ANALYSES OF PAVEMENT REHABILITATION NEEDS ON ARTERIAL ROAD NETWORK OF THE REPUBLIC OF SERBIA

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ABSTRACT

The paper deals with analyses of pavement rehabilitation needs on 4,800 km of arterial road network of Republic Serbia. The technical-economic analyses have been done using HDM-4 model with necessary calibration of the model for local conditions. According to the system of references for the main and regional road network, analysis implied 38 road routes, i.e., 427 road sections, considering various maintenance strategies.

KEY WORDS

PAVEMENT / MANAGEMENT / MAINTENANCE / ASSESMENT / CALIBRATION / HDM-4

1. BACKGROUND

During the last decade of the nineteenth century, the Serbian road network was entirely neglected. The available resources did not cover even mininimal needs for maintenance and rehabilitation and no condition surveys were performed. The budget retail had been performed utterly without any proper argumentation.

Most of the data bases on road features were created during the eighties with a contemporary concept for that time. The initial idea was that the Road Data Bank (RDB) had to serve as a multipurpose one, though the majority of data served primarily for the HDM-III program. In the mean time the expectations and needs propagated, analysis tools developed, but the RDB had not followed the trends. The bridge data base, established some time later, contains sufficient information for successful management, but the use of data bases was not introduced as a habitual means in the whole management process. Thus, the available data was not as useful as could be expected because of several reasons:

- After the initial feeding, the data bank on pavements was very seldom or not updated at all. There is no obligation to provide feed back information on repair measures or other executed interventions. Only traffic counts and data on traffic accidents are prompt.
- The initial feeding of the data bank lasted many years because of limited resources for this purpose and limited capacity of measuring equipment. In some cases, the same indicator had been measured with different types of devices. These two facts make the use of data more complicated and tiresome.

- There is no easy connection between the particular bases - between accident data and road roughness or slipperiness for example.
- There are no rules on data accessibility, i.e. on information management.

Thus, many professionals expressed the opinion that no reliable plan and program of interventions on road network can be done untill an appropriate condition survey is done. Such a survey would require a good plan, not negligible resources and much time. Not to postpone the most urgent actions needed, a study was performed trying to provide some notion on the whole arterial network state based on all available existing data.

2. THE SCOPE OF THE ANALYSES

Pavement quality and condition of the road network have a direct impact on the safety and driving comfort as well as on the travel time spent, and consequently, on the total road users costs.

The analysis of road asset preservation and pavement rehabilitation needs comprised 4,511 km of main arterial road network of the Republic of Serbia (without Kosovo and Metohija) in accordance with the reference system.

According to the reference system for the main and regional road network, analysis implied 38 road routes, i.e., 427 road sections. Only the sections with bituminous pavement have been analyzed. Sections passing through cities and sections with cement concrete pavement were excluded from the analysis.

The whole main arterial road network of the Republic of Serbia is divided into three groups according to traffic volume:

(a).Group A, motorways and semi motorways, with average AADT = 9,000 veh/day
(b).Group B, arterial roads with average AADT = 5,600 veh/day
(c).Group C, arterial roads with average AADT = 3,000 veh/day.

Group A and Group B make 1,500 km of the most important road links (Corridor X and connecting links). Basic average characteristic for section groups are presented in the Table 1.

As it could be noticed, the condition of the arterial road network of the Republic of Serbia appears to be in the critical stage, so the undertaking some interventions in order to prevent further pavement deterioration is essential.

3. APLIED METODOLOGY

A study of network level road rehabilitation program analysis was done using HDM-4 (Highway Design & Management) model.

Analysis on the level of pavement maintenance work planning (II level in HDM-4 analysis) in next 20 years was also made.

Table 1 - Average characteristics for section groups

Feature	Entire Network Considered		Group A		Group B		Group C	
Total number of sections:	427		57		86		284	
Total length:	4511.08	km	579.84	km	857.76	km	3073.48	km
Average length of sections:	10.56	km	10.17	km	9.97	km	10.82	km
Average AADT (vpd):	4428	vpd	9133	vpd	5638	vpd	3118	vpd
Average number of traffic lanes:	2.22		3.51		2.00		2.03	
Average pavement width:	8.13	m	18.50	m	6.76	m	6.46	m
Average CBR:	7.82	%	6.26	%	8.12	%	8.05	%
Average rut depth:	23.47	mm	29.65	mm	25.88	mm	21.50	mm
Average share of cracked area:	10.04	%	3.70	%	7.53	%	12.07	%
Average share of raveled area:	4.80	%	0.74	%	3.30	%	6.06	%
Mean value IRI (m/km):	4.04	m/km	3.66	m/km	3.54	m/km	4.27	m/km
IRI - maximal value (m/km):	7.00	m/km	4.90	m/km	6.80	m/km	7.00	m/km
IRI - minimal value (m/km):	2.00	m/km	2.00	m/km	2.00	m/km	2.20	m/km
IRI - standard deviation (m/km):	0.96	m/km	0.79	m/km	0.89	m/km	0.92	m/km
IRI - variance coefficient:	0.24	m/km	0.21	m/km	0.25	m/km	0.22	m/km
Average IRI weighted by length (m/km/km):	4.01	m/km/km	3.64	m/km/km	3.60	m/km/km	4.20	m/km/km

The existing information quality level (IQL) in the Road Data Bank is between IQL -II and IQL-III, and it is designed for the road network level analysis and partly for the project level analysis, as well as for planning and programming.

