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RUTTING PREDICTION MODELS IN HOLISTIC CONCEPT TO SUSTAINABILITY OF SEMI-RIGID PAVEMENTS

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Abstract

Authors have long been guided by the following premise in their research, educational, professional and publishing activities. Components of the Integrated Transport Infrastructure (ITI) of Slovakia, including roads, should be designed, built, managed, maintained, recycled (decomposed) at a reasonable price, in reasonable quality, respecting the relevant requirements of users, residents and sustainable development throughout life cycle. Elements of ITI Slovakia, as important landscape ecological elements, should be designed with respect to aesthetic principles considering the cultural and natural wealth of Slovakia. Slovak technical universities have recently been criticized for teaching 50-years-old curriculum. The authors dare to disagree with the statement and, due to their scientific profile, pre-sent their partial outputs of a holistic approach to the sustainability of transport structures with a priority focus on pavement. In the intentions of the above mentioned, it could perhaps be partly convergently concluded that they learn new things in the field of transport construction, but under the old names.

Keywords:

Pavement;
Holistic;
Surface;
Building Information Modelling;
Management of pavement.

1 Introduction

Slovak technical universities have recently been criticized for teaching 50-years-old curriculum. The authors dare to disagree with the statement and, due to their scientific profile, present their partial outputs of a holistic approach to the sustainability of transport structures with a priority focus on pavement. In the intentions of the above mentioned, it could perhaps be partly convergently concluded that they learn new things in the field of transport construction, but under the old names. Due to the fact that the term holistic is not a commonly used term in the field of transport constructions, the authors dare to give a brief interpretation of this term. Holism (gr. to holon = whole) is a philosophy of wholeness from the 20th century, which is emphasizing the priority of the whole over the part. Holism spread mainly in biology, originated as a reaction to reductionism and analytical procedures of the empirical sciences, and can be briefly characterized by the quotation of Aristotle from his work Metaphysics "The whole is more than the sum of its parts." The term holism was first used by South African politician Jan Smuts in 1926 in the sense of general theory of interpretation and clarification as a program of holistic interpretation of theories. In this paper, the authors try to stimulate a broader discussion on a holistic approach to sustainable preparation, construction and management (SPCAM) of integrated transport infrastructure with a particular focus on pavement. The authors present the application of the subject premise to the issue of pavement and give a specific example of outputs from the field of pavement surface unevenness assessment [1, 2].

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2 Holistic concepts of sustainable preparation, construction and management of pavement

Based on the scientific school of prof. Decky, the authors have long been guided by the following premise in their research, educational, professional and publishing activities. Components of the Integrated Transport Infrastructure (ITI) of Slovakia, including roads, should be designed, built, managed, maintained, recycled (decomposed) at a reasonable price, in reasonable quality, respecting the relevant requirements of users, residents and sustainable development throughout life cycle. Elements of ITI Slovakia, as important landscape ecological elements, should be designed with respect to aesthetic principles considering the cultural and natural wealth of Slovakia. ITI must ensure multimodal, interoperable, safe transport with the lowest possible carbon footprint, aimed at the development and cohesion of regions, tourism, with the maximum economically acceptable minimization of environmental noise, air pollution, traffic-induced vibration and ultimately contributing to citizen satisfaction. According to the authors, the mentioned scientific-educational premise implicitly contains all credible priorities of SPCAM of pavement structures. It is also fully convergent with world trends in the field of crucial pavement components, i.e., pavement serviceability parameters [2, 3], pavement using recycled aggregate [4], noise and particulate matter [5-7] and ultimately in the intentions of EU priorities in the field of Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal [8]. The authors implemented their scientific knowledge into the project Innovative proactive tool for comprehensive pavement management of settlements, Fig.1. The proposed outputs of the project comprehensively addressed all important aspects, such as environmental science, non-invasive pavement network diagnostics, passportization and, ultimately, evaluation of economic benefits of an innovative tool for the road network level as well as the project. In 2015, the authors presented that the integrated schematic approach shown in Fig.1 would not only bring a cost-effective system approach to SC but could significantly contribute with its subsystem outputs to higher civic satisfaction, both at the level of municipalities and regions.

