

ROAD ASSET MANAGEMENT OPTIMIZATION BASED ON PREDICTIVE PAVEMENT DEGRADATION MODELS

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Abstract

Nowadays, due to the need for efficient road management, we regularly encounter the term asset management. Asset management in practice represents the sum of theoretical and practical knowledge for achieving cost-effective and technically optimal use of assets throughout their life cycle. By road assets we mean all the elements necessary to ensure the functional, safe, and efficient use of the road infrastructure. In addition to roads, road structures, facilities, and technological equipment, assets include legal and regulatory aspects (rules and standards), documentation, databases, and asset management systems. We use asset management at every stage of the roadway life cycle, starting with pavement diagnostics and data collection as well as assessment and degradation modelling. Based on the evaluation of the current situation, it proposes a maintenance and rehabilitation strategy along with the allocation of material, financial, and human resources. By applying asset management within the road management department, we can reduce road management costs, improve the structural and pavement condition of the roadways, increase safety and driving comfort for users, and reduce travel times.

The degradation of pavement properties and behaviour over time is predicted using pavement degradation models. The paper demonstrates the link between the theoretical concept of asset management and its connection to experimental measurement. Specifically, the experimental measurement focuses on the predictive models of changes in pavement surface properties. The experimental measurement also presents specific degradation functions of variable pavement parameters determined at the premises of the University of Žilina, the course of the experiment itself, and its results. The resulting functions are focused on the degradation of the friction coefficient and transverse unevenness parameters of the surface course. The aim of the work was to demonstrate the significance and applicability of the outputs of the experiment in practice and to present their importance for the streamlining of the management of road assets.

Keywords

Pavement asset management, Degradation functions, Transverse unevenness, Friction

1 INTRODUCTION

Road asset management is a complex process ranging from planning and operations to maintenance and rehabilitation of road infrastructure used in the national economy. The application of asset management in a national economic sense has the task of optimally allocating financial resources for the management of roads while maintaining the good structural and technical condition of roads and associated facilities. Poor maintenance strategies and the rapid increase in traffic load with rapidly changing climatic conditions not only result in the rapid degradation of the road surface but also exponentially increase repair and maintenance costs. In selected cases, delayed pavement maintenance leads to pavement structure failures requiring extensive reconstruction, which is economically inefficient in terms of allocating funds for road management [1].

A systematic approach to managing road assets is aimed at maintaining and increasing the lifetime of road infrastructure. It aims to ensure the functionality and safety of roads for end-users throughout the life cycle of each road asset. The planning processes in the initial phase mainly include full-scale data collection and analysis. Data collection includes not only pavement diagnostics and data related to the condition of the road surface but also operational data such as traffic intensity or accident data. The asset management system also includes technical

data recording, proposals for technologies and prices for construction works, analysis of the cost-effectiveness of individual pavement maintenance plans, and, in the last step, the sequencing of pavement repair works. The final ranking of structures for the purpose of efficient management of the road network is influenced by several factors. In general, the most relevant include the importance of the selected road, development priorities, road safety, environmental impact, economic efficiency, and financial assurance [2], [3].

Asset management, whether in the context of roads or other assets, is a systematic and strategic approach to managing and optimizing the life cycle of assets in order to maximize their value and achieve strategic objectives through the application of a variety of methods and practices. Optimization of asset management of surface transportation assets refers to all steps taken to save costs, reduce the need for material or human resources, or increase the efficiency of operations. The benefits of optimization practices are mainly in the form of reducing the life cycle costs of roadways, extending the service life of roadways, increasing road safety, improving traffic flow, and minimizing negative environmental impacts [4], [5], [10].

The research focused on the road condition assessment phase, specifically on predicting the change in pavement surface properties using its own degradation functions. A degradation function is a form of mathematical model describing the dependence of the representative value of a selected parameter on time, or the number of repetitions of the design axle load [6]. The ability to predict the evolution of individual parameters over time is crucial for effective management and optimization of pavement management. Degradation or deterioration of a pavement surface is a process whereby the surface properties of a pavement are gradually altered due to external factors. This process leads to a reduction in the ability of the pavement to fulfil the required functional and performance parameters, which negatively affects its quality, safety, and also increases the costs associated with its use [7], [8]. Pavement degradation is mainly influenced by the traffic load and its increasing tendency, the properties of the individual structural layers, and the quality of construction and climatic conditions [9], [10].

