THE STRUCTURE MANAGEMENT SYSTEM ON CROATIAN HIGHWAYS

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ABSTRACT

The Structure Management System was designed by IGH INSTITUTE (Zagreb, Croatia) for the company Croatian Motorways. The task of the system is to provide insight into the value, condition and safety of motorway structures, and to maintain them at the expected and required level of the planned investments and with minimum expenses. The system is composed of seven subsystems, each comprised of a particular motorway structures group and representing a separate unit (pavements, bridges, drainage, tunnels, geotechnical structures, buildings and motorway equipment). Each subsystem is designed so that its management procedures are on a common platform with other subsystems in order to enable future integration into a unified system at the level of all structures within the motorway network. The principles of the COST Action 354 project are taken for such a common platform, applied to the pavement management subsystem and adjusted to the specifics of other groups of structures. This paper uses pavement management subsystem as an example to present the connections with other subsystems as a foundation of their integration at the level of the entire motorway management system.

1. INTRODUCTION

The purpose of the road and traffic infrastructure management system is to maintain value of the property at a desired level, during its usable lifetime, with the lowest possible maintenance costs, while preserving the adequate and assigned usability and safety. IGH Institute Inc, Zagreb, Croatia is designing and implementing such a system with the purpose of managing the structures administrated by the company Croatian Motorways Ltd. The system consists of seven subsystems representing structure groups (Figure 1): bridges, geotechnical structures, pavements, tunnels, drainage, road equipment and buildings.

Figure 1 - Structures management system

Each subsystem consists of three main parts:

- Permanent data - list of the structures, position on the road network, traffic load data, data on the structure (Figure 2);
- Variable data- data on structure condition, obtained by inspections (Figure 3);
- Management procedures - calculation of the current and forecasting the future condition indicators, determination of priorities and multi-year maintenance plans (Figure 4).

Figure 2 – Bridges, permanent data

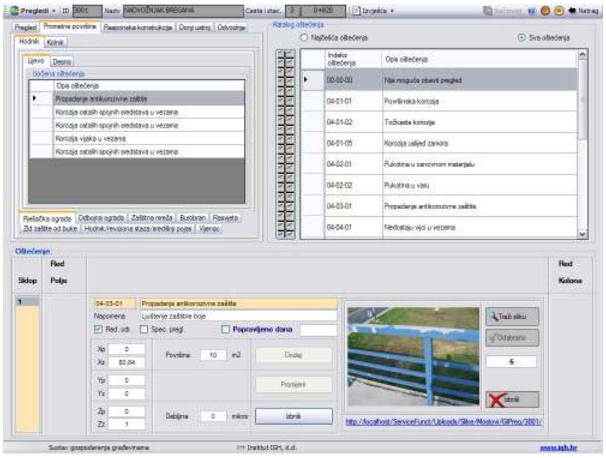


Figure 3 - Variable data, inspection of bridges

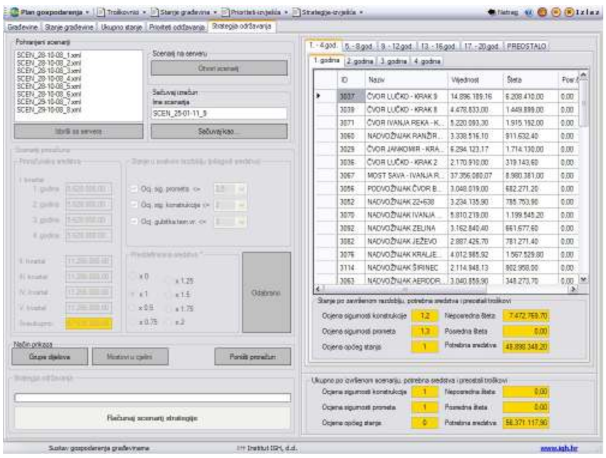


Figure 4 – Bridges, management procedures

By now, subsystems for bridges, drainage and tunnels are designed and implemented for the purposes of Croatian Motorways Ltd. A serious shortcoming of the separate observation of different types of structures in the road system is inability to address their mutual impacts, thus making it impossible to plan at the level of the entire road network. For instance, pavement condition is strongly influenced by the condition of drainage, cuts and fills and retaining walls. The same applies to all other structures groups. The basic problem is reducing structures of completely different characteristics and behaviour to a common equivalent. Upon completion of all subsystems, it will be necessary to integrate them into the joint (or integrated) structures management procedures at the road network level.

The Roneana (**Ro**ad **Ne**twork **Ana**lyser) web application calculates pavement structure condition indicators, applying the principles of the COST Action 354 project, and is intended for pavement management of all road categories. Its basic platform is a defined road network. The possibility exists, for its future widening with other structures groups. In this paper, this application will be used as an example of an approach in resolving the issue of integrating all road infrastructure facilities on a common platform. It should be noted that the input parameters used in the examples are fictitious. The presented damages and measurements were widely varied to fully test the application.

2. COST ACTION 354 [1]

COST (European **CO**operation in the field of **S**cientific and **T**echnical Research) is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally-funded research on a European level. This paper is based on the principles of the COST Action 354 project, where the technical parameters for pavement distresses are defined, and transformed to performance indices. To assess pavement condition, following distresses are recorded:

- Surface distress;
- Evenness (longitudinal and transverse);
- Skid resistance and texture;
- Bearing capacity.