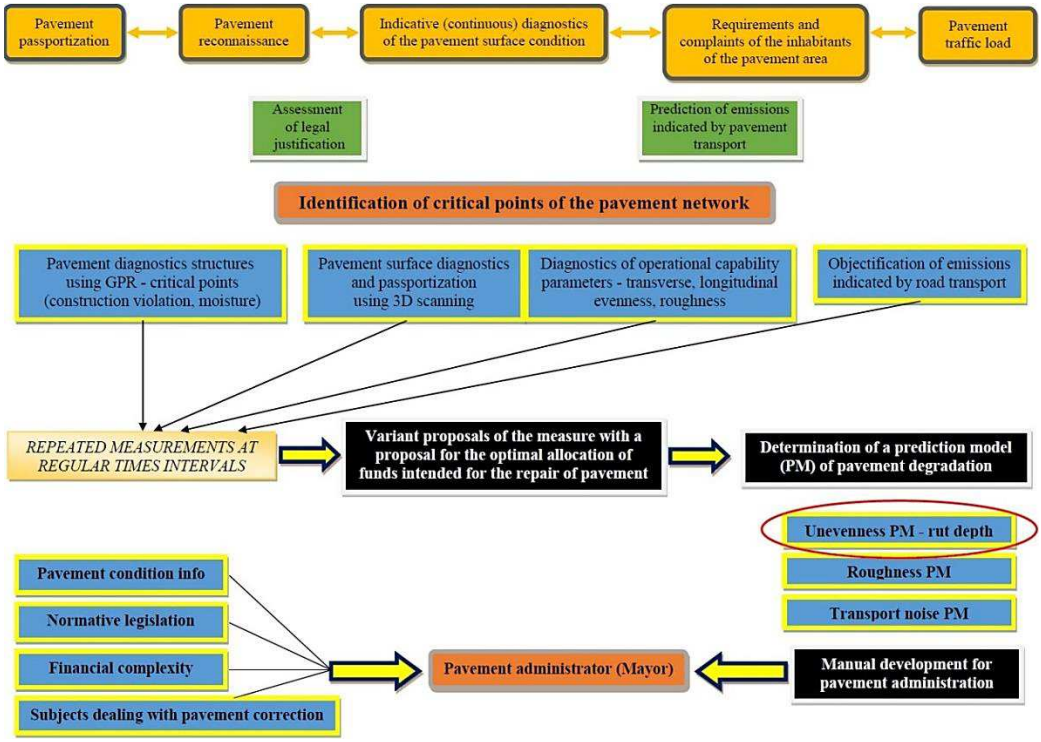


Fig. 1: Conceptual scheme proposed by the authors of Innovative proactive tool for comprehensive pavement management of settlements.

3 Sustainable construction and pavement according to pavement engineering

Kibert [9] laid down the foundation for Sustainable construction (SC) practice, and established SC around resource minimization and reuse, use of renewable and recyclable resources, and minimizing carbon footprint. Vanegas and Pearce [10] presented SC based on resource depletion and degradation, impact on built environment and human health, Braungart and McDonough [11] offered

the cradle to cradle definition, and Pulaski [12] presented a comprehensive approach towards sustainability in construction operation, Mallick and El-Korchi [13]. Sustainable construction tools and standards were first developed for buildings. The first set of assessment/rating concepts and tools in the US were provided by the Green Building System; the origin of these tools can be traced back to UK´s Building Research establishment (BRE) environmental assessment method (BREEAM).

Subsequently other systems were developed:

- Canada: Green Globe,
- Japan: CASBEE (Comprehensive Assessment System for Built Environment Efficiency),
- Singapore: BCA (The Building and Construction Authority) Greenmark,
- China: Green Olympics Building Assessment System (GOBAS),
- Australia: Building greenhouse rating (ABGR),
- India: TERI-GRIHA (Green Rating for Integrated Habitat Assessment),
- India: LEED-India (Leadership in Energy and Environmental Design).

Although differing in scope, the currently agreed common goals of SC are as follows:

1) reduce carbon footprint,
2) ecology and environmental protection,
3) healthy indoor and outdoor environment,
4) water use reduction,
5) energy use efficiency,
6) eliminating environmentally harmful materials,
7) improve resource efficiency,
8) conserve resources (land and raw materials).

Sustainability in transportation cuts across the various divisions and departments that are part of transportation agency. It applies to every stage of decision-making:

- planning,
- design,
- implementation of projects and infrastructure,
- day-to-day operations and maintenance [14].