Typical pavement structure is designed for service life of 20 years, but in practice, some resurfacing is needed after 10-12 years.

The maintenance and rehabilitation strategies applied in analysis are determined on the basis of expected deterioration in relation to actual traffic load.

Pavement roughness is measured with the Bump Integrator (data provided by Highway Institute from Belgrade) in terms of "International Roughness Index" (IRI), and for asphalt roads it is normalized according to recommendations of World Bank. (in simplified form - Table 2).

An economical evaluation of pavement rehabilitation improvement measures has been assessed by means of HDM-4 model (*program analysis by section*) under following conditions:

- Traffic analysis and forecasts based on traffic data from year 2001,
- Pavement condition surveys were done in year 1997 and some projections have been made to year 2001 based on partial updated data in year 2001,

- Period of analysis: 20 years
- Discount rate: 12%,
- Accident costs are not included,
- Exogenous benefits are not treated,
- Environmental effects are not considered.

Table 2 - Description of pavement condition categories

Pavement condition	Pavement Description	Indicative IRI	Applies during
GOOD	Free of defects, require only routine maintenance	1.5 to 4	First 5-7 years, there is provided a good routine maintenance
FAIR	Significant defects require resurfacing or strengthening to avoid failure.	3 to 6	First 7-12 years, pavement may stay in fair condition for few years more, but road user cost pit a pat arise
POOR	Extensive defects. Failure is occurring or already occurred. Reconstruction is required.	6 or more	First 12-15 years, once failed, serious deterioration and destruction rapidly occur

4. INPUT DATA FOR USING HDM-4 MODEL

For this Study, the following road network data have been used:

- Reference system for the arterial and the regional road network
- Road Data Base (Republic of Serbia Road Directorate)
- Traffic Data Base (Republic of Serbia Road Directorate).

The Road Directorate has been engaging Highway Institute and IMS Institute for collection and processing data during last ten years.

The following data collected and processed by Highway Institute have been used:

- pavement roughness data (collected by Bump Integrator)
- deflection measurement data (collected by FWD)
- skid resistance data (collected by pendulum)
- road alignment data (collected by gyroscope)

The following data collected and processed by IMS Institute have been used:

- traffic data (collected by means of automatic traffic counters)
- pavement surface distress data (collected by video system)
- cross-section characteristic data.

The following data have been extracted from the former executed studies:

- pavement structure data and geomechanical characteristics of subgrade, subbase and base
- historical data on construction and maintenance of pavements
- updated pavement condition data

In case of missing or inadequate data, some assumptions were done and/or default data from HDM-4 model were used.

The requirement for continuation of improvement and updating road database is evident, in order to achieve a better ground for technical-economic analysis as much as possible.

5. CALIBRATION OF THE HDM-4 MODEL

5.1. Analysis of the local climate characteristics

Climate characteristics have significant impact on the pavement deterioration model as well as on some aspects of road user costs. Therefore, it was necessary to calibrate HDM-4 model according to local climate characteristics of the Republic of Serbia. It was considered following the most important factors:

- air temperature,
- rainfalls,
- frost penetration and winter condition.

The Analysis of climate characteristics is based on data from the Republic Hydrometeorology College, for period from year 1930 to year 1960.

The following data were considered as indicators of climate and environment impacts:

- main/average monthly rainfalls,
- frost penetration index and
- average altitude of section.

Climate characteristics data are derived from "Climate Satin of Yugoslavia" issued in 1975. by The Republic Hydrometeorology College as well as adequate topographic maps belonging to considered sections.

5.2. Calibration of Pavement Deterioration Model

Calibration of pavement deterioration model has been performed for each type of pavement surface distress. Calibration was done through the sensitivity analysis for different influence factors for each model.

Calibration of models is based on the history of pavement surface distresses taken from previous pavement surveys for each section (done in period from year 1990 to year 2001).

5.3. Calibration of Vehicle Fleet Characteristics

National vehicle fleet characteristics were adopted from the Study prepared by The Faculty of Transportation and Traffic Engineering from Belgrade in 2002. Vehicle fleet characteristics are described in the next Chapter.

6. VEHICLE FLEET CHARACTERISTICS

For this analyses two different vehicle fleets have been used:

- vehicle fleet that includes heaver vehicles (articulated trunks) for section groups A and B (motorways, semi motorways and the most loaded main roads)
- vehicle fleet for section group C (the rest of main roads).

The basic difference between two vehicle fleets is in type of articulated trunk for different loaded roads, based on analysis of representative vehicle type characteristics on arterial road network of the Republic of Serbia prepared by Faculty of Transport and Traffic Engineering University of Belgrade in year 2002.

7. MAINTENANCE STANDARDS

Different maintenance strategies for rehabilitation/reconstruction of pavement were taken into consideration through the analysis.

There are two alternatives:

- basic option, the alternatives with minimum maintenance works (crack sealing and pothole patching),
- rehabilitation option, determined as work rehabilitation/reconstruction programme according to adopted criteria.