For this reason, research aimed at determining the exact degradation functions of selected variable parameters and at the same time refining the already existing degradation models has been carried out in the laboratory of the Department of Technology and Construction Management at the University of Žilina campus.

2 METHODOLOGY

The experiment was carried out using the cyclic traffic loading simulation device Pavement Tester Type 105–03–01. Fig. 1 shows the device positioned above the experimental pavement. In this case, we are talking about accelerated pavement testing, as the laboratory environment provided constant climatic conditions, and the pavement tester provided data on the exact number of passes of the design axles.

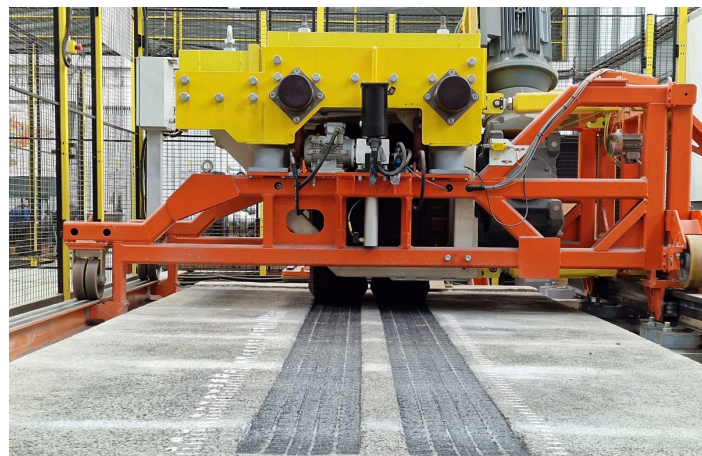


Fig. 1 Pavement Tester Type 105–03–01.

The equipment loaded a section of the test pavement simulating a non-rigid pavement design with a base course of mechanically bound aggregate, shown in Fig. 2. The design represents a Class III roadway, with an expected service life of 2 million passes. Due to the need to simulate the real roadway as accurately as possible, a layer of elastomeric rubber was established between the gravel layer and the concrete laboratory floor to represent the response of the ground embankment due to its equivalent modulus of elasticity.

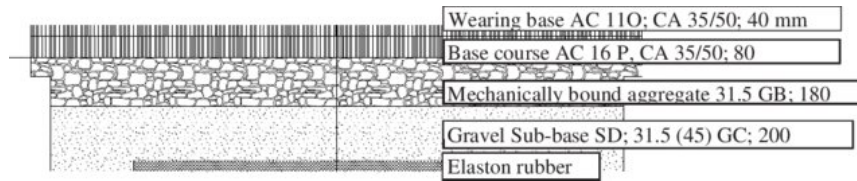


Fig. 2 Composition of the experimental pavement [10].

The measurements were aimed at determining the variable parameters of transverse unevenness and friction of the tested pavement.

Measurement of transverse unevenness parameters

The transverse unevenness of the roadway is characterized by the height change between the actual and the design roadway profile in the transverse direction and is defined by the rut depth.

The measurements were performed with a ZScanner 800 handheld scanner with an accuracy of 0.1 mm and a speed of 25,000 measurements per second, with three cameras and a class II laser. Fig. 3 shows the ZScanner 800 measuring device placed in its case with the hardware. The choice of the equipment was based mainly on its advantage of recording the surface in detail in a coordinate system, with the possibility of tracking the recorded model while the surface was being scanned.



Fig. 3 ZScanner 800 with hardware connection.

Before the measurement, selected parts of the surface were delineated with reflective points around the perimeter and along the axis of the scanned profile to facilitate orientation. At the same time, the road surface was coated with chalk dust to eliminate glare. The scanned 3D profiles were then processed in MATLAB and Microsoft Excel. The processing of the measurement outputs consisted of transforming the scanner outputs (3D profiles) into representative 2D diagrams of the transverse unevenness of the profile. For this reason, for the experiment, an algorithm was developed in the MATLAB software environment for the aforementioned transformation of the profiles and the subsequent readout of the rut depth. The above procedure was carried out at intervals of every 50 thousand passes of the design axle.

To increase the precision and quality control of the measurements, the measurement of the transverse unevenness with a wedge was carried out in parallel, based on the principle of transversely attaching a wooden batten and reading the depth of the unevenness with a wedge with a numerical scale. The second method of control was performed by profile leveling.