In the US, there is no federal regulation that explicitly focuses on sustainability - rather it is a collaborative process between the government and the industry. The development of sustainable practises guidelines is further complicated by the fact that there are many agencies that are responsible for transportation infrastructure [14], such as the U.S. Department of Transportation (U.S. DOT), FHWA, Federal Transit Administration (at the National level), state and toll authorities (at state level), and Metropolitan planning organizations, Local public Works and transportation departments, Public transit agencies, Local-level toll authorities (at local level).

Miyatake [15] mentions that one way to work towards Sustainable construction is by changing from the conventional linear process to a cyclical process. This essentially means a significant increase in the recycled materials, renewed and reused resources which is leading to a significant decrease in the consumption of energy and resources.

Miyatake cites examples from the Japanese construction industry:

- using environmentally friendly materials including recycled materials,
- developing a construction system that provides lower carbon-dioxide emission and energy consumption,
- using environmentally clean machinery and equipment,
- minimizing discharge of waste from jobsites,
- reusing/recycling residual materials and minimizing use of tropical timber plywood.

Supporting and accelerating these processes are activities that are carried out in technology development sectors:

- environmental assessment technology,
- coastal water clean-up technology,
- treatment of contaminated soil and hazardous waste,
- water purification and wastewater treatment systems,
- saline water irrigation systems,
- environmental monitoring by remote sensing technology,
- underground water simulation and ground-water dam technology.

The work on developing sustainable pavements first requires defining what are the sustainability requirements. There are several definitions but Miller and Bahia [16] suggests “pavement that minimizes environmental impacts through the reduction of energy consumption, natural resources and

associated emissions while meeting all performance conditions and standards“. New and more sustainable technologies are being developed in asphalt industry, the most noticeable are the:

- Warm Mix Asphalt,
- recycling,
- perpetual pavements,
- permeable pavements.

Soderlund [17] presented a model for sustainability rating system for roadway design. The major areas of concerns for impacts of pavement construction activities have been noted as:

- Site Disturbance,
- Waste Material Generation,
- Emissions and Energy Use and Health of workers.

Several sustainable activities were provided, such as: reuse of materials/recycling, use of waste/by-products and regional materials, and specific examples of assessment criteria/credits.

4 BIM optimal tool for SCAM pavement

Building Information Modelling (BIM), as a method of designing using an object information model, has experienced an extraordinary boom in recent years. Developments in this area have been largely determined by the private sector, where increasing efficiency and minimizing time costs have been one of the main advantages over competitive methods of design based on designing of two-dimensional projections. The public sector has also been very proactive in the BIM initiative.



Fig. 2: Data acquisition equipment for creating 5D BIM models - from left Roadscanner, FWD KUAB, Optech Lynx SG 1 owned by RC UNIZA.

Within the individual local markets, associations were established promoting the benefits of design in BIM, which subsequently promoted these aspects at the level of drafting legislation. As a result of this initiative, many binding regulations have been enforced to stimulate comprehensive development in BIM design.

Currently, the UNIZA Research Centre (RC) operates unique instrumentation for assessment quality of pavement surface, including the preparation of documents for BIM applications [18]:

- Roadscanner - the measuring vehicle has built-in Georadar measuring technology (GPR), a CamLink video recording system connected to a GPS unit, an accelerometer and a laser scanner. In one pass of the vehicle, it is possible to obtain comprehensive information about the pavement and its variable and non-variable parameters,
- FWD KUAB is a non-destructive pavement testing device that uses measured deflection values to determine the bearing capacity of the pavement. It is a point measurement simulating the passage of a truck under a 50 kN load, with deflections in micrometres measured at distances of 0 (centre of load), 30, 45, 60, 90, 120 and 150 cm from the centre of the load,
- Optec Lynx SG 1 is a mobile mapping device based on the reflection of a laser beam from a device (LIDAR). The device uses 2 LIDAR sensors with an accuracy of 5 mm, each with a power of 600 kHz and a range of 360°. The scanning range is up to 250 m, and at 10 % reflectance, the output can be set up to 1.2 million points per second. Vehicle travel speed during data collection can be up to 80 km·h-1.

For this article, it is important to understand that BIM is not just a 3D model of the building itself. BIM is the documentation of a building throughout its entire life cycle, from pre-project preparation to demolition, and therefore its capabilities go far beyond a digital model. According to the authors, BIM represents the optimal tool for sustainable preparation, construction and management (SPCAM) of pavements.

