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Conceptual Framework for Road Pavement Monitoring and Evaluation

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Abstract - For the effective maintenance of roads, appropriate procedures for pavement monitoring and evaluation are required. Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to criteria that define the pavement condition based on which the pavement "health" is perceived, helping decide whether there is the need or not to intervene in the pavement. The present paper presents a conceptual framework for the development of a procedure for PAvement Monitoring and Evaluation (PAME) that is outlined by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis in order to determine the optimum section strategies and priority interventions.

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CONCEPTUAL FRAMEWORK FOR ROAD PAVEMENT MONITORING AND EVALUATION

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Conceptual Framework for Road Pavement Monitoring and Evaluation

Christina Plati [α], Panos Georgiou [Ω], Aggeliki Armeni [β]

Abstract- For the effective maintenance of roads, appropriate procedures for pavement monitoring and evaluation are required. Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to criteria that define the pavement condition based on which the pavement "health" is perceived, helping decide whether there is the need or not to intervene in the pavement. The present paper presents a conceptual framework for the development of a procedure for PAvement Monitoring and Evaluation (PAME) that is outlined by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis in order to determine the optimum section strategies and priority interventions.

Keywords : pavement, non destructive, monitoring, evaluation, criteria.

I. Introduction

In road maintenance activities, the selection and prioritization of appropriate remedial treatments facilitates the development of a projected rolling works program over a given timeframe. Methodologies used are mainly based on engineering-driven criteria based upon road condition data available at the time of the assessment. They include pavement condition assessment, performance prediction and needs analysis, which are three sequential yet interconnected processes (Shekharan et al., 2010). These processes aim to assess the appropriate maintenance and rehabilitation strategies on the basis of given budget constraints, identifying life-cycle cost alternatives and determining the optimum scheduling for pavement maintenance and rehabilitation interventions in terms of pavement preservation. Preserving pavements in an appropriate manner, extends their service life, and most importantly improves users' safety and saves public resources (FHWA, 2003; FHWA, 2006). and evaluation, which are important in many areas of pavement engineering, especially in the case of Long Life Pavements (LLP) (Loizos, 2006). Non Destructive Testing (NDT) has played a major role in pavement condition monitoring and evaluation accomplishing a continuous and quick collection of pavement data. The analysis of this data can lead to indicators related to trigger values (criteria) that define the pavement condition, based on which the pavement "health" is perceived, helping decide whether there is the need or not for pavement intervention. This definition appoints required management activities for preserving pavements in favor not only of the involved highway/road agencies but also users' satisfaction.

In order to support effectively the implementation of pavement management activities, often there is the need to apply a framework for pavement monitoring and evaluation that agencies can adapt depending on the situation. For this purpose the present research concerns a conceptual framework for the development of a practical procedure for PAvement Monitoring and Evaluation (PAME) that can be described by four basic pillars: NDT data, periodic monitoring, reliable analysis methods and weighted evaluation criteria. The PAME procedure is implemented on a project level basis along an approximately 80 km highway using individual data i.e. traffic (ESALs), layers thickness, deflections and roughness in order to determine the optimum section strategies and priority interventions. Thickness data is determined using the Ground Penetrating Radar (GPR) technique (Al-Qadi et al., 2005), deflections are recorded using Falling Weight Deflectometer (FWD) testing (Aalavi et al., 2008) and roughness data collection is accomplished utilizing a highway inertial profiler (Perera & Kohn, 2002).

The implementation of the developed procedure to support pavement management activities demonstrates multiple advantages that include its simplicity in application, economic benefits and familiarity. It is representative of circumstance where limited resources and minimal information is available. The present paper demonstrates the implementation of the proposed procedure and related results.

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II. Developed procedure

a) Required data

The main objective of the developed procedure is the periodic evaluation of both the structural and functional condition of an existing pavement. Based on this, the pavement performance affected by environmental changes and the accumulation of traffic loads can be predicted. Thus, an accurate and reasonable evaluation is important, in order, to increase the pavement service life through adequate rehabilitation. For this purpose, various data needs to be collected taking into consideration that "good" data is extremely important in providing effective pavement management. For the structural pavement evaluation, the minimum individual data required includes traffic information, pavement layer thicknesses and pavement deflection records. For the pavement functional evaluation, it is necessary to collect roughness data that best reflects the public's perception of the overall condition of the pavement section. Functional evaluation may, of course, benefit from additional data, including rutting measurements or surface distress records to support pavement management activities; roughness data, however, is considered as the minimum required data, addressing the simplicity of the developed procedure.

