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THE PAVEMENT MANAGEMENT SYSTEM ON CROATIAN MOTORWAYS - EXAMPLE FROM PRACTICE

The pavement management system, as an integral part of the RoNeAna- Road Network Analyser of the Croatian Road Asset Management System, is implemented in managing pavements on Croatian motorways. This paper provides a brief overview (using the example of the A3 motorway) of pavement management procedures, from the collection of basic network and pavement construction data, to data processing aimed at determining performance indicators, to predicting the future behaviour of pavement, the required repair treatments with lists of priorities and expected costs, and various scenarios for multiannual maintenance planning. The condition of the A3 motorway, the most loaded highway in Croatia covering 300 km from the Slovenian to the Serbian border, is completely identified by visual inspection (cracking and surface defects) and other measured parameters (longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity).

Keywords: Croatian motorways, road management system, RoNeAna, pavement condition

1. INTRODUCTION

The structure management system (SMS) has been under development by the Institute IGH Inc. for the needs of Croatian Motorways Ltd since 2007. Upon completing modules for managing bridges, drainage and tunnels, a module for managing pavements using the RONeANa-Road Network Analyser,[3] a project developed by the company Geoexpert-project Ltd. Zagreb, has been implemented on the SMS platform. The system was tested in 2013 on sections of the A3 motorway, covering a length of approximately 100 km (from the Slovenian border to the town of Kutina). During 2015 and 2016, visual inspections were conducted and technical parameters measured on the remaining 200 km of the A3 (from Kutina to the Serbian border). Visual inspections and measurements were performed to collect data on damages to the surface, longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity of the pavement. The data was processed and the results, together with the system settings and management procedures are outlined below.

2. A3 MOTORWAY (BREGANA - ZAGREB - LIPOVAC)

The A3 motorway runs from the border with the Republic of Slovenia to the border with the Republic of Serbia over a total length of 306 km. It was built in stages over some 25 years and consists of a total of 25 sections, i.e. road parts between the traffic junctions. To simplify, this paper shows the condition of eight representative parts of the A3, grouped by the year of construction, pavement structure design and the average annual daily traffic (AADT). The grouped sections are shown in Table 1

Table 1. Grouped sections of the A3 Motorway

Section no.	Length [km]		CPI_c	Operational since	AADT
1		0,0	13,7	2001	3.04
2		13,7	41,7	1981	3.05
3		41,7	118,2	1980	2.81
4		118,2	161,5	1985/1986	2.00
5		161,5	222,3	1988 to 1991	1.94
6		222,3	250,1	1996 to 1999	1.97
7		250,1	276,0	2002	2.71
8		276,0	306,4	2006	1.80

Section no 1. Slovenian border-Jankomir
Section no 2. Jankomir-Ivanja Reka
Section no 3. Ivanja Reka-Lipovljani
Section no 4. Lipovljani-Prvča
Section no 5. Prvča-Slavonski Brod
Section no 6. Slavonski Brod-Velika Kopanica
Section no 7. Velika Kopanica-Županja
Section no 8. Županja-Serbian border

It is apparent that the most loaded section of the A3 is the grouped section 2- Jankomir-Ivanja Reka (also known as the Zagreb bypass), followed by the adjacent sections. Figure 1 shows a GIS display of the A3 motorway from RoNeAna [3]. The different colours represent the condition of the pavement by performance indicators.

3. TECHNICAL PARAMETERS AND PAVEMENT PERFORMANCE INDICATORS

Visual inspections and other measurements to pavements form the basis for establishing the technical parameters and determining performance indicators. Technical parameters obtained by visual inspection and measurements, and the corresponding performance indicators, are in accordance with the settings and recommendations of the COST Action 354, Performance Indicators for Road Pavements.[1] Damages to the final layer (cracks and surface defects) are established by visual inspection, and data is collected on the longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity via a range of measurements. These data create the technical parameters of pavement condition (TP_i). Using transformation functions, the technical parameters are translated into individual pavement performance indicators (PI_i). The individual indicators, adjusted by the weighting influences (W_i), create the combined performance indicators (CPI_i), determined from the perspective of CPI_c- traffic comfort, CPI_s- traffic safety and CPI_b- bearing capacity.