The criteria for applying of different maintenance strategies are based on foreign and local experiences. There are separately defined criteria for applying maintenance works for each group sections (on motorways and semi motorways higher level of service is required).

Before applying of each maintenance works it is assumed that preparatory works have been performed. The maintenance strategies applied in this study are presented in the tables 3, 4 and 5.

Table 3 - Base Alternative for Motorways and semi motorways - Group A, B and C

	Maintenance standard	Standard Code	Unit	Econ. Price (€)	Finan. Price (€)	Trigger criteria	Achieved effects
1	POTHOLE PATCHING	POTPAT	m^2	6.6	8.3	every year	Pothole patching 80%
2	CRACK SEALING	CRKSL	m^2	3.2	4.0	every year	Wide and transversal cracks 80%

Table 4 - Rehabilitation alternatives for motorways and semimotorways - Group A

	Maintenance standard	Standard Code	Unit	Econ. Price (€)	Finan. Price (€)	Trigger criteria	Achieved effects
1	POTHOLE PATCHING	POTPAT	m^2	6.6	8.3	each year	Pothole patching 80%
2	CRACK SEALING	CRKSL	m^2	3.2	4.0	each year	Wide and transversal cracks 80%
3	THIN AC OVERLAY, d=25 mm	THIN25	m^2	7.8	9.4	Total area damaged > 15% and rut < 25 mm	IRI=2.2, Mean rut depth =0mm
4	THIN AC OVERLAY d=25 mm + SHAPE CORRECTION	THSC25	m^2	8.2	9.9	Total area damaged > 15% and rut 25-40 mm	IRI=2.2, Mean rut depth =0mm
5	REMIX PLUS (40+20mm)	REM+	m^2	12.5	15.2	mean rut ≥ 50mm and total damaged area >25%	IRI=2.1, Mean rut depth =0mm
6	AC OVERLAY d=50mm	OVL50	m^2	10.5	12.6	IRI ≥ 4.0	IRI=2.0, Mean rut depth =0mm
7	AC OVERLAY d=70+50=120mm	OVL120	m^2	23.8	28.6	IRI ≥ 5.0	IRI=2.0, Mean rut depth =0mm
8	PAVEMENT RECONSTRUCTION d=50+70+300=420mm	PAVREC	m^2	31.7	38.0	IRI ≥ 6.0	IRI=2.0, Mean rut depth =0mm

Table 5 - Rehabilitation alternatives for motorways and semimotorways - Group B and C

	Maintenance standard	Stand. Code	Unit	Econ. Price (€)	Finan. Price (€)	Trigger criteria	Achieved effects
1	POTHOLE PATCHING	POTPAT	m^2	6.6	8.3	each year	Pothole patching 80%
2	CRACK SEALING	CRKSL	m^2	3.2	4.0	each year	Wide and transversal cracks 80%
3	SURFACE DRESSING d=16mm	SDD15	m^2	5.0	6.0	Total cracking area >15%	IRI=2.2, Mean rut depth =0mm Skid resist. 0.55SFC DT: 0.7mm
4	SURFACE DRESSING+SHAPE CORRECTION d=16mm	SDSC15	m^2	5.4	6.5	Total cracking area >15% and ruts 20 - 30mm	IRI=2.2, Mean rut depth =0mm Skid resist. 0.55SFC DT: 0.7mm
5	THIN AC OVERLAY, d=25 mm	THIN25	m^2	7.8	9.4	Total area damaged > 15% and rut < 25 mm	IRI=2.2, Mean rut depth =0mm
6	THIN AC OVERLAY d=25 mm + SHAPE CORRECTION	THSC25	m^2	8.2	9.9	Total area damaged > 15% and rut 25-40 mm	IRI=2.2, Mean rut depth =0mm
7	REMIX PLUS (40+20mm)	REM+	m^2	12.5	15.2	mean rut depth ≥ 50mm and total damaged area >25%	IRI=2.1, Mean rut depth =0mm
8	AC OVERLAY d=50mm	OVL50	m^2	10.5	12.6	IRI ≥ 4.5	IRI=2.0, Mean rut depth =0mm
9	AC OVERLAY d=70+50=120mm	OVL120	m^2	23.8	28.6	IRI ≥ 5.5	IRI=2.0, Mean rut depth =0mm
10	PAVEMENT RECONSTRUCTION d=50+70+300=420mm	PAVREC	m^2	31.7	38.0	IRI ≥ 6.5	IRI=2.0, Mean rut depth =0mm

8. ROAD NETWORK PROGRAM ANALYSIS

The analysis was performed on the level of work planning (II level in HDM-4 analysis) for the period of 20 years. A discount rate of 12% was adopted for economic consideration. Presented results of road network program analysis for each group section are detailed in the following chapters:

8.1. Section group A (unconstrained budget)

Section group A has been analyzed in total length of 579.84 km. In the case of unconstrained budget, for defined pavement condition and criteria for applying of some maintenance standards, the following conclusions were achieved:

- For the analysis period of 20 years, applied optimum technical - economic maintenance standard through HDM-4 model are economically justified on 48 sections, total length of 509.63 km (87.9% of considered length).
- Average Economic Internal Rate of Return (EIRR) per section for group A is EIRR = 36.5%. The range of achieved EIRR is from 13.2% to 95.7%.

