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The improving of the road infrastructure management quality by using of modern diagnostic tools

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Abstract Today's society is confronted with the need to apply innovation to the widest possible extent. This also includes primary areas such as the mobility sector and the related infrastructure management. The aim is to achieve a higher level of sustainability in the segments. This is ideally done by improving the selected processes, introducing new approaches and re-evaluating the efficiency of spending. The article presents partial activities of the research team, which, through its own research and development activities, seeks to obtain recommendations for more efficient road management in the context of increasing the cost-effectiveness of the allocated financial resources.

Key words pavement, maintenance, economy, diagnostics, degradation

1. INTRODUCTION

A functioning transport system is one of the key factors in the development of any modern society. It is not appropriate to regard it as an objective, but as an instrument of economic development, which is a prerequisite for achieving social and regional cohesion. For this reason, the most important strategic plans for the development of regions, states, but also of the European Union deal with the conditions of ensuring sustainable development of mobility. With optimal settings, the latter should ensure that the company's ever-increasing transport needs are met. Emphasis is placed on the timeliness and quality of the measures (ie not responding to situations, but being prepared for the future) and reducing the ever-increasing negative environmental impact.

The role of the responsible authorities within the Slovak Republic is to create suitable conditions to support the economic activities of the entities present and to respond to the needs associated with the elimination of regional disparities between their own and cross-border regions. At the same time, these authorities are responsible for generating tools that can contribute to the modernization of the road network in the context of increasing its capacity and quality characteristics. These tasks stem mainly from the context of raising the standard of living of society and the resulting increase in road transport performance (especially individual transport). The table below illustrates the development of traffic volumes in recent years. Against this background, it is clear that performance is expected to increase, which is directly related to the higher load on the road network.

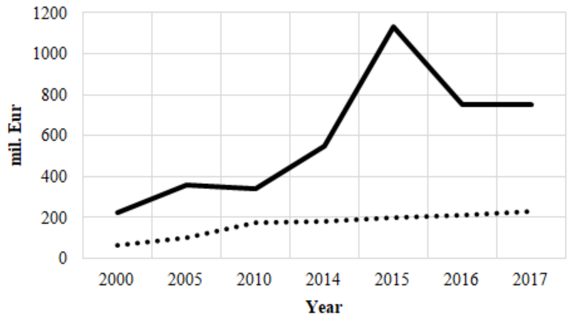
Table 1: Selected data on transport volumes in transport

Year		2018	2017	2016	2015	2014	2013	2012
Gross domestic product of Slovak Republic	mil. Eur	88 620	84 985	81 153	78 896	76 087	74 169	72 703
Transport of goods in freight transport	thousand tone	177 222	176 790	156 279	147 275	142 622	128 855	132 074
Transport of persons in public passenger transport	thousand people	242 733	245 731	259 164	252 175	262 262	270 123	289 228
Performances in public passenger transport	mil. seat-kilometres	5 394	5 060	4 996	4 499	4 495	4 388	4 584
Performances in freight transport	freight ton-kilometers	35 589	35 361	36 106	33 525,30	31 304	30 005	29 503
Year		**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**
Gross domestic product of Slovak Republic	mil. Eur	70 627	67 577	64 023	65 941	56 231	45 513	39 354
Transport of goods in freight transport	thousand tone	132 568	143 071	163 148	199 218	179 296	181 422	195 405
Transport of persons in public passenger transport	thousand people	299 579	312 717	323 142	365 519	384 637	403 270	449 456
Performances in public passenger transport	mil. seat-kilometres	4 611	4 436	4 538	6 446	7 596	7 665	7 525
Performances in freight transport	freight ton-kilometers	29 044	27 410	27 484	29 093	27 049	22 114	22 550

Source: Own construction, Input value: Statistical Office of the Slovak Republic

An important part of the infrastructure management tools must also be a set of tasks devoted to creating new and improving existing approaches in the management and systematic renewal of road infrastructure. The aim of this must be to ensure the necessary standard in terms of scope (ie to realize the allocated performance to the extent necessary), but in direct concurrence with the targeting of the intervention and its economic efficiency. Within the Slovak Republic, there is a clear trend associated with an increase in the volume of financial resources that are allocated to the needs of administrators in the form of investment resources and current expenditure on maintenance, repairs, winter service, restoration of buildings, etc.