Appropriate procedures are applied to transform the technical parameters into performance indices according to the following scheme:

- Technical parameters (TP) are transformed via transfer functions into dimensionless single performance indices (PI);
- Sets of single performance indices (PI) adjusted by impact weighting factors (W pi) form the dimensionless combined performance indices (CPI) regarding safety, comfort, structure and environmental impact;
- Combined performance indices (CPI) adjusted by impact weighting factors (W cpi) are combined into dimensionless general performance index (GPI).

Performance indices are dimensionless numbers on a scale for evaluation of involved technical parameter. The values for single (PI), combined (CPI) and general performance indices (GPI) vary within the ranges shown in Table 1. Considering that the assessment of condition is largely subjective, COST Action 354 provides the recommended values of transfer functions for roads of higher and lower categories, and each road authority is given the opportunity to develop transfer functions according their own expectations, needs and maintenance strategy.

Table 1 - Limit values of the Performance indices

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

3. ROAD NETWORK AND DEFINITION OF ITS STRUCTURES

Location of road infrastructure facility within the road network is essential for both, the individual structures management procedures and for their integration into a unified road network management system.

Sections of the road network are divided longitudinally (Figure 5), by construction type, into: bridges (routes on bridges), tunnels (routes through tunnels) and the basic route (all road sections that do not belong to the previous categories). These subsections are made of main structure elements and the set of all other structures elements belonging to the observed road chainage, according to the division in the transversal direction (Figure 6).

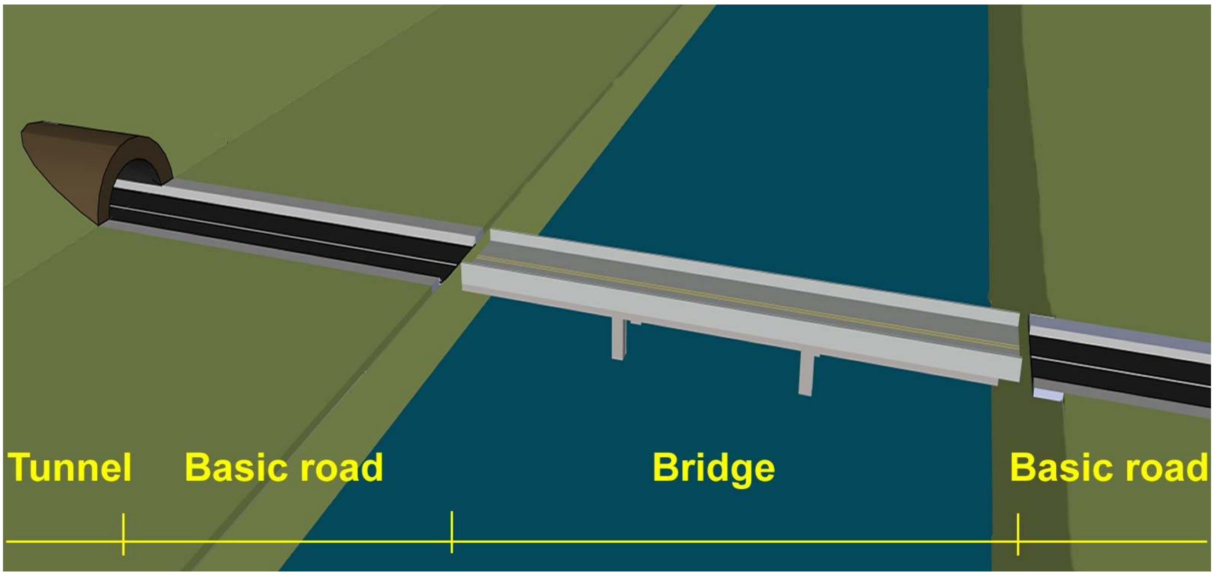


Figure 5 - Division within the road network, by structures in the longitudinal direction

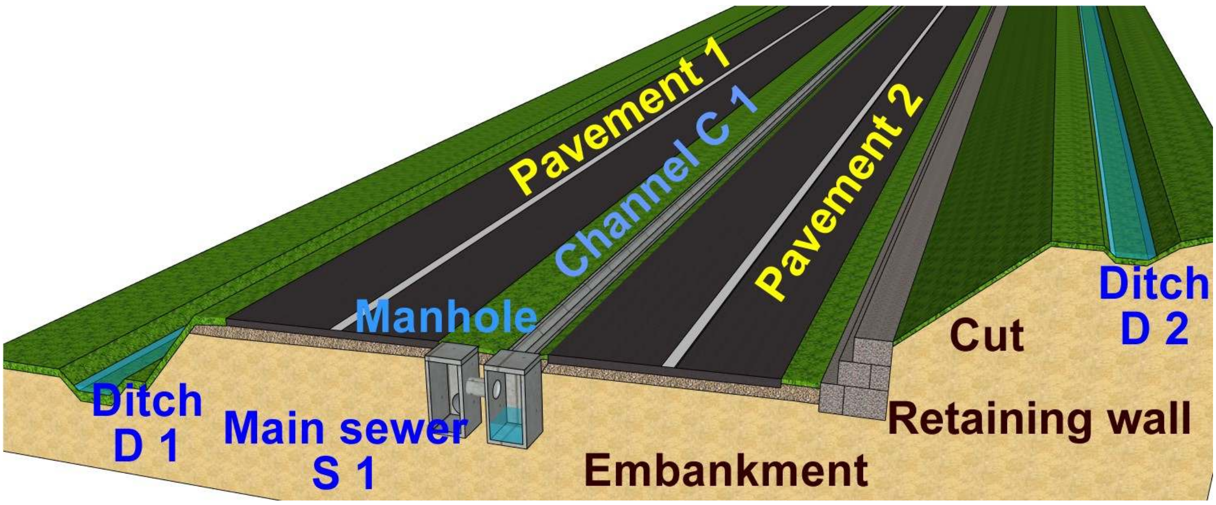


Figure 6 - Division within the road network, by structures in the transversal direction