- Total Net Present Value (NPV) is NPV=417.48 millions EUR. The average NPV per section is NPVav=7.6 millions EUR. The range of achieved NPV per section is from 0 to 65.2 millions EUR.
- The average pavement condition in 2021 expressed by pavement roughness (IRI), in case of base alternatives (do minimum) will be IRI=9.0 m/km (see Figure 1)
- The average pavement condition expressed by pavement roughness (IRI), in case of rehabilitation alternatives (do minimum) will be IRI=2.8 m/km. (see Figure 1)
- Total cost of maintenance works in case of rehabilitation options is estimated to be 252.93 millions EUR.
- In the first year of analysis period, costs of rehabilitation works are 91.5 millions EUR (36.2% of total rehabilitation costs).

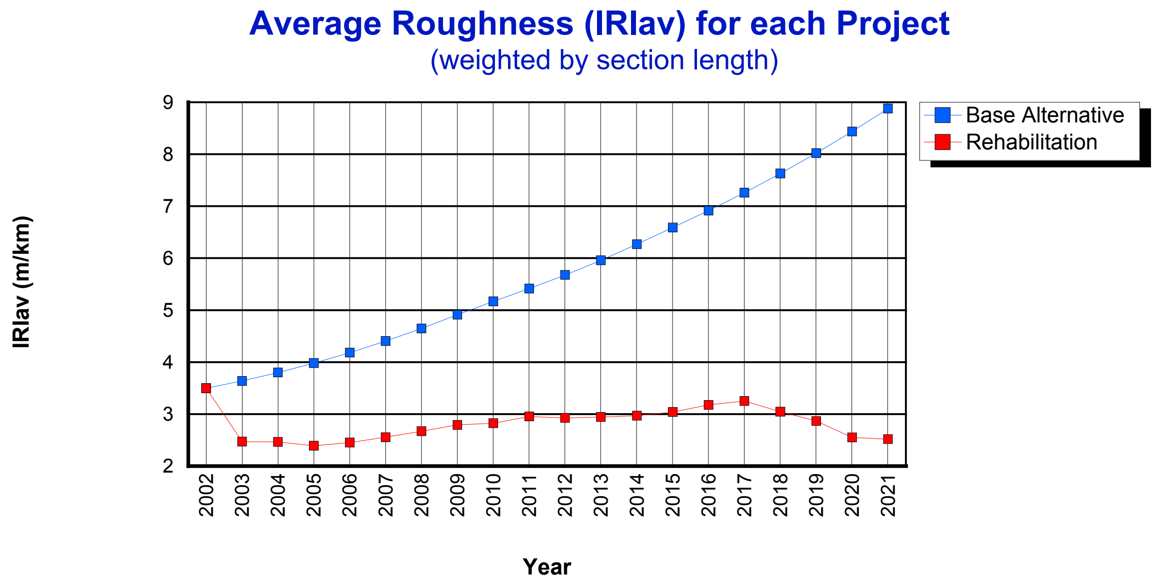

Figure 1 - Average Roughness for Project - Group A (unconstrained budget)

Figure 2 shows total costs of rehabilitation works by years for section group A.

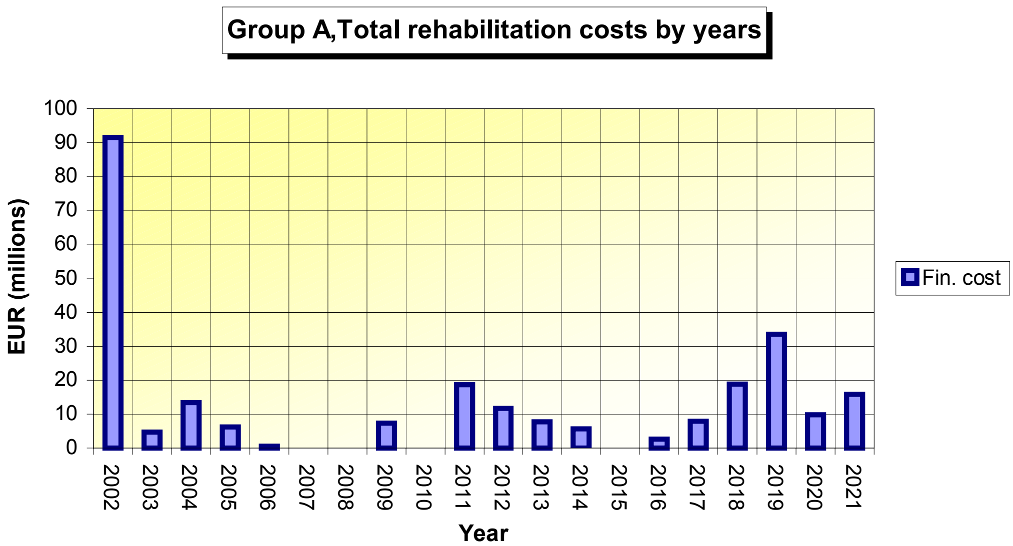

Figure 2 - Total rehabilitation costs by years - Group A (unconstrained budget)