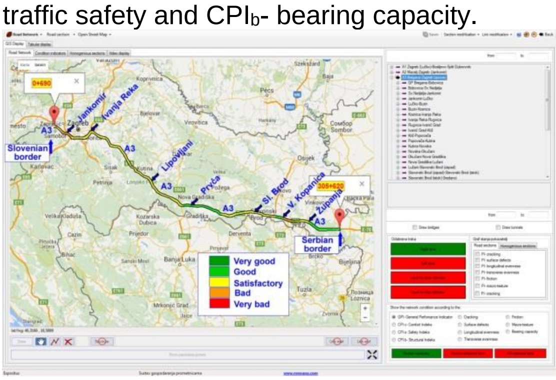


Figure 1. RoNeAna GIS display)

The combined performance indicators (CPI_i), adjusted by the weighting influences, forms the general performance indicator (GPI). The weighting influence values W_i (W_c-traffic comfort, W_s-traffic safety and W_b-bearing capacity) are used to determine the general performance indicators (Table 2).

Table 2. Weighting influences for the General Performance Indicator (GPI)

Combined Performance Indicators (CPI_i)		
$W_{cpi\ c}$	$W_{cpi\ s}$	$W_{cpi\ b}$
W_i – weighting influences for GPI		
0.7	1	0.65

The value range of the performance indicators ranges from 0 to 5, as shown in Table 3.

Table 3. Pavement performance indicators

Very good	Good	Satisfactory	Poor	Very poor
0 - 1	1 - 2	2 - 3	3 - 4	4 - 5

4. TECHNICAL PARAMETERS AND PAVEMENT PERFORMANCE INDICATORS

4.1 PAVEMENT PERFORMANCE INDICATORS

After processing the results of the inspections and measurements, the management system calculates individual, combined and general performance indicators. The performance indicators are continuously calculated every 10 m, individually for each traffic lane. The results are shown in tabular and graphic form for each lane of pavement. Figure 2 shows the performance indicators for the driving lane on the left pavement of the section Velika Kopanica - Babina Greda (listed as Section 7. Velika Kopanica-Županja in Table 1). The critical technical parameters for this section are the cracks and the macro-texture. Medium severity alligator cracking determines pavement bearing capacity as very poor, and the general performance indicator as poor. Cracks have the greatest influence on the indicator of pavement bearing capacity, which is within the limits of the very poor condition ratings. The performance indicators for the driving lane of that section are shown in Table 4.

Table 4. Section Velika Kopanica-Babina Greda - performance indicators

No.	From [km]	To [km]	CPI_c	CPI_s	CPI_b	GPI
7.1	250.1	263.7	2.86	1.54	4.16	3.03

Figure 2. Performance indicators for the section Velika Kopanica-Babina Greda (left pavement, right lane)

The state of this section surface layer is shown on Figure 3.

4.2 HOMOGENEOUS SECTIOS

For practical purposes, in order to determine the necessary repairs, the combination of technical parameters and status indicators are grouped into homogeneous sections, i.e. parts of the section with similar performance indicators and requiring the same kind of repair. Input data for determining homogeneous sections are a combination of technical parameters on the defined part of the pavement lane. Figure 3 shows the state of the surface layer of this section.

Figure 3. Alligator cracking on the section Velika Kopanica- Babina Greda (left pavement)

These combinations are included in the decision- making procedures such as "if the technical parameter $TP_1 > n_1$ and/or technical parameters $TP_2 > n_2$ and/or … and/or technical parameters $TP_i > n_i$, then the repair that covers all of those damages is the standard repair "$REPAIR_i$". The decision-making procedures of the management system regarding homogeneous sections and standard repairs can be called the “Decision Tree”. In the calculation module of the application, it is possible to set a minimum length for calculation of homogeneous sections.