Such a division enables management procedures to recognise, associate and operate with different types of structures at every point of the road network. These types of structures are determined by the basic division in the longitudinal direction:

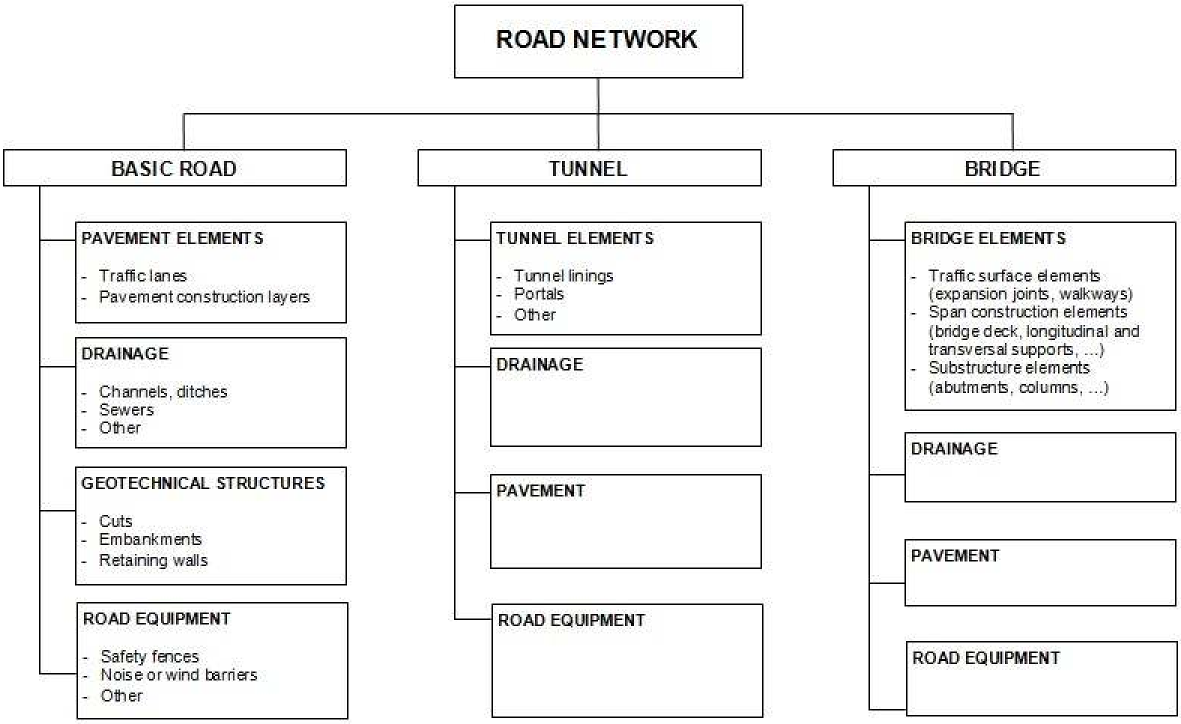


Figure 7 - Division within the road network

4. TECHNICAL PARAMETERS AND PERFORMANCE INDICES – PAVEMENT [1]

Technical parameters are values determined and measured during inspections and measurements performed on structures. Inspections and measurements of pavement structures are performed in the prescribed time intervals, and their results (technical parameters) form the base for calculation of the structures performance indices. For easier monitoring of their application on other types of structures, technical parameters and performance indices are outlined below.

4.1. Technical parameters and single (individual) performance indices for pavement

4.1.1. *Surface distress*

These are determined by visual inspections and logging according to the catalogue of possible damages (Figure 8). They are divided into:

- Cracking (TP cr) - percentage of cracking on a specific surface. The technical parameter is a weighted sum of different types and dimensions of cracking in reference to the investigated surface, and the unit of measure is %.
- Surface defects (TP sd) - percentage of the surface defects on a specific surface. The technical parameter is a weighted sum of different types and dimensions of surface defects in reference to the investigated surface, and the unit of measure is %.

The size of investigation surface for determination of the technical parameters can be selected in the Roneana application. Default values are a section length of 100 m with 10 m steps along the route, meaning that for every 10 m along the route, the technical parameters for the section 50 m before and 50 m after the current position (Figure 9) are calculated. In this way, the values for the technical parameters are obtained for every 10 m (i.e., the length of the selected step) of the chainage.