From the measured and evaluated values at selected intervals, the degradation functions of the change in the transverse unevenness parameters as a function of the number of passes of the design axles were subsequently developed.

Measurement of friction parameters

The second analyzed variable parameter is the friction parameter reflecting its anti-slip properties and the quality of the road surface, whose unsatisfactory parameters largely affect the safety of vehicle driving. The friction parameters express the friction and interaction of the tire with the road surface.

The method chosen was to determine the friction parameters by measuring the skid friction with a pendulum. The method is classified as an "indirect measurement" method because the road structure is not damaged when the test is performed. A Cooper pendulum was used for the test, which is shown in Fig. 4.



Fig. 4 Cooper pendulum.

The main advantages of this method are the speed of the test, the easy handling of the equipment, and the direct reading of the results. The mechanism of the pendulum is based on the resistance of the rubber foot of the arm in contact with the road surface under test. The rubber pad located at the end of the arm, when the mechanism is released from the horizontal position, determines the longitudinal shear friction read from a scale located on the left side of the device. The resulting shear friction is determined by the distance traveled by the rubber pad after impact with the road surface.

Before the actual measurement, it is important to consider the positioning of the device so that the rubber pad falls centrally in the selected part of the track. The equipment needs to be centered and mounted prior to measurement, adjusting the length of the arm as necessary to accurately fit the rubber pad and wet the road surface. The resulting skid friction parameter of the selected part of the road surface is determined as the arithmetic mean of at least five measured values at one location.

3 RESULTS

Measurement and data analysis resulted in degradation functions for the friction and transverse unevenness parameters, representing the correlation between the design axle pass value and a representative degradation value.

The degradation functions were developed for the measured parameters at intervals of every 50,000 design axle passes. The data and their progression as a function of the number of passes were described by third-order polynomial functions due to the need for the most accurate representation of the actual road surface degradation. The air temperature at the time of measurement was $20\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$.

Degradation function of transverse unevenness

Measurements using a 3D scanner provided detailed information on the surface profile, including precise values of the transverse unevenness degradation. The selected method provided a more exact representation of the depth of the unevenness compared to the manual methods, which were used as control measurement methods.

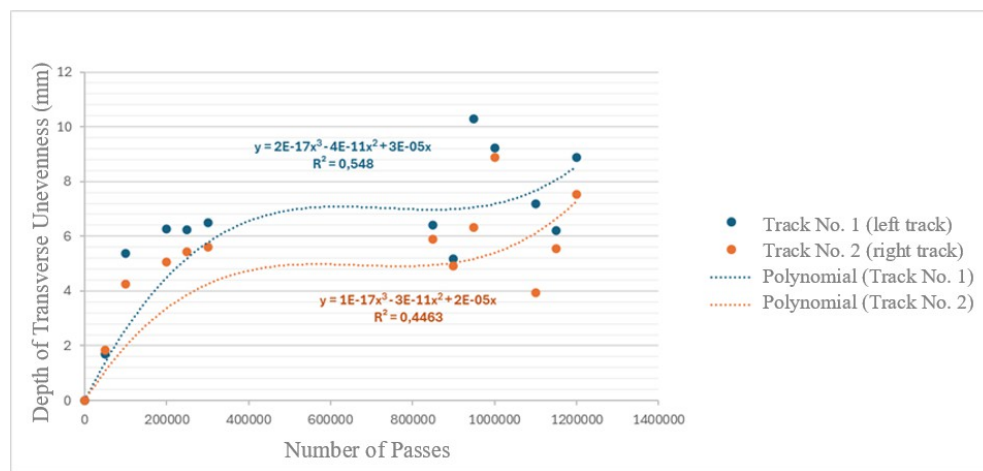


Fig. 5 Degradation function of transverse unevenness.

Fig. 5 shows the evolution of the change in transverse unevenness as a function of the number of passes of the design axle.