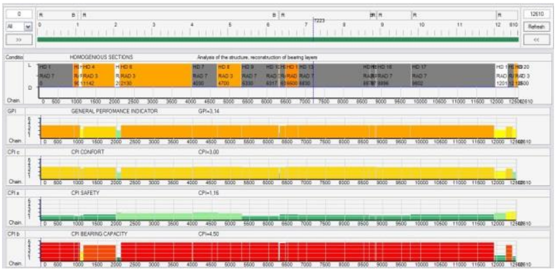


Figure 4. Alligator cracking on the section Velika Kopanica- Babina Greda (left pavement)

The most accurate calculated condition is for homogeneous sections of shorter length (since it takes all local damages into account), though this approach may be impractical and unprofitable during repair works. Testing different variants and, ultimately, manual adjustment, leads to an accurate and technologically reasonable model. Figure 4 shows the graphical representation of homogeneous sections and standard repairs with related costs for the driving lane of the left pavement from the previous example.

5. PERFORMANCE INDICATORS ON THE A3 MOTORWAY

Table 5 shows the performance indicators on grouped sections of the A3, the average value for all lanes on the left and right pavement. This gives some general insight into the overall condition. The specific condition, in the example of the characteristic section for each of the groups from the table, with the proposed repairs, will be outlined later.

Table 5. Pavement condition on the grouped sections of A3

Section no.	Length [km]	CPI_c	CPI_s	CPI_b	GPI
1	13.7	1.65	2.91	1.21	3.04
2	28.0	1.24	2.96	0.95	3.05
3	76.5	0.86	2.76	0.75	2.81
4	43.3	1.28	1.90	0.91	2.00
5	60.8	1.17	1.84	0.89	1.94
6	27.8	1.45	1.59	1.53	1.97
7	25.9	2.50	1.62	3.34	2.71
8	30.4	1.23	1.68	0.89	1.80
Aver./km	306.4	1.28	2.17	1.14	2.37

The average combined performance indicators of the A3 motorway per kilometre are good (traffic comfort and pavement bearing capacity) or satisfactory (traffic safety). The overall performance indicator is satisfactory.

5.1 SECTION 1 (SLOVENIAN BORDER – JANKOMIR)

The grouped sections of the motorway listed under the number 1 shows that the macro-texture and skid resistance have the greatest impact on traffic safety (CPIs), which approaches the limit of poor condition, and the general performance indicator (GPI) is already in the zone of poor condition. The performance indicators of a characteristic section on that part of the A3 (Bregana-Bobovica, driving lane of the right pavement) are shown in Figure 5.

Values of the technical parameters of macro-texture and friction are considered in the decision-making procedures to determine homogeneous sections and the required standard repairs. As a result, the proposal is final layer replacement or coating with micro-asphalt, Figure 6.

Figure 5. Performance indicators for the section Bregana-Bobovica (right pavement, driving lane)
Figure caption

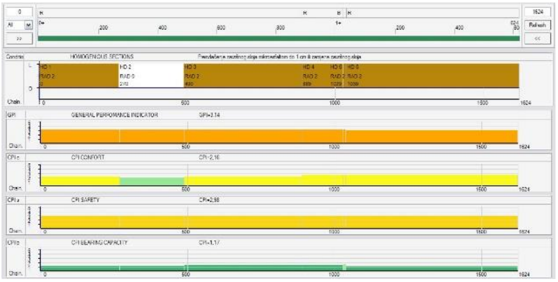


Figure 6. Homogeneous sections on the section Bregana-Bobovica (right pavement, driving lane)

5.2 SECTION 2 (JANKOMIR – IVANJA REKA)

On this section of the A3 motorway, skid resistance and macro-texture of the pavement and, in places, longitudinal unevenness have the highest impacts on pavement condition. These technical parameters have the greatest influence on the traffic safety indicator CPIs, which approaches the limit of poor condition, and the general performance indicator GPI, which is already in poor condition.