8.2. Section group B (unconstrained budget)

Group B has been analyzed in total length of 857.76 km. In the case of unconstrained budget, for defined pavement condition and criteria for applying of some maintenance standards, following conclusions were achieved:

- For the analysis period of 20 years applied optimum technical - economic maintenance standard through HDM-4 model are economically justified on 86 sections, total length of 857.76 km (100.0% of considered length).
- The average Economic Internal Rate of Return (EIRR) per section for group B is EIRR = 65.4%. Range of achieved EIRR is from 12.7% to 130.2%.
- Total Net Present Value (NPV) is NPV=364.28 millions EUR. Average NPV per section is NPVav=4.3 millions EUR. Range of achieved NPV per section is from 0 to 35.2 millions EUR.
- The average pavement condition in 2021 expressed by pavement roughness (IRI), in case of base alternatives (do minimum) will be IRI=9.8 m/km (see figure 3)
- The average pavement condition expressed by pavement roughness (IRI), in case of rehabilitation alternatives (do minimum) will be IRI=2.6 m/km. (see figure 3)
- Total cost of maintenance works in case of rehabilitation options is estimated to be 139.1 millions EUR.
- In the first year of analysis period, costs of rehabilitation works are 21.4 millions EUR (15.4% of total rehabilitation costs).

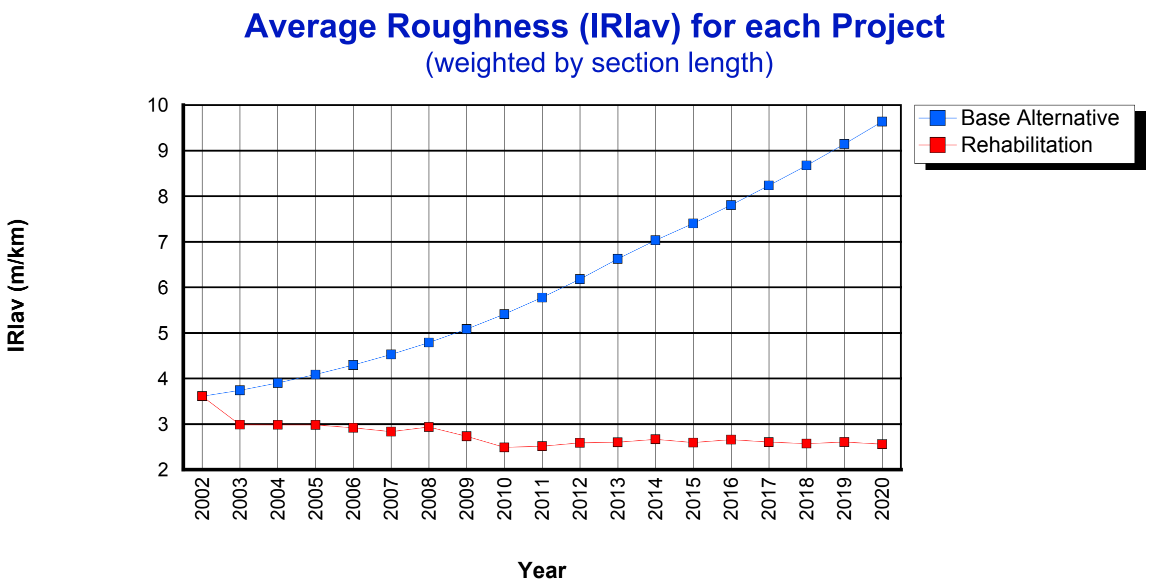

Figure 3 - Average Roughness for Project - Group B (unconstrained budget)

Figure 3 shows total costs of rehabilitation works by years for section group B.

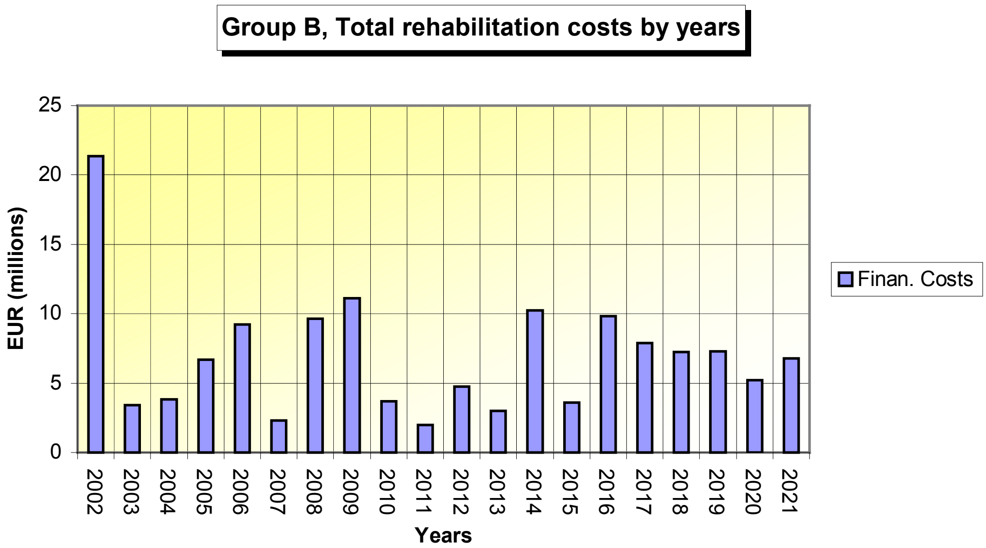

Figure 4 - Total rehabilitation costs by years - Group B (unconstrained budget)