Figure 1: Amount of expenditure on road infrastructure in the Slovak Republic



Source: Own construction, Input value: Ministry of Transport and Construction of the Slovak Republic

Table 2: Quality of roads

Overall ranking	Country	Rating
9.	Austria	6,0
15.	Germany	5,5
62.	Hungary	4,1
65.	Poland	4,1
73.	Slovakia	4,0
74.	Czech R.	4,0
130.	Ukraine	2,4

Source: Own construction, Input value: World Economic Forum, Executive Opinion; Quality of roads: how is the quality (extensiveness and condition) of road infrastructure [1= extremely poor—among the worst in the world; 7= extremly good - among the best in the world].

The deteriorated state of the road network in Slovakia is not only responsible for a long-term undersized budget, but also for a poor set-up of processes that allocate these resources to individual activities. All this in combination with frequent overpricing of performed work beyond the real needs. With regard to improving the cost-effectiveness of the funds spent, it has to be added that in recent years a number of measures have been introduced in the process of increasing the transparency of public procurement and closer monitoring of the quality of work performed, in order to limit work beyond the scope of the original contracts. This gradually makes the pricing that brings savings and realizes the possibility of reallocating finances to other investment and operating actions on the part of managers. Currently, as one of the most significant negative factors responsible for the state of the road network, it represents the poor targeting of the money spent. It is conceived as an intersection of two decision algorithms. The first is the allocation of funding for transport infrastructure management through subjective political decision-making. The second decision algorithm is based on the urgency of repair, maintenance, reconstruction or modernization. Its results should be generated from the evaluation of the existing and predictive state of roads in combination with the importance of a particular section on the transport network (in particular through the traffic load factor, i.e. the intensity). Determining priorities through this indicator is the fulfillment of the so-called. The concept of 'value for money', which represents a clearly defensible approach by the controller in its planned steps towards efficient management of transport infrastructure. In the overview below, it is possible to present what should be a priority outside the development of the superior road infrastructure (construction of motorways and expressways). This is to improve the condition of lower-class roads, which have not been designed to withstand the traffic load they currently have to withstand.

Table 3: Condition of road infrastructure in SR

1ST CLASS ROAD	km				
Rutting RUT	EXC.	G	SAT.	UNSAT.	EM
2018	1419	933,9	459,3	430,8	155,3
2015	1294,6	947,8	483,2	446	151,8
2013	1234,9	988,1	532,9	484	158,1
2011	788,4	1201,5	652,8	568,8	185
2010	874,5	1206,1	661,1	572,6	174,4
1ST CLASS ROAD	%				
Rutting RUT	EXC.	G	SAT.	UNSAT.	EM
2018	41,8%	27,5%	13,5%	12,7%	4,6%
2015	39,0%	28,5%	14,5%	13,4%	4,6%
2013	36,3%	29,1%	15,7%	14,2%	4,7%
2011	23,2%	35,4%	19,2%	16,7%	5,4%
2010	25,1%	34,6%	18,9%	16,4%	5,0%
1ST CLASS ROAD	km				
LONGITUDINAL UNEVENNESS /IRI/	EXC.	G	SAT.	UNSAT.	EM
2018	522,8	1020,3	589,8	858,7	136,8
2015	492	1076,2	913,6	766,9	75,4
2013	430,1	1066,7	970,5	846,9	83,8
2011	253,2	970,3	1093,9	986,4	92,8
2010	277,8	1022,5	1137,3	965,8	85,1
1ST CLASS ROAD	%				
LONGITUDINAL UNEVENNESS /IRI/	EXC.	G	SAT.	UNSAT.	EM
2018	16,7%	32,6%	18,9%	27,4%	4,4%
2015	14,8%	32,4%	27,5%	23,1%	2,3%
2013	12,7%	31,4%	28,6%	24,9%	2,5%
2011	7,5%	28,6%	32,2%	29,0%	2,7%
2010	8,0%	29,3%	32,6%	27,7%	2,4%
2ST CLASS ROAD	km				
Rutting RUT	EXC.	G	SAT.	UNSAT.	EM
2018	1397,7	1323,6	524,9	332,3	63,1
2015	1237,1	1192,6	466	284,1	60,2
2011	1056,8	1132,8	440,8	256,4	47,7
2ST CLASS ROAD	%				
Rutting RUT	EXC.	G	SAT.	UNSAT.	EM
2018	38,4%	36,3%	14,4%	9,1%	1,7%
2015	38,2%	36,8%	14,4%	8,8%	1,9%
2011	36,0%	38,6%	15,0%	8,7%	1,6%
2ST CLASS ROAD	km				
LONGITUDINAL UNEVENNESS /IRI/	EXC.	G	SAT.	UNSAT.	EM