The resulting degradation functions of the transverse unevenness determined by the experiment are shown in the following formulas. Formula 1 shows the degradation function of the transverse unevenness in track No. 1 (left track). Formula 2 shows the degradation function of the transverse unevenness in track No. 2 (right track).

$$y = 2 \cdot 10^{-17}x^3 - 4 \cdot 10^{-11}x^2 - 3 \cdot 10^{-5}x \quad (1)$$

$$y = 1 \cdot 10^{-17}x^3 - 3 \cdot 10^{-11}x^2 - 2 \cdot 10^{-5}x \quad (2)$$

Analysis of the data demonstrated that the degradation follows an increasing trend up to approximately 300,000 passes, which may be partly influenced by the compaction of the pavement structural layer material. From this value, the function is largely constant up to 1,000,000 passes, where it starts to take on an upward trend again. From this point onwards, the degradation rate starts to deteriorate faster, which in practice would mean a faster increase in user costs and travel times. From the research, we can assume that the critical point of increase in transverse roughness degradation occurs when the design axle reaches approximately 1,000,000 to 1,100,000 passes.

Parallel measurements using the wooden batten and wedge method demonstrated the accuracy of the measurements and the minimal variation caused by the inaccuracy of the method.

Degradation function of friction

Pendulum measurements were taken at five locations in both roadway footprints. The average value, the parameter PTV, represents the shear resistance of the road surface as determined by the pendulum.

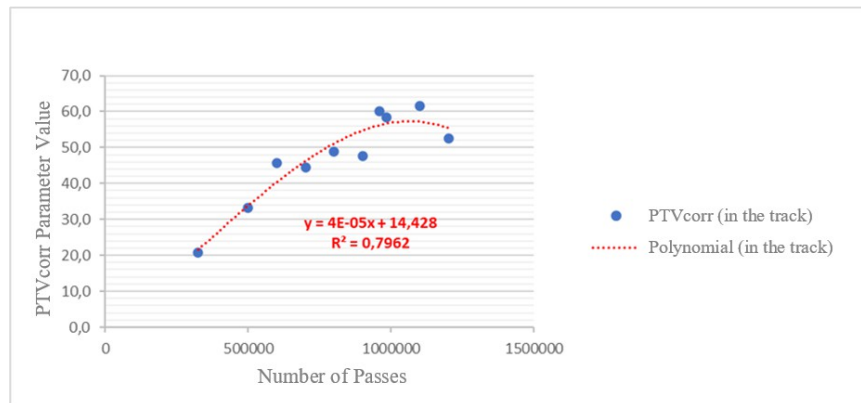


Fig. 6 Degradation function of friction.

Fig. 6 shows the evolution of the change in the friction parameter as a function of the number of passes of the design axle. The resulting friction degradation function is shown in Formula 3.

$$y = 4 \cdot 10^{-5}x - 14,428 \quad (3)$$

The progression of the function alternates between an increasing tendency and a constant one in the pass interval from approximately 600,000 to 1,000,000 passes. The degradation of the parameter in the driving track from the number of passes at 1,100,000 begins to show a significant deterioration of the road friction parameter, which in this case can be referred to as a critical point of change in the tendency of the degradation course.

4 DISCUSSION

The results of the experiment confirmed the importance of degradation functions in the field of pavement asset management. In the analysis of the resulting degradation functions, the need for more detailed monitoring of the evolution of these parameters throughout their lifetime was identified for the prediction of critical moments when the degradation of individual parameters occurs more rapidly. The determination of this moment is important for effective road maintenance planning. The application of the obtained results proves to be beneficial not only from the economic point of view but also from the point of view of increasing traffic safety. Predictive models offer important tools for optimizing maintenance, but the challenge is to integrate them directly into existing road management systems.

At the same time, it has been noticed that changes in the degradation of real pavements are influenced not only by traffic loads but also by environmental and climatic influences, such as changes in temperature and humidity. This fact suggests the need for additional research that could implement these variables in existing pavement surface degradation models.

5 CONCLUSION

The research focuses on the possibilities of optimizing the management of road assets by applying degradation functions to the pavement management system. The application of degradation functions makes it possible to predict the behavior of the pavement during its life cycle. By pavement behavior, we mean the change of its variable parameters as a result of traffic loading or the influence of climatic conditions. Proper prediction of pavement degradation and application of research results will enable managers to optimize the cost of road network reconstruction through efficient maintenance and repair planning. The research determined degradation functions for two types of pavement variable parameters. The degradation functions demonstrate the evolution of degradation and the critical moments of change in their progression, which are particularly important in planning the maintenance and management of road infrastructure. With an appropriate road asset management strategy, we can reduce user costs, improve driving safety, and reduce the cost of maintaining the road network.

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