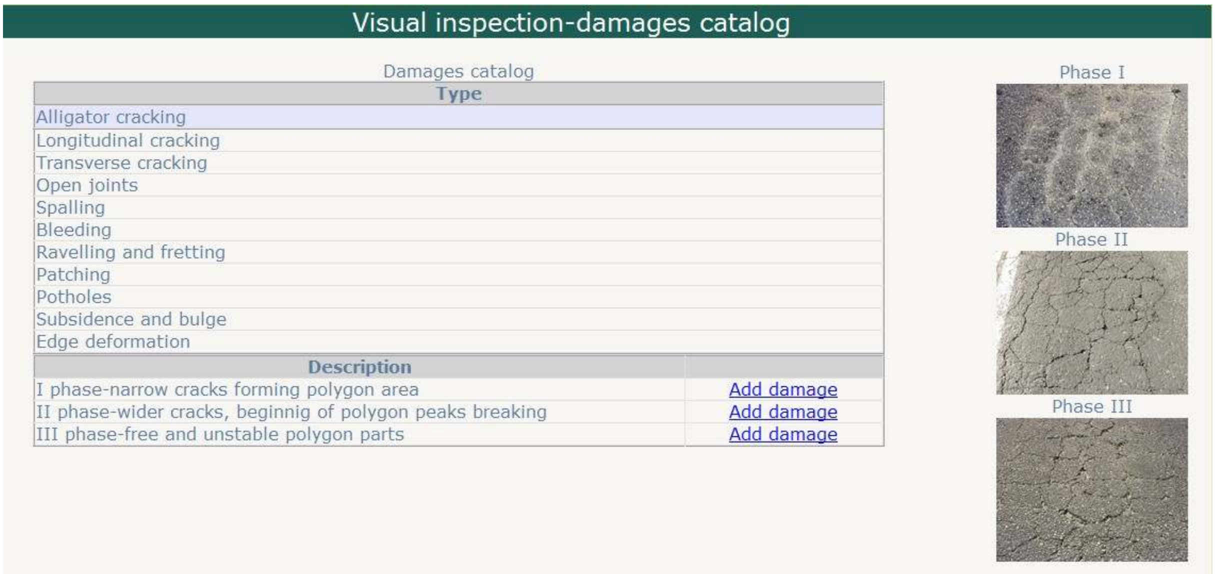


Figure 8 – Pavement, catalogue of the possible damages

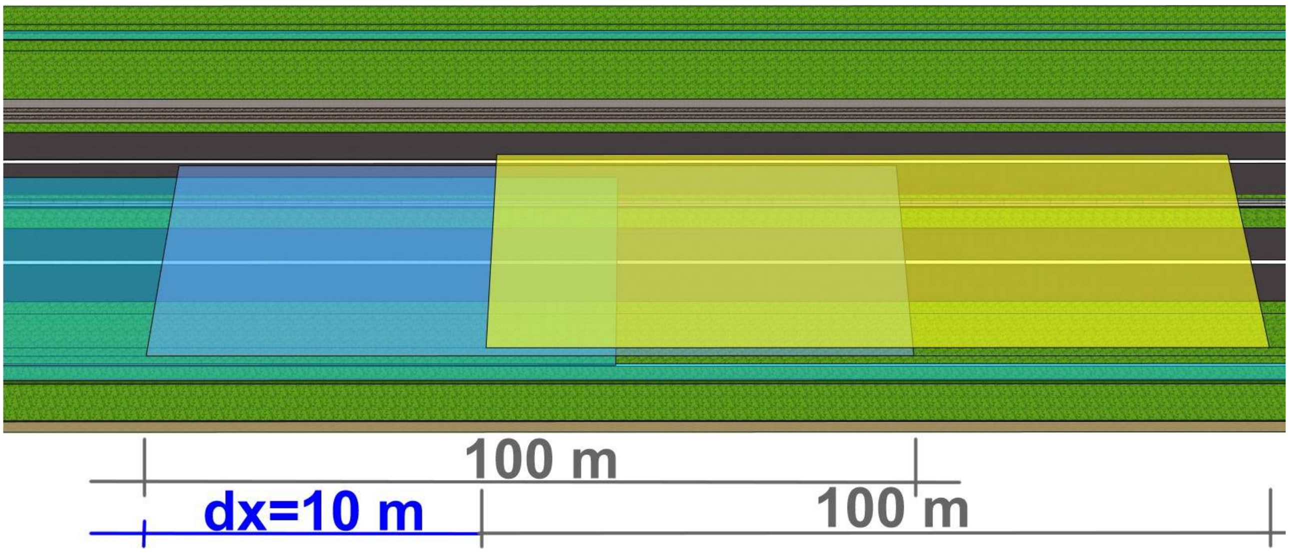


Figure 9 – Pavement, iteration of the technical parameters along the chainage

Performance indices (PI cr, PI sd) are dimensionless numbers on a 0 (very good) to 5 (very poor) scale, which are transformed from the technical parameters (TP cr, TP sd) via the transfer functions given in the form:

PI cr = A * TP cr, where A = constant;
PI sd = B * TP sd, where B = constant.

COST 354 proposed the values:

A = 0.16 – cracks, roads of the higher rank;
A = 0.1333 – cracks, roads of the lower rank;
B = 0. 1333 – surface damages, all roads.

4.1.2. *Longitudinal evenness*

Longitudinal evenness is the deviation of the longitudinal profile from a straight reference line for the specific section of the road. The technical parameter is the International Roughness Index (IRI) and the unit of measure is mm/m. The performance indices (PI e) are calculated from the technical parameters (TP e) via the transfer function given in the form:

$PI\ e = A * (TP\ e)^2 + B * TP\ e - C$, where A, B, C = constants.

COST 354 proposed the values:

Roads of the higher rank: A = 0.1733, B = 0.7142, C = -0.0316;
Roads of the lower rank: B = 0.1816, A = 0, C = 0.

4.1.3. *Transverse evenness*

Transverse evenness is deviation of the transversal profile evenness, i.e. Rut Depth (RD) and the unit of measure is mm. The performance indices (PI r) are calculated from the technical parameters (TP r) via the transfer function given in the form:

$PI\ r = A * (TP\ r)^2 + B * TP\ r$, where A, B = constants.

COST 354 proposed the values:

Roads of the higher rank: A = -0.0015, B = 0.2291;
Roads of the lower rank: A = -0.0023, B = 0.2142.