2018	141,1	793,1	1108,2	1347,4	251,9
2015	85,6	585,9	951,5	1307,8	309
2011	168,5	720,1	981,3	948,9	115,6
2ST CLASS ROAD	**%**				
LONGITUDINAL UNEVENNESS /IRI/	EXC.	G	SAT.	UNSAT.	EM
2018	3,9%	21,8%	30,4%	37,0%	6,9%
2015	2,6%	18,1%	29,4%	40,4%	9,5%
2011	5,7%	24,5%	33,4%	32,3%	3,9%

Source: Own construction, Input value: Slovak Road Administration EXC = EXCELLENT; G = GOOD, SAT = SATISFACTORY, UNSAT = UNSATISFACTORY, EM = EMERGENCY

In addition, as far as third-class roads are concerned, the proportion of unsatisfactory kilometers has been around 30% (ie around 3 000 km) over the last ten years and, on an emergency basis, around 4.2% roads (approx. 400 km). Road managers therefore face serious decisions in the form of prioritization, so as to slow down the trend of infrastructure degradation. These decisions should be based on high-quality diagnostics and subsequent analysis of the existing situation, according to relevant professional bodies. All this in parallel with the introduction of innovations based on advanced research tasks. An example is activities within the Slovak and foreign research teams, which bring the necessary change of view of the issue. An example of innovation in the prioritization process is given in [9]. In an attempt to address the limitations of standards methods, is possible to present a Reliability Centered Maintenance and Analytical Hierarchy Process based hybrid model for trunk road network maintenance prioritization. It is worth noting knowledge improving the material research associated with roads, which focuses on the topic microtexture of asphalt pavement surface [3]. The results show that microtexture an essential parameter from the traffic safety point of view and it closely relates to a geometrical, petrological and physical properties of aggregate particle used in asphalt pavement.

Microtexture has a significant influence for assurance basic friction values between tire and pavement in relation to a skid resistance properties. [4], [5] The following example is the relatively significant knowledge in the field of application of recycled asphalt mixtures applicable mainly to lower road categories [12]. Even interesting values are recorded in terms of the application of new additives to asphalt mixtures. The tests have shown a positive impact of additives (ground rubber, hydrate lime component) on the results of these mixtures. [13]. A relatively sensitive topic on the side of administrators is the condition of bridge structures as objects on the road network. The high number of bridges that are at the edge of their lifetime is gradually being overrun to an unsatisfactory or an emergency state. This often leads to the need to close roads, define detour routes with a negative impact on the economy of transport processes, as well as the quality of life and the environment of the regions concerned. In this respect, however, new knowledge can be observed which can bring direct effects in order to extend their lifetime and introduce higher resistance to excessive traffic load. An interesting example is the possibility within reinforced concrete (RC) beams strengthened with CFRP lamellas in bending areas were investigated [1] or implementing increasingly detailed diagnostic systems [2]. The application of IoT and ICT elements in combination with traditional measurement systems is increasingly involved in the process of infrastructure diagnostics.The measuring method applied in RCT is essentially based on analysis of the relationship between linear accelerations recorded while vehicles move in the given road network elements. The results obtained in measurements of traffic dynamics make it possible to estimate indicators of the road infrastructure condition assessment [11]. The resulting quality of evaluation outputs is also based on the wider application of mathematical theories. According to [10] is applicable the self-correcting neural network in the process of road pavement diagnostics to deliver more relevant results for administrators.