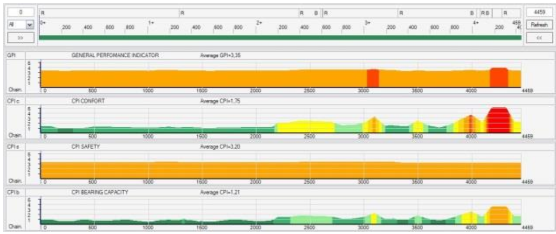


Figure 7. Performance indicators for the section Jankomir-Lučko (right pavement, right lane)

Performance indicators of a characteristic section on that part of the A3 (Jankomir-Lučko, driving lane of the right pavement) are shown in Figure 7. Near the end of the section, longitudinal unevenness has an effect on the homogenous section, with the recommendation for replacement of the final layer. Over the whole section, friction values are very near the limit values that represent the “trigger” for deciding on the repairs as defined in the decision-making procedures (“Decision Tree”).

5.3 SECTIONS 3 TO 5 (FROM IVANJA REKA TO SLAVONSKI BROD)

Part of the highway that encompasses section groups 3 to 5 has an overall satisfactory or good condition, according to all the performance indicators. The repairs to homogenous sections generally predict the filling of cracks and the replacements of the final asphalt layer.

5.4 SECTION 6 (SLAVONSKI BROD – VELIKA KOPANICA)

This part of the A3 motorway has an overall good condition according to all performance indicators, though unlike the section of the motorway in paragraph 5.3, it has some parts with extremely poor condition. This primarily refers to the left pavement (direction towards the border with Serbia). The greatest influence on the performance indicators of the left pavement are cracks, mostly alligator cracks of low and medium intensity. The performance indicators of the characteristic section on that part (Slavonski Brod east-Sredanci, right driving lane of the left pavement) are shown in Figure 8.

Homogenous sections with estimated repairs depend primarily on the type and quantity of cracks. For homogenous sections with alligator cracks of medium intensity which, corrected with weighting influences, extend over 20% of the surface area, an analysis of the structure of the pavement and the reconstruction of layers is estimated. For the remainder of the homogenous sections with cracks of lesser intensity and quantity, repairs to the asphalt layers (from replacement of the final layer to larger repairs) are estimated. Those repairs cover both the poor condition of friction and the macro-texture.

Figure 8. Performance indicators for the section Slavonski Brod-Velika Kopanica (left pavement, right lane)

5.5 SECTION 7 (VELIKA KOPANICA – ŽUPANJA)

This part of the A3 motorway characterizes the combined performance indicator of bearing capacity on all sections of that part of the A3, ranging from poor to very poor. A characteristic section of this part is shown and described in paragraphs 4.1 and 4.2.

5.6 SECTION 8 (ŽUPANJA – SERBIAN BORDER)

This part of the A3 motorway is in good condition with respect to every performance indicator. No pavement repairs are estimated for the majority of the section (with the exception of the boundary area with the preceding section).

6. LISTING PRIORITIES AND MULTIANNUAL MAINTENANCE PLANNING

After determining the condition and necessary repairs, the Pavement management system lists the maintenance priorities, and predicts the future condition as a function of time, thus enabling the creation of different scenarios and for multiannual maintenance plans.

6.1 MAINTENANCE PRIORITIES

The process of determining the priorities, i.e. the order of section maintenance, is performed done with a mathematic multi-criteria analysis that calculates the strengths and weaknesses of the decision to repair each section relative to all other sections, based on the established criteria and their weighting influences. The difference between the advantages and disadvantages for each observed parameters give the list of priorities. The importance criteria include the category of roadway, ability of bypass, average annual daily traffic (AADT), combined (CPIi) and the general performance indicator of the pavement (GPI).