4.1.4. *Skid resistance*

Skid resistance is the friction coefficient for the specific section of the road. The technical measuring parameter is the Sideways Friction Coefficient (SFC) (60 km/h) or Longitudinal Friction Coefficient (LFC) (50 km/h), and there is no unit of measure. The performance indices (PI f) are calculated from the technical parameters (TP f) via transfer function given in the form:

$PI\ f = A * TP\ f + B$, where A, B = constants.

COST 354 proposed the values:

Roads of the higher rank: A = -13.875, B = 9.338;
Roads of the lower rank: A = -17.600, B = 11.205.

4.1.5. *Texture*

Texture depth is measured as the average depth of the profile formed by the aggregate particles, Mean Profile Depth (MPD), and the unit of measure is mm. The performance Indices (PI t) are calculated from the technical parameters (TP t) via the transfer function given in the form:

$PI\ t = A - B * TP\ t$, where A, B = constants.

COST 354 proposed the values:

Roads of the higher rank: A = 6.6, B = 5.3;
Roads of the lower rank: A = 7.0, B = 6.9.

4.1.6. *Bearing capacity*

The condition of deeper layers of the pavement construction is indirectly determined by measuring deflections using a specially equipped vehicle. The measuring results are interpreted via the **S**urface **C**urvature **I**ndex (SCI_{300}), with the unit of measure of μm or **R**esidual **L**ife (RD), which has no unit of measure. The performance indices (PI b) are calculated from the technical parameters (TP b) via the transfer function given in the form:

PI b = TP b / A, where A = constant.

COST 354 proposed the values:

Strong base: A = 253;
Weak base: A = 129.

4.2. Combined and general performance indices for pavement

Single (Individual) performance indices (PI), adjusted by impact weighting factors (W pi), form the dimensionless combined performance indices (CPI) in relation to road safety (CPI s), user comfort (CPI c), pavement bearing capacity (CPI b) and environmental impact (CPI e). The combined performance indices (CPI) adjusted by the impact weighting factors (W cpi) are combined into dimensionless general performance index (GPI). They are calculated via the transfer function given in the form:

CPI i = I_1 + p/100 * AVERAGE(I_2,...,I_n), where:

CPI i = CPI c, CPI s, CPI b, CPI e;
(p /100) = constant, 0.10-0.20;
I_1 = MAXIMUM(PI cr*W cr, PI sd*W sd, PI e* W e, PI r*W r, PI t*W t, PI b*W b, PI env * W env);
(I_2, …, I_n) - other adjusted individual indicators (without I_1).

GPI = I_1 + p/100 * AVERAGE(I_2,...,I_n), where:

I_1 = MAXIMUM(CPI c*W c, CPI s*W s, CPI b* W b, CPI e*W e);
(I_2,...,I_n) - other adjusted combined indicators (without I_1).

Using the iterative calculation method (Figure 9), the single (individual), combined and general performance indicators are obtained for every point along the chainage of the observed road section (Figure 10). The figure shows that, during calculation, parts of the observed sections were identified as either the pavement of basic road or the pavement of tunnel.

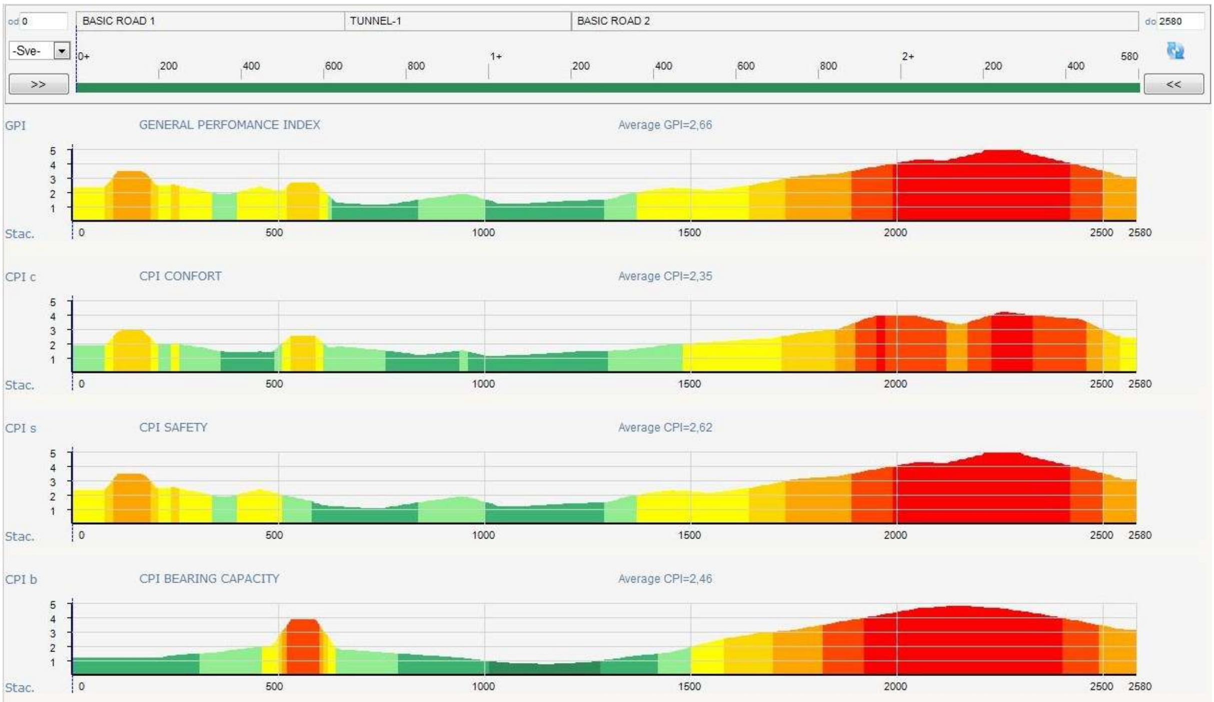


Figure 10 – Pavement, condition indicators along the selected section (environmental impact has not yet been assessed)

