic volume with 95 % probability level).

For the determination of permissible (allowed) deflection, the knowledge on design traffic is needed, using one of the following methodologies:

- based on combined vehicle classes (F100, repetition number of 100 kN standard axles; vehicle classes: busses, heavy trucks, heavy trucks with trailers, articulated trucks, equivalency factors for vehicle classes, design life in years, multiplication factor for directions; multiplication factor for vehicle lane number; traffic evolution factor),
- based on detailed vehicle classes using dynamic axle load measurement results,
- based on actual vehicle axle loads coming from WIM (Weigh-in-Motion) measurements or other sources, usually 10 kN load classes are applied, special parameter is selected for super single (wide) tyres,
- based on actual axle repetitions without the knowledge on axle loads using the nominal maximum axle loads of various vehicle classes and their mean utilization factors.

Figure 7 presents fatigue curves for the pavement structures with super flexible, flexible and semi-rigid base courses. The permissible pavement deflection is determined for each pavement type as a function of design traffic. (In the case of super flexible, asphalt macadam pavement structures, the highest design traffic value considered is 400,000 number of 100 kN-axles above which the flexible pavement curve is to be applied).



Note: 1 – super flexible, 2 – flexible, 3 – semi-rigid pavement structure

Figure 7: Permissible deflection (Sperm) values as a function of design traffic

The equation of the relationship presented in Figure 7 is as follows:

$$S_{perm} = a.(N)^{-1/b},$$

where S_{perm} permissible deflection, mm,

N F100, that is the repetition number of 100 kN standard axles

a and b constant values as a function of pavement structure types

super flexible	a = 25.0	b = 4.00
flexible	a = 14.5	b = 4.55
semi-rigid	a = 9.0	b = 5.00.

The necessary Δh (mm) thickness of asphalt overlay can be determined for homogeneous sections using the curves in Figure 8. (The Δh value obtained is to be rounded up to the next 5 mm).

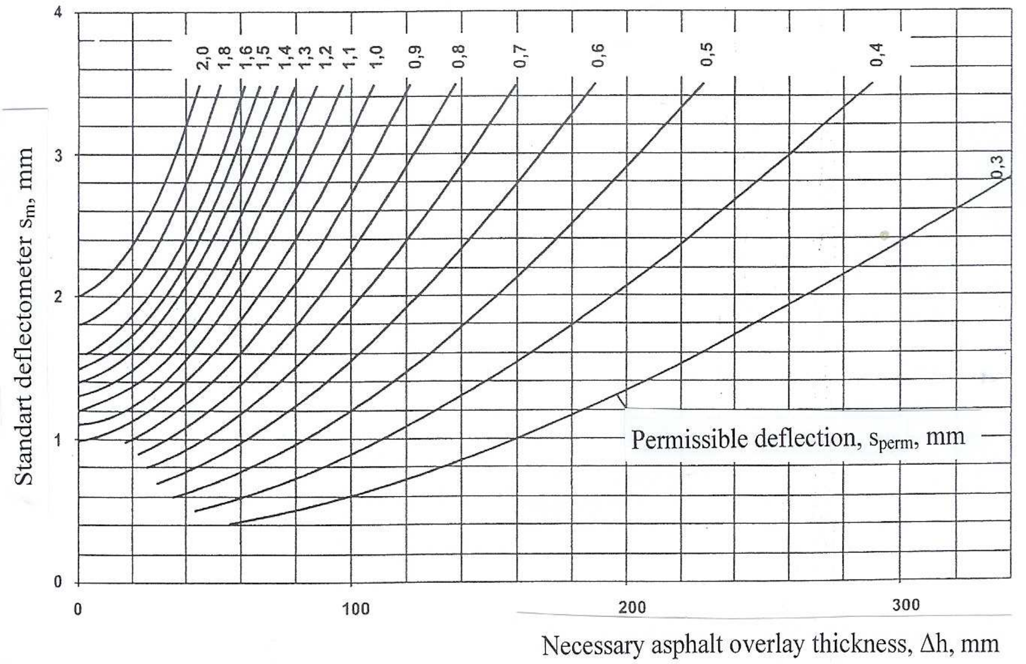


Figure 8: Relationship between necessary asphalt overlay thickness (Δh mm), standard deflections (s_m, mm) and permissible deflections (S_{perm}, mm)

The overlay design can be performed by the so-called comparison method in the traffic classes D, E, K and R. In the case of high-volume semi-rigid pavement structures with cement concrete base, it occurs that there are fatigue cracks on the surface of the pavement at the end of service life while the standard pavement deflection happens to be low. This case, it is advisable to make a pavement cut in order to learn the structure is detail, and to compare it with the new standard pavement structures for the same design traffic and base course type. The necessary thickness of asphalt overlay can be determined as the difference between the asphalt thickness of new standard pavement structure and the effective asphalt thickness of the old structure. (The eventual loss in base course thickness is also substituted by thicker asphalt layer). The calculation of effective asphalt thickness considering the damage and fatigue of the asphalt layer(s) can be carried out by the help of the following equation:

$$h_{eff} = v.h_{act}$$

where h_{eff} effective asphalt thickness (mm),
v reduction factor as a function of pavement surface condition note (Table 20),
h_{act} actual asphalt thickness (mm).