5 BIM optimal tool for SCAM pavement

The behaviour of the pavement during the operation was constitutionally monitored (years 1994 - 2019) by measuring the transverse unevenness of BUS STOP Hurbanova in Žilina and measurements were made at least once a year according to STN EN 13036-7 [19], Fig. 3. According to [19], the measurement was carried out until 2005 with a 2 m stick and after the amendment of standard [19] in 2005 with a 3 m stick. Possible monitored characteristic of pavement transverse unevenness in our case was a depth of ruts. Based on the long-term relevant results obtained was created by degradation model for maximum rut depth, where it was measured throughout the reporting period, Fig. 3.

As it is apparent from the observations made, the problem of the quality of construction of bus and tram stops is still high. In many towns in Slovakia, it is possible to see that the normal asphalt pavement constructions are often in very poor condition severely deformed and therefore are not suitable for public bus stops.

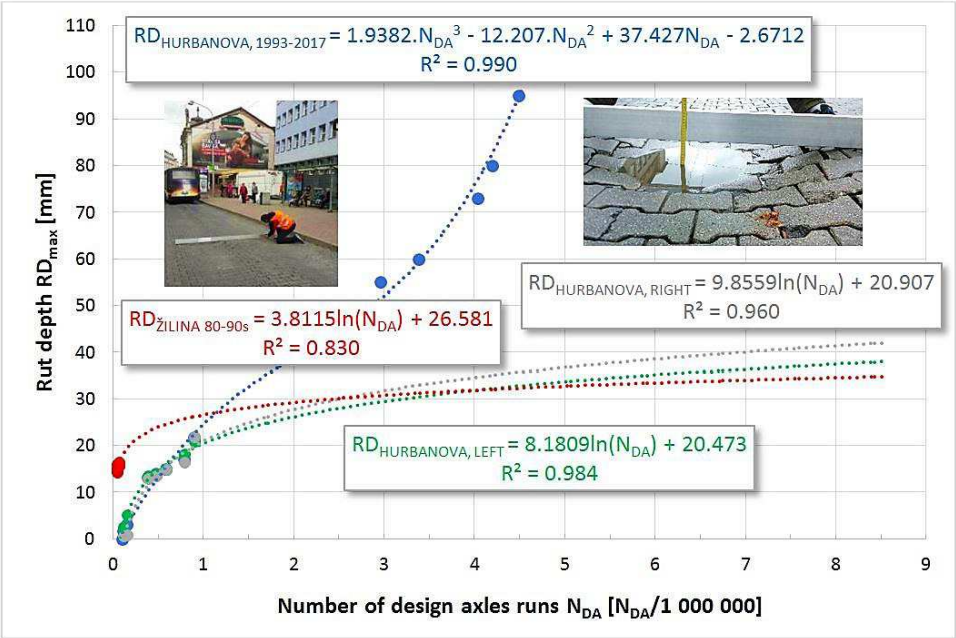


Fig. 3: Comparison of correlation dependences of the pavement BUS STOP rut depth on the design axle number obtained after the $N_{DA}=0.1\times10^6$; $N_{DA}=0.9\times10^6$; $N_{DA}=4.5\times10^6$ (years 1994 - 2019) [2].

In the article were presented results of long-term rut depth measurements performed during 25 years on selected BUS stops which were intended to determine correlation dependences of pavement rut depth on several design axles. However, the found dependencies of rut depth on number of design axles seem to be logarithmic at first (up to 1 million of design axles passes), it was showed that after 3 million of design axle passes the dependencies confirmed the theoretical 3rd degree polynomial correlation function, which is typical for pavements with asphalt layers.

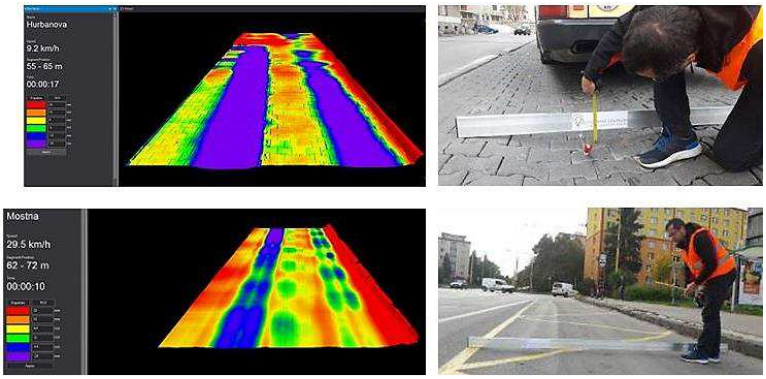


Fig. 4: Results of Dynamic Road Scanner measurements of Bus stop Hurbanova and Mostna in Zilina and standardized measurements according to STN EN 13036-7 [2].