5. CONDITION INDICATORS FOR OTHER STRUCTURES - A POSSIBLE APPROACH

Technical parameters are calculated from the damages determined during inspections and recorded according to the catalogue that is unique for each individual type of structure (an example is the catalogue of damages for tunnels, Figure 11). The calculation method is identical to the calculation applied for the pavement, though the transformation functions and impact weightings are adjusted for different types of damages and different structures elements. The structure indicators are calculated according to the division in the transversal direction (Figure 6), and the calculation results are assigned to the structure according to the division in the longitudinal direction (Figure 5).

5.1. Drainage, geotechnical structures, road equipment

The technical parameters and performance indices are calculated for each individual structure from each group of structures, separately. The starting assumption is that each of the individual structures on the road, as well as each of the elements of these structures has a specific function. Reduction or loss of the functionality of any structure has certain (greater or lesser) consequences for the functionality of the road as the whole. These consequences can be represented as the impact on riding comfort and road safety, structures bearing capacity, and the environmental impact. An example for drainage is shown in Figure 6. Drainage in cross-section (for selected position) is made up of the individual structures:

- Channel C 1 (with gutter shafts),
- Main sewer S 1 (with manholes),
- Ditches D 1, D 2.

For each individual drainage structure, from the recorded damages adjusted by impact weighting factors, the iterative process is used to calculate the performance indices (PI j) by the length of the structure, and the combined and the general performance indices (CPI j, GPI j) according to the advanced maximum criteria, item 4.2:

$CPI\ c\text{-}j_{drainage} = I\ j_{c-1} + p/100 * AVERAGE(I\ j_{c-2},...,I\ j_{c-n})$...comfort;
$CPI\ s\text{-}j_{drainage} = I\ j_{s-1} + p/100 * AVERAGE(I\ j_{s-2},...,I\ j_{s-n})$... safety;
$CPI\ b\text{-}j_{drainage} = I\ j_{b-1} + p/100 * AVERAGE(I\ j_{b-2},...,I\ j_{b-n})$... bearing capacity;
$CPI\ e\text{-}j_{drainage} = I\ j_{e-1} + p/100 * AVERAGE(I\ j_{e-2},...,I\ j_{e-n})$...environmental impact;

$GPI\ j_{drainage} = I\ j_1 + p/100 * AVERAGE(I\ j_2,...,I\ j_n)$...general performance indices ;

where "j" is the individual drainage structure (CL-1, SW-1, KA-1, KA-2), and the other expressions are in every aspect as for the item 4.2.

From the performance indices of individual structures, the total condition of the drainage for each cross-section of the observed road section, can be calculated following the principle of the "weakest link" and the function of advanced maximum criteria, i.e. condition of drainage as a whole, in every point of chainage is determined by the worst condition of the individual structures, increased by the average condition of all drainage structures.

$CPI\ c_{sum\ drainage} = CPI\ c_1\ drainage + p/100 * AVERAGE(CPI\ c_2,...,CPI\ c_n)$...comfort;
$CPI\ s_{sum\ drainage} = CPI\ s_1\ drainage + p/100 * AVERAGE(CPI\ s_2,...,CPI\ s_n)$...safety;
$CPI\ b_{sum\ drainage} = CPI\ b_1\ drainage + p/100 * AVERAGE(CPI\ b_2,...,CPI\ b_n)$...bearing capacity;
$CPI\ e_{sum\ drainage} = CPI\ e_1\ drainage + p/100 * AVERAGE(CPI\ e_2,...,CPI\ e_n)$...environmental impact;

$GPI_{sum\ drainage} = GPI_{1\ drainage} + p/100 * AVERAGE(GPI_{2\ drainage},...,GPI_{n\ drainage})$... general performance indices ;

where:

$CPI\ c_1$, $CPI\ s_1$, $CPI\ b_1$, $CPI\ e_1$ are the largest CPI c, CPI s, CPI b, CPI e of the individual structures (drainage, geotechnical structures or road equipment) on the observed cross-section;
GPI_1 is the largest GPI of the individual structures (drainage, geotechnical structures and road equipment) on the observed cross-section;
$CPI\ c_2$ to $CPI\ e_n$ – other combined performance indices individual structures (except the largest);
GPI_2 to GPI_n – other general performance indices individual structures (except the largest).

The total condition of the drainage, calculated in such manner, is associated to other structures according to the division along the longitudinal direction (basic road, tunnels and bridges), as the structure "drainage".

5.2. Basic road, tunnels and bridges

These structures consist of their construction elements and of other types of structures along the observed section of the road, according to Figure 7. The principles of the calculation of the Performance Indices and combining of the various structures types are the same as in examples represented under items 4 (pavement) and 5.1 (drainage). This example will be used to show a possible determination of tunnel conditions.

5.2.1. *Tunnel construction - technical parameters and performance indices*

The technical parameters and single (individual) performance indices for each element of tunnel construction are determined by visual inspection and logging according to the catalogue of possible damages (Figure 11). The surface for determination of the technical parameters is the surface of tunnel lining between two joints (block). The tunnels on Croatian motorways usually have such sections of 12 m lengths. All damages have a certain impact on riding comfort and traffic safety, bearing capacity, and the environment. From the technical parameters and their impact weightings, the individual, combined and general performance indices are calculated in the same manner as shown for the pavement, item 4.