Table 20 Asphalt thickness reduction factor as a function of pavement surface condition note

Pavement surface condition note	Reduction factor
5	0.40
4	0.60
3	0.80
2	0.95
1	1.00

The 5-scaled pavement surface condition note is given by the visual evaluation of an experienced rater aided by the key-board type device Road master.

If the missing base course thickness has to be substituted by additional asphalt layer thickness, the following rules are to be kept:

- 50 mm unbound granular base is equal to 10 mm asphalt layer,
- 50 mm hydraulically bound stabilized base is equal to 30 mm asphalt layer,
- 50 mm lean concrete base is equal to 40 mm asphalt layer.

In such a way, the necessary thickness of asphalt overlay can be calculated using the following equation:

$$\Delta h_a = h_{an} - h_{ae} + h_{ab},$$

where Δh_a necessary thickness of asphalt overlay, mm,
h_{an} asphalt thickness in the new standard pavement structure, mm,
h_{ae} effective asphalt thickness in the existing pavement structure, mm,
h_{ab} additional asphalt layer thickness for the substitution of the base course thinner than that of the new standard pavement structure, mm.

If Δh_a is below the minimum technological thickness of the respective asphalt wearing course, Δh_a has to be increased to this value. If Δh_a is above the maximum technological thickness, two layers have to be built following the asphalt technological rules.

2.5 Polish pavement rehabilitation and strengthening methodology

There is no national specifications for low-volume roads which would describe a methodology on the systematic decision making in Poland. However, there is the Catalogue for the strengthening and rehabilitation of main roads [18] (General Administration) which will be presented briefly.

a.) Traffic classification

Design period – 20 years

Design traffic – heavy load traffic in the 10th year of operation

The traffic classification is carried out in accordance with Table 21.

Table 21 Traffic classification

Traffic category	100 kN ESALs per day	Fatigue durability: 100 kN ESALs in 20 years
KR1	≤ 12	≤ 90 000
KR2	13 – 70	90 001 – 51 000
KR3	71 – 335	51 001 – 2 500 000
KR4	336 – 1 000	2 500 001 – 7 300 000
KR5	1 000 – 2 000	7 300 001 – 14 600 000
KR6	≥ 2 001	≥ 14 600 001

b.) Traffic category calculation

The number of ESALs can be calculated using the following equation:

$$L = (N_1 \times r_1 + N_2 \times r_2 + N_3 \times r_3) \times f,$$

where:

- L – number of ESALs,
- f – coefficient of number of traffic lanes,
- N_1 – AADT of lorries,
- N_2 – AADT of lorries with trailers,
- N_3 – AADT of buses,
- r_1 – equivalent axle load factor of lorries,
- r_2 – equivalent axle load factor of lorries with trailers,
- r_3 – equivalent axle load factor of buses.

Table 22 presents the determination of the value of coefficient f as a function of the number of traffic lanes.

Table 22 Determination of the value of the coefficient f

Number of traffic lanes		*f*
single carriageway	dual carriageway	
2	-	0.5
3	-	0.5
4	4	0.45
-	6	0.35

Table 23 introduces the determination of the equivalent axle load factors for some vehicle types.

Table 23 Determination of equivalent axle load factors for various vehicle-types

Vehicle type	Equivalent axle load factor
Lorry without trailer	0.109
Lorry with trailer	1.245
Bus	0.594

c.) Assessment of pavement condition

Pavement condition parameters measured are:

- bearing capacity,
- longitudinal evenness,
- transverse evenness,
- surface defects,
- skid resistance.

The range of the criteria for different condition parameters is determined by the road administration depending on road class and previous experience. The tool for such data management is PMS or at least pavement maintenance system and pavement evaluation system. The scheme of pavement rehabilitation decision methodology is presented in the Figure 9.

The pavement condition parameters mentioned are the basis for routine assessment. For the preparation of the road section rehabilitation or strengthening, additional survey is needed. The list of necessary previous investigations is:

- visual condition survey (traffic lanes, shoulders, ditch, surface drainage),
- rebound deflection (KR3 – KR6),
- modulus of elasticity (KR3 – KR6),
- layer thickness (bored cores, GPR),
- transverse cracking,
- longitudinal evenness,
- transverse evenness,
- skid resistance,
- designed traffic category.

The investigation should be done at least one year before the planned rehabilitation. The second step before choosing the technology is the carrying out of laboratory tests: CBR, modulus of elasticity of asphalt layers, resistance to deformation modulus of asphalt layers, resistance to deformation of asphalt layers and mix formula. These kinds of information are needed for making a decision on rehabilitation technology.