The University of Žilina is one of the most competent organizations in this field through the Faculty of Civil Engineering and the Research Center. Within this article they present a partial part of their own research and development activities aimed at improving the quality of the diagnostic infrastructure and related processes.

2. SCIENTIFIC OBJECTIVE AND RESULTS OF EXPERIMENTAL MEASUREMENTS

An internationally recognized and applied approach to road management is the system tool named Pavement Management System (PMS). In Slovak conditions, it is known as the Road Management System, which focuses on a comprehensive assessment of the road condition, its roadworthiness and the design of strategies for its maintenance and restoration. It also includes the so-called. Pavement Performance Models, a toolkit that helps the management of the road network determine the best (optimal) strategy for restoring, rehabilitating or reconstructing the road to maintain its good condition. The approach of thorough analysis and prediction of the behavior of the road structure body is utilized using diagnostics and mathematical operations. It is present in the development of degradation models that represent a key element in road management systems. In general, it can be understood as the actual course of road degradation within the individual monitored parameters. From the perspective of adherence to the correctness of the procedure associated with the determination of the degradation dependencies in question, it is necessary to ensure that the approaches to the creation and modification of road performance models are supervised. These are used to achieve the highest accuracy of forecasts associated with the decision-making process for road management and maintenance. Several roadway prediction models are designed and applied worldwide. Many of these models are developed for use in a particular region or country, with modifications for their own specific traffic and climatic conditions. In this context, it is established that they cannot be directly applied in countries where significantly different marginal conditions apply. Although a large number of research tasks are devoted to modeling the road performance, it is necessary to continually work to improve it and continually improve the process of obtaining / creating a comprehensive model that can accurately predict the performance.

By mathematically expressing the degradation model, it is possible to obtain a degradation function. Its notation is generally defined by the relation following the time dependence of the parameter:

$$P_x(t) = 1 - A.(\frac{t}{T})^B$$

This relationship is usually modified to depend on traffic load without time specification.

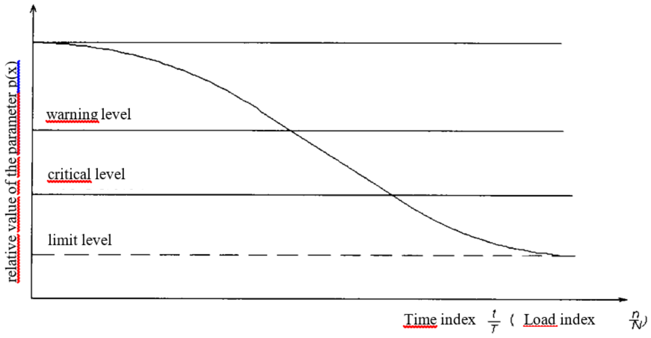
$$P_x(n) = 1 - A.\left(\frac{n}{N}\right)^B$$

where:
$P_x(t)$ - parameter value at time t,
P_x (n) - parameter value under load n,
T - residual lifetime of the parameter in years
N - residual service life of the parameter in the design load
A.B - degradation curve shape parameters

In determining the degradation functions of the individual parameters, 3 basic limit values are applied as standard by the assessment process, which are applicable when using models within the Road Management System in Slovakia:

- The limit value is a threshold value that is not exceeded for the parameter
- Parameter warning value indicates the expected time at which the parameter reaches the degree of violation requiring repair.
- Critical value of a parameter indicates that the monitored parameter is no longer

Figure 2: General shape of degradation function [6]



From the point of view of correctness of the procedures, it is important to focus also on the information that enters the subsequent mathematical theories of degradation modeling. They are represented by the obtained values of the surface properties of pavements, data on the bearing capacity of pavements and on the traffic load, climatic conditions, technical solution and databases of technological and economic elements. Surface properties are defined by parameters of roughness (microtexture and macrotexture of the surface), longitudinal unevenness (IRI), transverse unevenness (track depth, water depth, permanent deformation), cover failure state (IPSV parameter, respectively PSI). As also stated [7] one of the requirements concerning pavement quality is the evenness of its surface. Pavement unevenness has a random character and has an adverse influence to rolling resistance, tyre–pavement coherence, safety and the driving com-fort.