6.2 MULTIANNUAL MAINTENANCE PLANNING

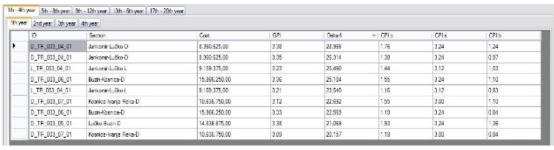
The acquired data on roadways (traffic loads, pavement structure, completed pavement renewal, etc.) and information on the current condition, forms the basis for the drafting of multiannual maintenance plans.

6.2.1 Prediction of future condition

For the needs of multiannual planning and the creation of the maintenance strategy, models of pavement behaviour as a function of time are an integral part of RoNeAna. These models predict the progress of certain type of damages over time, depending on the type of pavement construction and the traffic loads. Models have been implemented from the MDOT pavement management system report, Prediction Models and Feedback System, Final Report[2], a study conducted by the Department of Civil Engineering, University of Mississippi (October 2000). The models are created on the basis of data collected through the years on approximately 20,000 km of roads and on expert opinions.

6.2.2 Development of multiannual maintenance plans

During the life cycle of roads, the level of service is reduced by the curve, dependent on the progression of damage over time, as outlined in paragraph 6.2.1. Reduction in the level of service can be slowed, delayed, or remedies by returning the road to satisfactory condition through the application of certain maintenance strategies. The Road management system, RoNeAna, allows for the creation of different maintenance scenarios over a 20-year planning period, leaving the road administration to select the most favourable model. The input parameters are the annual budgetary resources through the planning period and the limitation of the allowable levels of pavement performance indicators. The output results for each scenario are annual, 4-year and 20-year maintenance plans with yearly and total costs, as well as the values of the performance indicators at the end and in each period within the planned timespan.



ID	Section	Cost	GPI	Delta I	CPIc	CPIs	CPIb
D_TR_003_04_01	Jankomir-Lučko-D	8.360.625,00	3.38	28.966	1.76	3.24	1.24
D_TR_003_04_01	Jankomir-Lučko-D	8.360.625,00	3.35	26.314	1.38	3.24	0.97
L_TR_003_04_01	Jankomir-Lučko-L	9.159.375,00	3.23	25.490	1.44	3.12	1.03
D_TR_003_06_01	Buzin-Kosnica-D	15.866.250,00	3.36	25.104	1.55	3.24	1.10
L_TR_003_04_01	Jankomir-Lučko-L	9.159.375,00	3.21	23.540	1.16	3.12	0.83
D_TR_003_07_01	Kosnica-Ivanja Reka-D	10.638.750,00	3.12	22.692	1.55	3.00	1.10
D_TR_003_06_01	Buzin-Kosnica-D	15.866.250,00	3.33	22.569	1.19	3.24	0.84
D_TR_003_05_01	Lučko-Buzin-D	14.836.875,00	3.38	21.069	1.93	3.24	1.36
D_TR_003_07_01	Kosnica-Ivanja Reka-D	10.638.750,00	3.09	20.157	1.19	3.00	0.84

Figure 9. Maintenance scenario with fixed annual budget

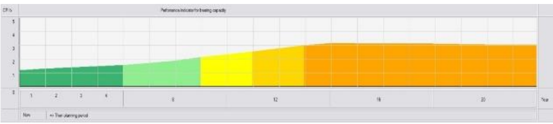


Figure 10. Fixed annual budget- graphic representation through the years

With regard to the selected input requirement, two general groups of possible scenarios can be distinguished:

For certain budget resources, possible projects are planned and the scenario calculates the performance indicators during and at the end of the planning period (as shown in the example in Figures 9 and 10).

For previously defined limit values of the performance indicators during and at the end of the planning stage, the necessary budget resources are being calculated.

7. CONCLUSIONS

Management procedures and different maintenance scenarios allow road authorities to compare the relationships between total costs and achieved performance indicators, thereby selecting the most favourable scenario as the maintenance strategy for the multiannual planning period. This should be a scenario which uses the lowest budgetary resources to return the desired pavement performance indicators.

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