Multi-annual experience suggests that the appropriate type of construction of the bus stop can be a design with a paved cover. As it was shown by realized measurement of these structures and paved construction leads to the formation of permanent deformations but compared to pavements with asphalt wearing course the increment of permanent deformation is slower. Similarly, it can be positively assessed the overall status of the pavement after 5 years of operation with almost a million times passes of design axles, pavement structure doesn't show any significant deficiencies.

6 Conclusion

The authors tried to stimulate a broader discussion on a holistic approach to sustainable preparation, construction and management (SPCAM) of integrated transport infrastructure with a particular focus on a pavement in the middle Europe area. The road pavements should be designed, built, managed, maintained, recycled at a reasonable price, in reasonable quality, respecting the relevant requirements of users, residents and sustainable development throughout the life cycle. Pavements, as important landscape ecological elements, should be designed regarding current climatic change [20, 21], with respect to aesthetic principles considering the cultural and natural wealth of Slovakia. Of the wide range of required credibility inputs of pavement management system [3, 23], specific attention is paid to the degradation model and rut depth development functions from the number of passes of all vehicles, Fig.1.

As part of their previous activities, the authors objectified a degradation model of the development of rut depth from the number of passes of all vehicles according to Fig. 3. Fig. 5 presents the correlation dependences of the rut depth development on the number of passes of all vehicles for 8 long-term monitored sections of the Slovak road administration.

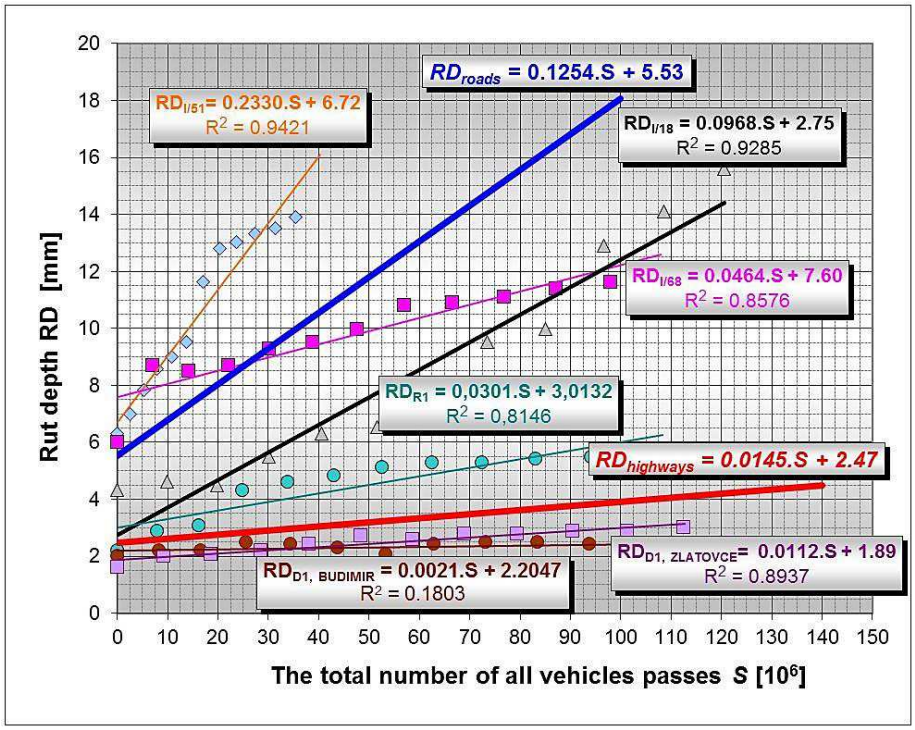


Fig. 5: Correlation dependence of rut depth development on the number of passes of all vehicles in both traffic directions [1].

Fig. 6 shows a recapitulation of the author's correlations depending on the development of rut depth from the number of truck passes.