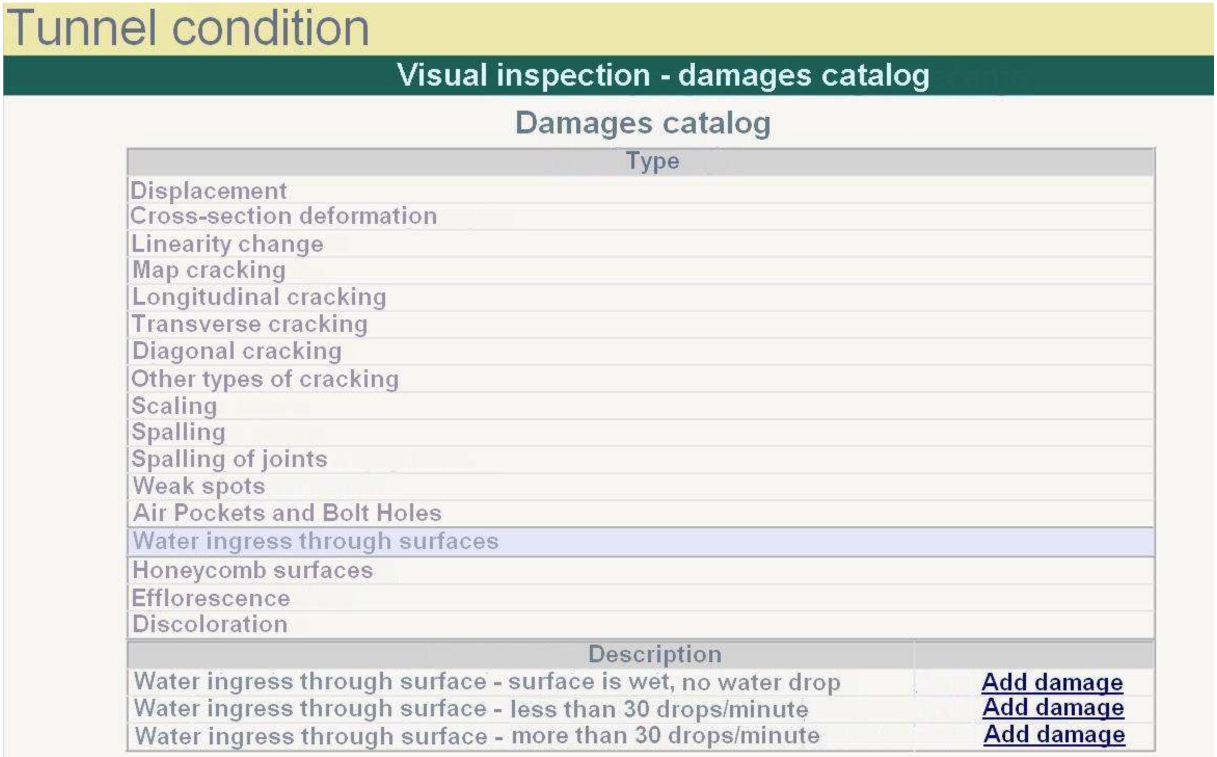


Figure 11 – Tunnel construction, catalogue of possible damages

5.2.2. *Tunnel – other structures*

With the exception of the construction of the tunnel itself, the tunnel construction includes the pavement, drainage and road equipment, the condition of which is determined separately (items 4 and 5).

5.2.3. *Tunnel – total*

The total condition of tunnel as a structure is defined by the condition of the tunnel construction, and the conditions of the pavement, drainage and road equipment fitted in the tunnel. From the performance indices of individual structures, the total condition of the tunnel in each cross-section along its length can be calculated using the "weakest link" principle and the function of advanced maximum criteria, i.e. the condition of the tunnel as a whole in every point of chainage is determined by the worst condition of the individual structures, increased by the average condition of all structures.

$CPI\ c_{sum\ tunnel} = CPI\ c_1 + p/100 * AVERAGE(CPI\ c_2,...,CPI\ c_n)$...comfort;
$CPI\ s_{sum\ tunnel} = CPI\ s_1 + p/100 * AVERAGE(CPI\ s_2,...,CPI\ s_n)$...safety;

$CPI\ b_{sum\ tunnel} = CPI\ b_1 + p/100 * AVERAGE(CPI\ b_2,...,CPI\ b_n)$...bearing capacity;
$CPI\ e_{sum\ tunnel} = CPI\ e_1 + p/100 * AVERAGE(CPI\ e_2,...,CPI\ e_n)$...environmental impact;
$GPI_{sum\ tunnel} = GPI_1 + p/100 * AVERAGE(GPI_2,...,GPI_n)$... general performance indices ;

where:

$CPI\ c_1$, $CPI\ s_1$, $CPI\ b_1$, $CPI\ e_1$ are the largest of CPI c, CPI s, CPI b, CPI e of individual structures on the observed cross-section;
GPI_1 is the largest GPI of the individual structures on the observed cross-section;
$CPI\ c_2$ to $CPI\ e_n$ – other combined performance indices of individual structures (except the largest);
GPI_2 to GPI_n – other general performance indices of individual structures (except the largest).

The calculated total tunnel condition is shown in Figure 12.