8.3. Section group C (unconstrained budget)

Section group C has been analyzed in total length of 3,073.48 km. In the case of unconstrained budget, for defined pavement condition and criteria for applying of some maintenance standards, the following conclusions were achieved:

- The applied optimum technical - economic maintenance standards are economically justified through HDM-4 model on 244 sections, (total length of 2661.47 km, i.e. 86.6% of considered length) for the analysis period of 20 years.
- The average section level Economic Internal Rate of Return (EIRR) for group C is EIRR = 40.0%. Range of achieved EIRR is from 12.3% to 112.2%.
- Total Net Present Value (NPV) is NPV=1,082.08 millions EUR. Average NPV per section is NPVav=3.9 millions EUR. The range of achieved NPV per section is from 0 to 53.0 millions EUR.
- The average pavement condition in 2021 expressed by pavement roughness (IRI), in case of base alternatives (do minimum) will be IRI=11.8 m/km (see Figure 5)
- The average pavement condition expressed by pavement roughness (IRI), in case of rehabilitation alternatives (do minimum) will be IRI=2.9 m/km. (see Figure 5)
- Total cost of maintenance works in case of rehabilitation options is estimated to be 468.7 millions EUR.
- In the first year of analysis period, the costs of rehabilitation works are 164.5 millions EUR (35.1% of total rehabilitation costs).

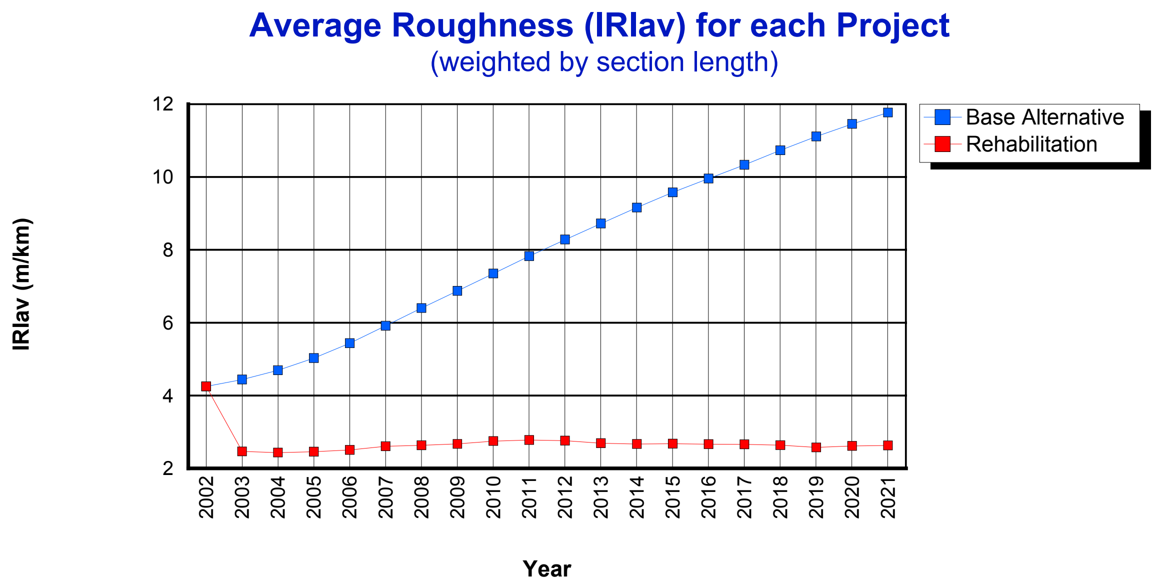

Figure 5 - Average Roughness for Project - Group C (unconstrained budget)

Figure 6 shows total costs of rehabilitation works by years for Section group C.