The bearing capacity is a parameter classified on the basis of measured road deflection, by means of which we can determine the residual road life.

One of the most reliable methods to determine the road structure is the use of non-destructive diagnostics. They have two major advantages over destructive methods. The first is that destructive testing disrupts the underlying road layers. It requires physical collection of road construction materials, which are subsequently tested under laboratory conditions. The second big advantage is the speed of the road test performance. In most cases, it can also be done without major traffic restrictions or any traffic restrictions. At the same time, it is possible to obtain a large amount of different data with one diagnostic passage and thus test the road from several points of view at the same time [8]. The research team at the University of Žilina has its own laboratory through which the procedures for more accurate diagnostics of the state of transport infrastructures are gradually improved. In particular, the following devices may be included:

Deflectometer FWD 150 - In the test, the roadway is impacted by a shock-absorbing rubber pad, and the timeline usually measures the change in the impact force and deformation at and off the point of impact in the vertical direction, referred to as deflection.

Georadar GPR consisting of a radio transmitter and receiver that cooperate with GPR antennas. The principle of the georadar method consists in repeatedly transmitting high-frequency electromagnetic pulse by a transmitting antenna to the examined environment. In places where there is a change in the electromagnetic properties of the environment, some of the energy of the transmitted electromagnetic pulse is reflected, which is registered by the receiving antenna. This impulse is obtained from different kinds of layers, material continuity disturbances caused by moisture or other causes. The time of sending and receiving the pulse is monitored. In the case of frequent repetitions at short intervals, it is possible to obtain results in a continuous display. GPR analysis involves evaluating the thickness of the bonded layers, the underlying layers, and determining the interface of the structural plan. The accuracy of the thickness of individual structural layers based on georadar measurements is in the range of 5 - 10%. Part of the analysis is a video record with the results of measured parameters in one graphical interface and localization of the surveyed sections via GPS.

Using a laser scanner and an accelerometer, it can be used to assess the depth of track traveled, transverse and longitudinal irregularities. At the same time, they can be used to evaluate the transverse slope of the roads and to graphically display the cross-section of the road (the transverse alignment of the road, roadside and roadway body) and the international IRI.

The research team continuously carries out several experimental measurements on the road network. Here are partial results that show the progress of the acquisition at different points in the road.

Figure 4: Evaluation of deformation depth and IRI 20

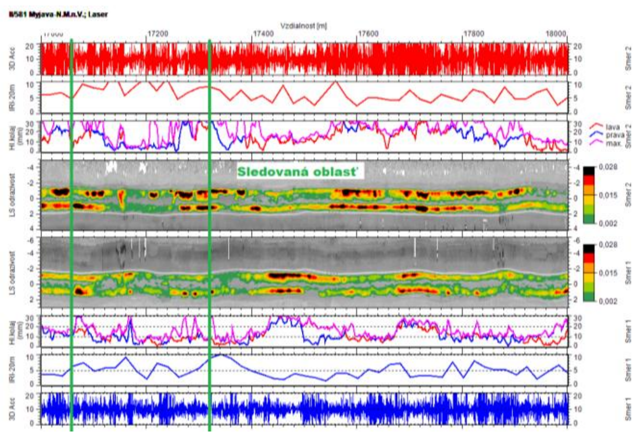


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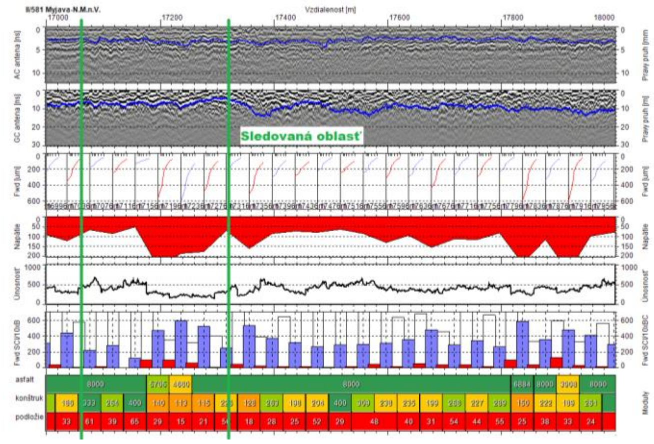
Figure 5: Evaluation of road bearing