Figure 12 – Tunnel, performance indices

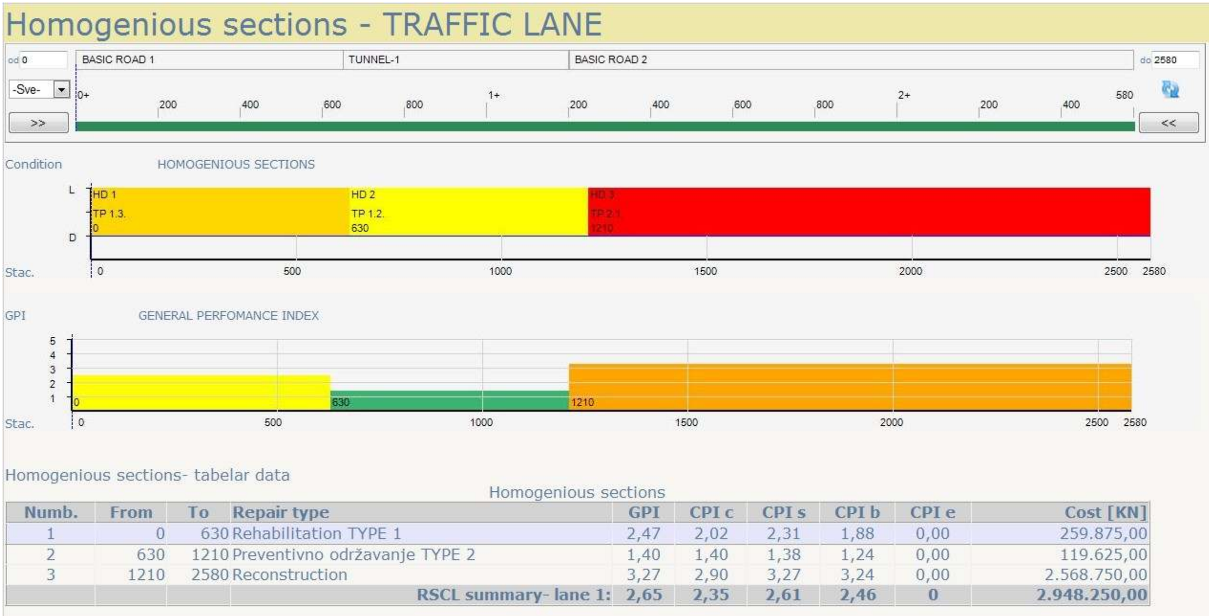
6. HOMOGENOUS SECTIONS AND TYPICAL REPAIRS

A homogenous section can be defined as a road section with approximately uniform Technical Parameters/ Performance Indices where it is possible to apply the same type of repair. The possible repairs depend on type of the structure and can be grouped into:

- Regular maintenance;
- Preventive maintenance;
- Rehabilitation;

• Reconstruction.

From the performance indices (i.e. technical parameters according to which they are calculated) homogenous sections with type repairs and costs are determined. Figure 13 represents the homogenous sections for traffic lane with performance indices according to Figure 10. The tunnel from the example in item 5, Figure 12, would have homogenous sections for each of the component structures group, as well as for performance indices of the whole tunnel structure.



Numb.	From	To	Repair type	GPI	CPI c	CPI s	CPI b	CPI e	Cost [KN]
1	0	630	Rehabilitation TYPE 1	2,47	2,02	2,31	1,88	0,00	259.875,00
2	630	1210	Preventivno održavanje TYPE 2	1,40	1,40	1,38	1,24	0,00	119.625,00
3	1210	2580	Reconstruction	3,27	2,90	3,27	3,24	0,00	2.568.750,00
			RSCL summary- lane 1:	2,65	2,35	2,61	2,46	0	2.948.250,00

Figure 13 – Homogenous sections, current condition

Homogenous sections enter the procedure for forecasting future condition as the baseline for multi-year planning and preparation of the optimal maintenance strategy.

7. MULTI-YEAR PLANNING AND MAINTENANCE STRATEGY

Degradation of the structure condition as a function of time is a curve defined by the relation of technical parameters for individual types of damages and the performance indices (individual, combined and general). At any moment, the curve is within the area where it is possible to apply one of the maintenance methods, described under the previous item. From the present and predicted future conditions, the priorities and different maintenance scenarios are calculated for a certain time period. The optimal scenario provides the most advantageous ratio of costs and structure condition during and after planned period, taking the calculation limits into the consideration.

CONCLUSIONS

Individual management systems (pavements and bridges management systems are the most used to date) are only parts of the whole road infrastructure management system. Their integration at the level of the traffic infrastructure management system enables the management procedures for:

• implementation of mutual impacts of different structures types ;

- determination of the condition of road network section according to the conditions of all structures constituting this section;
- prevention of future damages on individual types of structures caused by the condition of other structures;
- forecasting the future condition for certain group of structures, taking into the consideration the impacts of other structures conditions ;
- multi-year planning at the level of the road network as a whole.

Integration of completely different types of structures into a unique system is a demanding task. Whatever the approach is regard solving this issue, it is necessary to define the common characteristics to be met by all structures of the road infrastructure. In the described approach, these characteristics are taken from the COST Action 354 (comfort, safety, bearing capacity and the environmental impact). When preparing the umbrella model for the road infrastructure management system, special attention must be paid to harmonisation (calibration) of the impact weightings of individual damages on individual elements of the structure, regarding their common properties. Through continuous work with the system, shortcomings and the need for improvements will become apparent. The general behaviour models for the structures comprising the road must be improved and adjusted to local conditions over time and by accurate data collection. The purpose is not only preserving the enormous financial assets invested in the construction, but also to make them profitable. To achieve this, the management system should also provide answers to the questions how much, when, how and where to invest, by using the tools that will provide answers in a simple and efficient manner, and which are understandable to both engineers and managers.

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