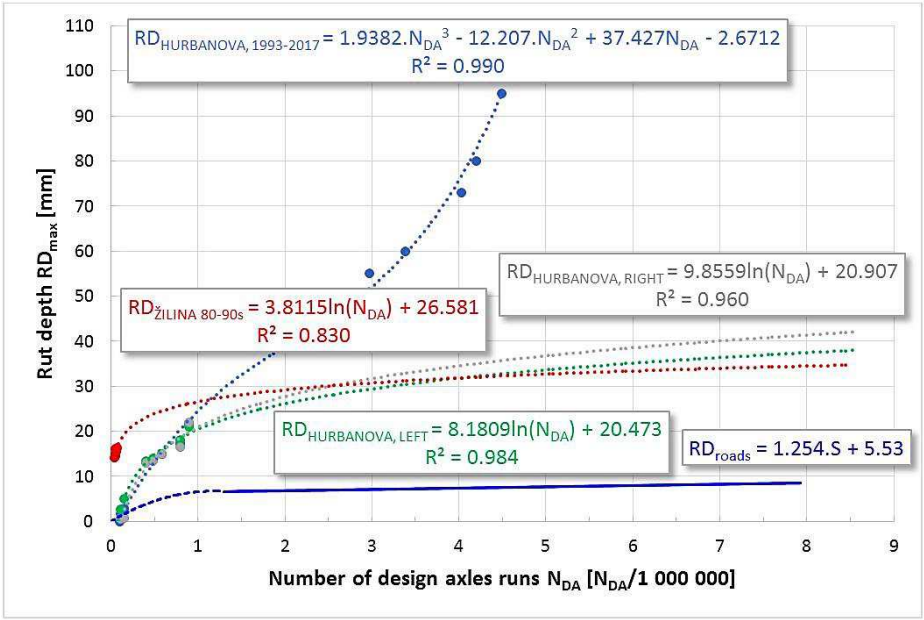


Fig. 6: The author's objectified correlation dependencies of the evolution of RD (Ruth Depth) on the number of truck passes for the semi-rigid pavements [2].

It is also evident from Fig. 6 that the correlation dependencies presented in Fig. 5 represent only the 2nd stage of rut depth development from S. Equations for 2nd stage of rut depth were objectified for long-term monitored sections of roads and highways:

$$RD_{roads} = 0.1254.S + 5.53, \quad (1)$$

$$RD_{highways} = 0.0145.S + 2.47. \quad (2)$$

Therefore, for this type of degradation equation it is necessary to provide additional data on the rut depth status at the beginning of the degradation equations indicate the number of years to be assessed and the method of maintenance.

As it shows in Fig. 7, a 3-stage model of rut depth development from the number of truck passes has been confirmed. Repeated loading, the permanent strain of asphalt mixture can be classified into three stages:

- the primary stage is the migration period in which permanent strain enlarges instantaneously,
- the second stage is the stability period in which the permanent strain increases stably in a linear way and this period constitutes most of the whole process,
- the tertiary stage is the damage period in which the permanent strain increases rapidly until any damage occurs [23], as shown in Fig. 7.

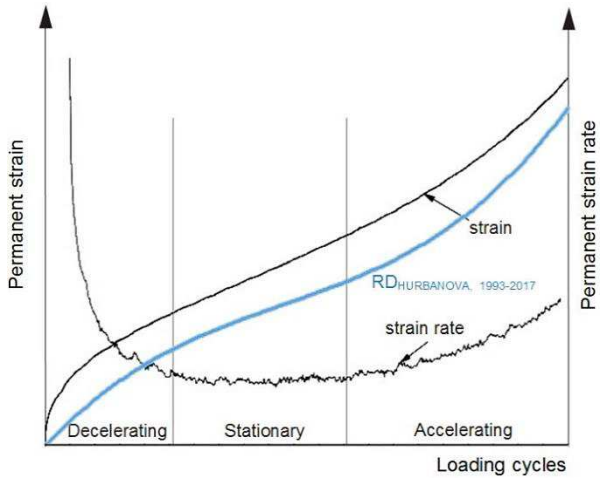


Fig. 7: The development of rut depth according to the empirical semi-logarithmic model [23].

The authors point out the problem of degradation functions created without the "zero states" being known. If the rut depth values are not known from the start of the operation on the monitored section of pavement, incorrect development curves may be objectified. Predictions and real development curves of rut depth development from the number of passes of all vehicles are necessary for the management of pavement and their life cycle [3, 18, 23, 24].

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