The road section in question served to verify the accuracy of the evaluation of the thickness of the asphalt layers as well as the overall thickness of the road construction. The figures below show real roadway thickness measurements. The table shows the deviations from the measurement of the thickness of the asphalt-concrete pavement layer and the total thickness of the pavement structure by GPR

Figure 6: Total construction thickness 535mm (left) and asphalt layer thickness (right) in place**

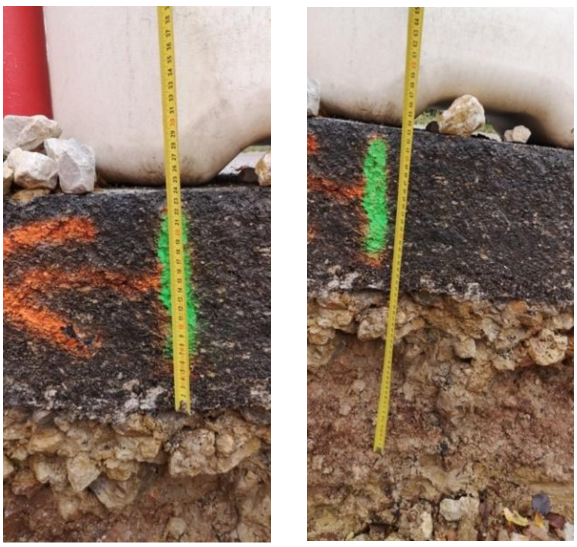


Table 4: Comparison of road construction thicknesses determined by GPR technology and found thicknesses during reconstruction

Bitumen layer thickness (m)			Road construction thickness (m)		
GPR	Real value	Gap	GPR	Real value	Gap
0.22**	0.24	10%	0.49	0.53	9%
0.23	0.25	7%	0.56	0.52	- 9%
0.22	0.24	8%	0.58	0.56	- 4%
0.25	0.26	1%	0.65	0.64	- 3%
0.23	0.27	15%	0.63	0.56	- 10%
0.23	0.25	10%	0.48	0.58	21%

By comparing non-destructive measurements with non-destructive measurements and real measurements (road disrupted during its reconstruction), valuable knowledge has been gained that can again improve the knowledge base associated with the use of modern diagnostic approaches. There is scope not only for R&D progress in the development of such devices (through not enough accuracy in measurements), but also for the introduction of new economic tools that could calculate the risks associated with diagnostic imperfections.

3. CONCLUSION

Existing road infrastructure will increasingly be exposed to increasing traffic load trends. It is the task of administrators to adequately reflect on this situation. The still relatively high rate of unsatisfactory and emergency road sections represents the need to invest relatively high financial volumes. This is due to the time required, which is directly reflected in the pricing of supply companies and the extent of construction and technological work to be carried out. One of the tools to eliminate this situation is to perform quality diagnostics of the road surface and obtain relevant data on the technical condition of its construction. With careful mapping, administrators would be able to capture the need to spend financial resources on individual sections in a state that would not require such extensive costs. Against this background, it is appropriate to exert pressure on improving the quality of road condition monitoring and diagnosis, which in part has to be delegated from managers to R&D organizations such as research institutes or universities concerned with the subject. Lessons learned by the research team of the University of Žilina in the course of experimental measurements presented in this paper can significantly improve the approaches of monitoring the state of transport infrastructure. In combination with this, it is possible to obtain more valuable inputs into degradation models. And it is through these models that the decision-making algorithm can be improved to help transport infrastructure managers manage their intervention more effectively. This will gradually eliminate the frequent inconsistency in managing the assigned assets.

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