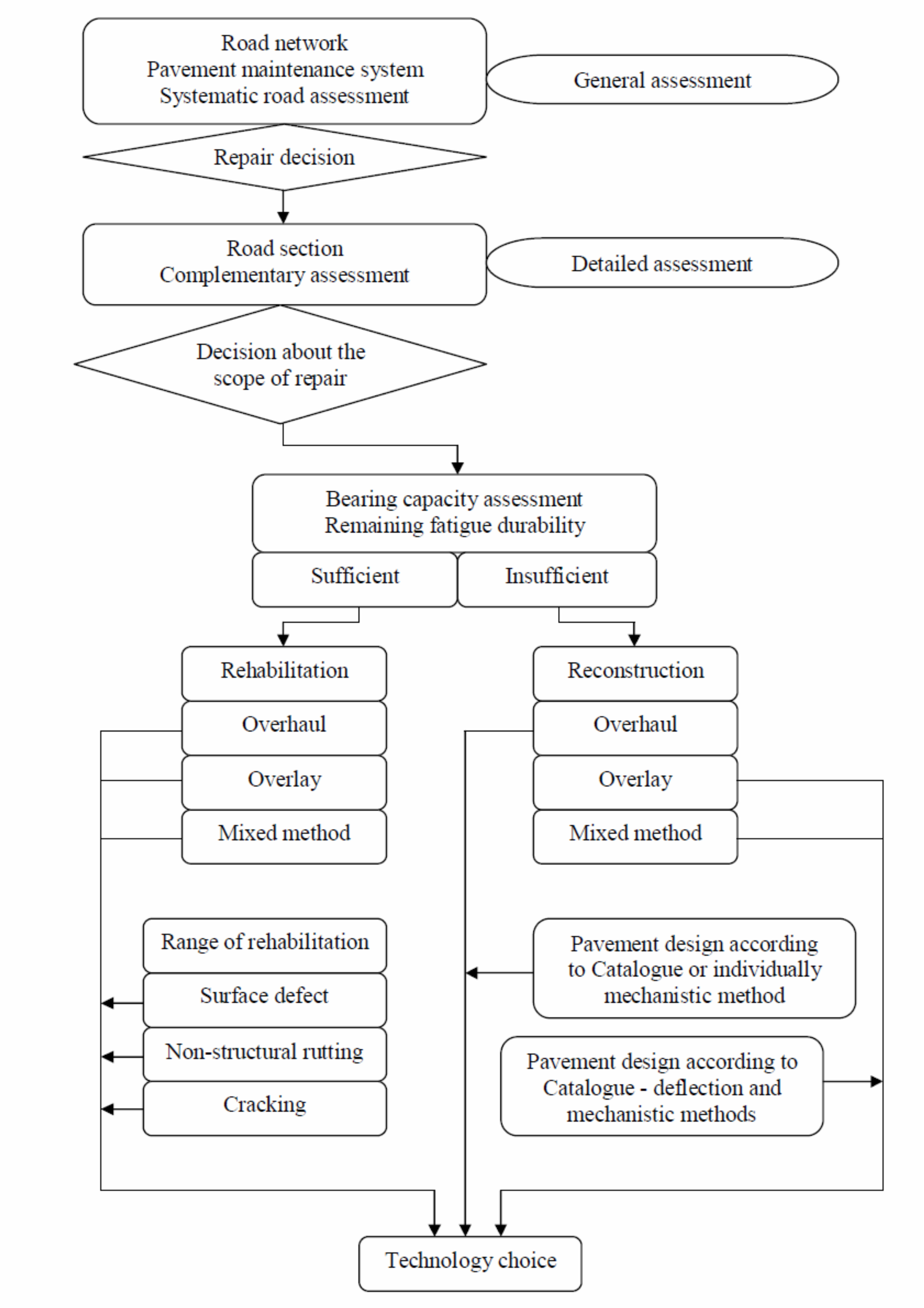


Figure 9 Scheme of pavement rehabilitation decision methodology

Three methods of pavement repair are applied in Poland:

- inlay – replacing existing pavement layers with a new one without changing pavement surface level,

- correction,
- overlay – new pavement layers built on the existing pavement,
- mixed method – combination of inlay and overlay methods.

d.) Pavement strengthening design methods

Two of the strengthening design methods are accepted in Poland:

– deflection method based on Benkelman beam measurement or equivalent,
– mechanistic method.

Criteria for choosing the rehabilitation method are presented in Table 24.

Table 24 Criteria for choosing the strengthening design method

Traffic category	Type of pavement construction	
	flexible	semi-rigid
KR1 – KR2	deflection method	deflection method (mechanistic method)
KR3 – KR4	deflection method (mechanistic method)	
KR5 – KR6	mechanistic method based on FWD measurements and laboratory tests	