All necessary pavement data is gathered using NDT techniques. GPR (ASTM, 2010) allows the acquisition of accurate, continuous pavement layer thicknesses data. The GPR system consists of an antenna unit, a transmition/reception unit, a control unit and a storage/display unit. The antenna unit can be a single antenna that transmits and receives radar signals or two separate antennas one for transmission and one for reception. In both cases the antennas must be lightweight and manoeuvrable so that they can be easily positioned over the area under investigation. The transmition/reception unit consists of a transmitter for signal generation, a receiver for signal detection and timing electronics for synchronizing the transmitter and the receiver. The control unit is the operator interface that controls the overall operation of the GPR system and sends the received data to the data storage and display unit.

Utilizing the GPR techniques 'black' spots can be identified and these locations can be further examined with FWD testing or coring. In addition, the GPR technique is able to provide thickness data to be used in the pavement mechanistic analysis models incorporated within the FWD technique to addresses the evaluation of the physical properties of the pavement structure.

FWD generates a load pulse by dropping a weight on a damped spring system mounted on a loading plate. The falling mass, the spring system (rubber buffers) and drop height can each be adjusted to achieve the desired impact loading on the pavement. Vertical deflection peaks are measured at the centre of the loading plate and at multiple radial positions by a series of deflection sensors. The impulse load acting on the pavement causes a "wave front" of recoverable deformations, or deflections, that spread out from the centre of the load. Both the peak impulse load (force) and maximum vertical deflections of the "wave front" are measured at multiple radial distances from the load centre. These deflections, considered as a function of the applied impulse load, provide an indication of the structural strength of the pavement. Taking into account available traffic information and considering the GPR thicknesses, FWD deflections are analyzed to estimate the pavement bearing capacity, to determine the necessity for repairs.

For roughness data collection, high speed inertial profilers, which are the most technologically advanced and most widely used systems, are incorporated into the developed procedure. These systems are able to record the characteristics of the pavement surface profile at regular traffic speeds using accelerometers and sensors (lasers), which measure the vertical distance between the accelerometer and the surface. Profilers usually have a beam as a basic unit that has integrated electronic laser sensors and accelerometers. The beam is able to be mounted on the front or rear of a suitably modified vehicle, to provide a planar surface for the installation of the sensors. The profiler scans the surface and the measured parameters are processed and analyzed, in order to produce a longitudinal surface profile of the surveyed pavement and determine the International Roughness Index (IRI) (Hajek et al., 1998; Perera & Kohn, 2002).

In summarization the proposed procedure for pavement monitoring and evaluation involves both the pavement structural capacity and user-related roughness factors to determine the optimum section strategies and priority interventions in an optimal way.

b) Setting pavement monitoring and evaluation parameters

In order to describe the developed procedure for pavement monitoring and evaluation it is essential to address two sub-procedures related to the structural and functional condition of the investigated pavement(s). In addition, trigger values (criteria) to indicate when detailed evaluation at project level is needed are of major importance. These trigger values are based on individual indicators keeping in mind that a detailed evaluation should be triggered in time for optimum maintenance (Fig. 1) (Thom, 2008).

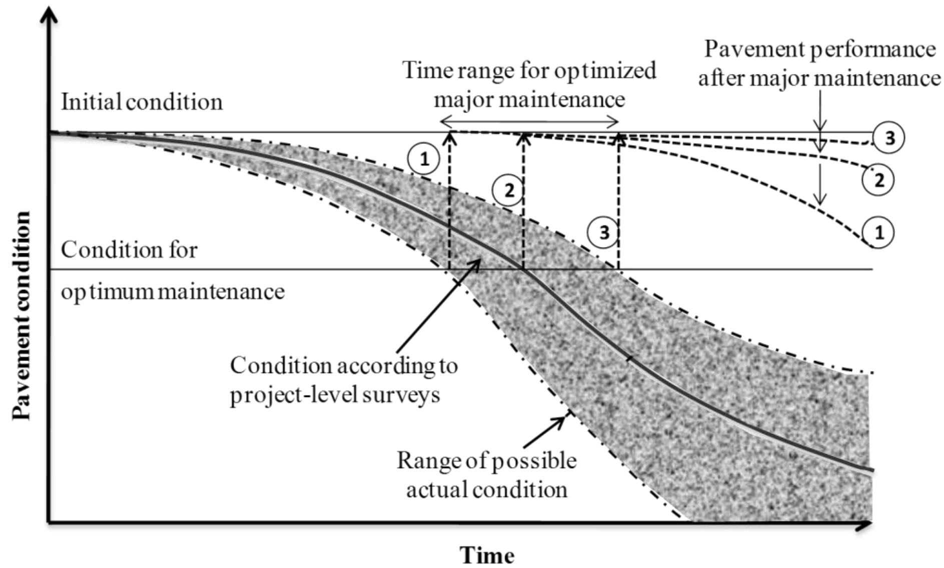

Fig. 1. Concept for pavement maintenance.