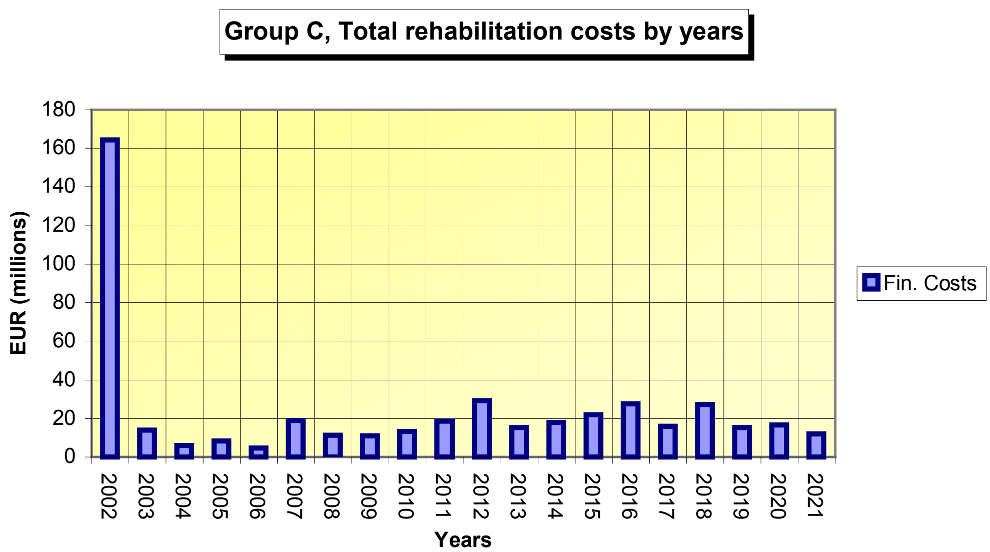

Figure 6 - Total rehabilitation costs by years - Group C (unconstrained budget)

9. ASSESSMENT OF THE OPTIMAL BUDGETING LEVEL FOR GROUP C

Programming level searching for optimal rehabilitation measures in conditions of unrestricted budget provides the most efficient set of actions at minimal expenses. If the network is extremely ruined, such a program does not provide either a stable budgeting level, or equal yearly quantities of particular types of interventions, which are desirable for stable conditions for contractors. Thus, a brief analysis has been carried out to find an optimal annual budget by means of Modup program. It has been searched between 30 and 70 millions EUR and different priority criteria for rehabilitation works. The best level, giving the least area under the backlog function, is obtained for the 65 millions EUR a year in the first three years. The starting value of 30 millions EUR in six years allows a very significant percent of good pavements to reach poor condition at the end of analysis period. As there is no significant difference from 60 to 70 millions EUR, it was recommended to assure 60 millions EUR bringing the road network encompassed by group C during four year period into acceptable condition (figure 7).

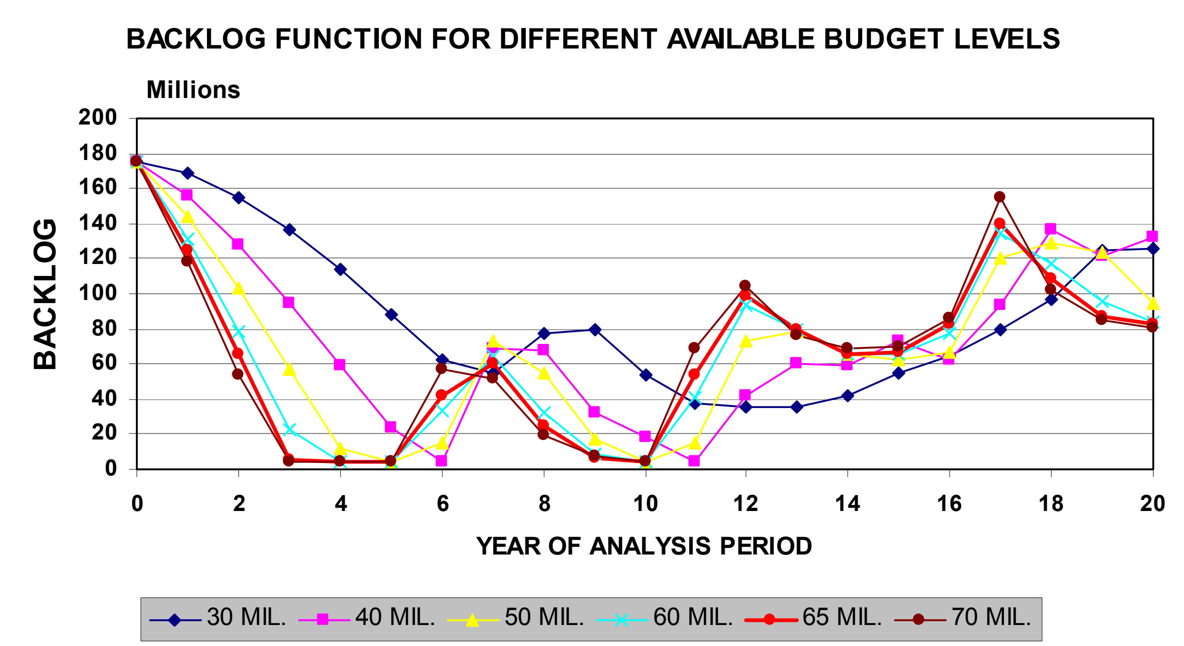

Figure 7 - Backlog function for different budget levels

10. CONLUSION

The analysis of road asset preservation and pavement rehabilitation needs comprised 4,511 km of main arterial road network of the Republic of Serbia (without Kosovo and Metohija) in accordance with the reference system.

The overview of economically justified program is presented in table 6.

As could be noticed the total urgent rehabilitation interventions in the first year are estimated to 277.4 millions EUR for arterial road network of Republic of Serbia.

Table 6 - The overview of economically justified program (unconstrained budget)

Group of sections	A	B	C
Type of roads	Motorways and express ways - Corridor X, Xb and part of Xc, E-70	Connections of Corridor X with the Corridor IV	Arterial roads except groups A and B
Number of sections	48	86	244
AADT [vpd]	1,024 - 21,430	958 - 17,980	184 - 18,587
Total length of viable sections [km]	509.63	857.76	2661.47
% of length considered	87.9 %	100.0 %	86.6 %
Average EIRR	36.5 %	65.4 %	40.0%
Costs of optimal 20-year program	253 M EUR	139 M EUR	469 M EUR
First year backlog	91.5 M EUR	21.4 M EUR	164.5 M EUR
Total urgent rehabilitation interventions in the first year			277.4 M EUR

The condition of the arterial road network of the Republic of Serbia appears to be in the critical stage, so the undertaking some interventions in order to prevent further pavement deterioration is essential.

The requirement for continuation of improvement and updating road database is evident, in order to achieve a better ground for technical-economic analysis as much as possible.

For the basic strategies considered, the resulting EIRRs (Economic Internal Rate of Return) are as follows, in relation to traffic levels pavement condition (Table 7):

Table 7 - The range of achieved EIRR related to traffic and condition

Road Starting Condition	Achieved EIRR (%) based on Optimum M&R Strategies (20 years analyses period)				
	AADT<1,000 vpd	1,000 to 3,000 vpd	3,000 to 7,000 vpd	7,000 to 12,000 vpd	>12,000 vpd
IRI ≤ 2.5 m/km	- [1]	-63.0 to 56.9%	2.6 to 85.6%	64.8 to 86.0%	33.2 to 85.4%
2.5 m/km < IRI ≤ 4.5 m/km	-67.7 to 14.1%	-16.3 to 78.2%	14.1 to 130.2%	I9.0 to 120.5%	28.5 to 80.9%
4.5 m/km < IRI ≤ 6.0 m/km	-81.1 to 17.5%	7.3 to 51.1%	24.7 to 90.9%	31.8 to 56.1%	51.9 to 55.8%
IRI > 6.0 m/km	17.0 % [2]	16.4% [4]	59.4% [4]	- [3]	- [3]

Figure 8 shows achieved EIRR weighted by length related to traffic volume and pavement condition for main arterial road network of Republic of Serbia as well as invesment cost analyses.

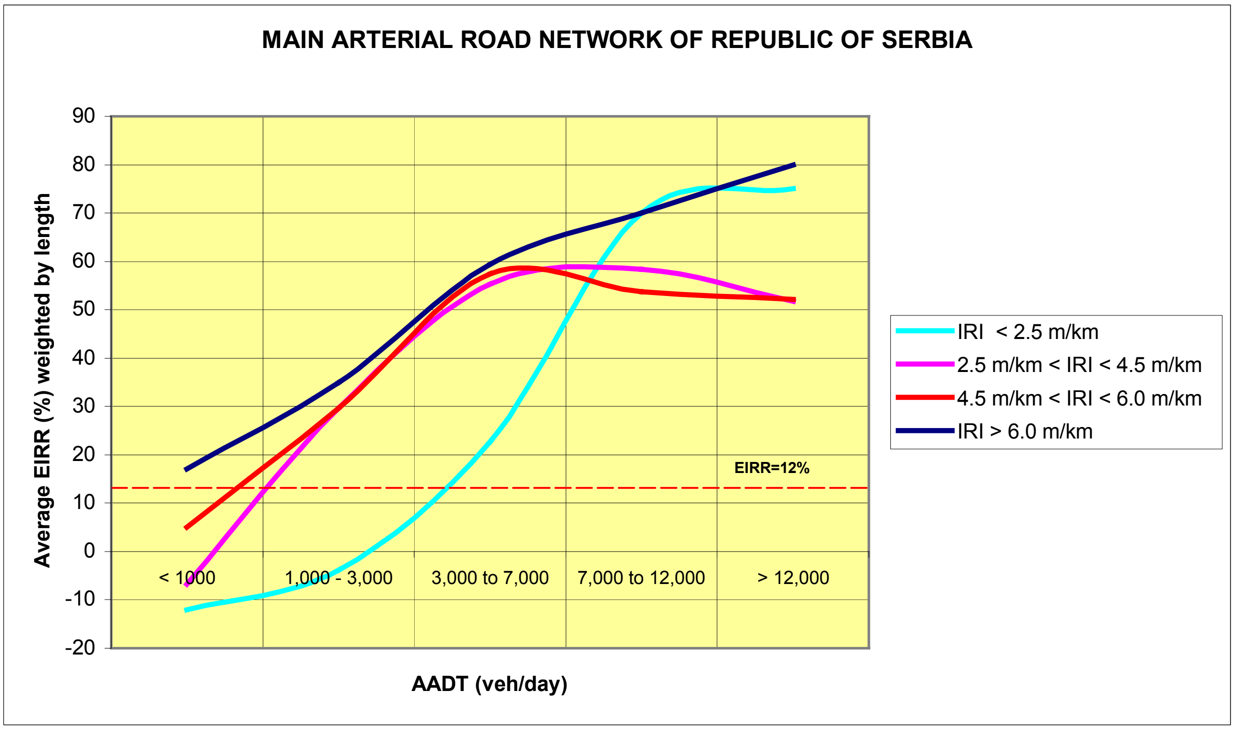

Figure 8 - Average EIRR (%) for main arterial road network of Republic of Serbia related to traffic volume and pavement condition

[1] This case was not appear in the Project
[2] Only one section in the Project

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