Investigation of the structural condition of the pavement may be performed, based on guidelines (COST-336, 1998). Initially, the section under investigation is divided into homogeneous subsections, based on pavement layer thicknesses, traffic and deflection data. The final segmentation of the section is a combination of the intermediate divisions (Fig. 2).

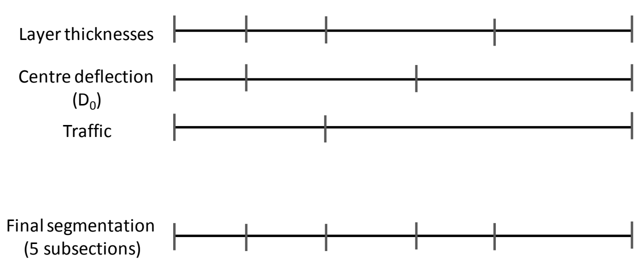

Fig.2. Road section segmentation.

For the section division based on deflection data, an internationally used index (D_0 index) derived from FWD measurements is utilized (COST-336, 1998; Hakim et al., 2002). The D_0 index is based on the maximum center deflection measured by the FWD and represents the overall structural condition of a pavement. For the estimation of this index, the measured deflection should be normalized to the target test load and reference temperature (usually 20^o C) using suitable international factors (COST-336, 1998). Normalization is required, as the mechanical characteristics and behavior of the asphalt mixes are significantly influenced by temperature and deflections are dependent on the imparted load.

In order to divide the section into homogeneous subsections based on the three parameters mentioned above, multiple statistical techniques may be employed. The cumulative sum (Cum Sum) method is one such technique. The method requires the plot of the cumulative sums of the deviations from the mean of a parameter and indicated homogeneity when the slope of the line connecting all cumulative sum values changes. However the difference between two adjacent sections may not be significant and the statistical difference of adjacent sections can be checked with the T-test. For each subsection, the number of measurements, the average, the median and variance are calculated. By estimating the weighted variance of two adjacent subsections, their homogeneity can be determined.

After the final segmentation of the main section into homogeneous subsections, an evaluation of the structural condition of each individual uniform subsection can be performed, utilizing international experience and practice (Brunton et al., 1992; COST-336, 1998; Hakim et al., 2002). Among these procedures, it is believed that by setting the 85th percentile of the D_0 values (only 15% of the values are higher) as representative of the in subject subsection we are able to achieve a more objective design analysis for reinforcement (i.e. overlay thickness). Road authorities may, of course, perform the analysis for higher percentile values, but are not advised to use lower values.

The reinforcement design results (overlay needs) are followed by the longitudinal profile evaluation of the pavement surfaces for each subsection, based on statistical analysis of the measured IRI values, which specifies the users' perception of ride quality. IRI is a widely used and well established roughness index and is considered to be a good indicator of pavement condition in regards to road roughness (Sayers et al., 1986). IRI is accepted as a key decision criterion for the selection of deficient roads and is also accepted as an index for quality control purposes in new construction (Ong et al., 2010).

Three criteria are established, based on three critical IRI values for particular characteristic variables and confidence levels (i.e. IRI_{cr1}, IRI_{cr2}, IRI_{cr3}). It should be mentioned that the characteristic critical values are dependent on the road class classification, as defined by the traffic level (i.e. Average Annual Daily Traffic, % trucks, ESALs). For the purpose of the present evaluation the IRI critical values address highway specifications (Table 1). The statistical analysis determines the theoretical distribution function that best fits the distribution of the obtained IRI data and the calculation of the characteristic variable values at the relevant confidence levels (i.e. IRI_{85}, IRI_{95}, IRI_{100}) (Table 2).

Characteristic base variables		Recommended values and confidence levels	
Symbol	Definition	Value	Percentile
IRI_{cr1}	Characteristic acceptability limit value	1.1	85%
IRI_{cr2}	Upper limit value of a confidence interval	1.8	95%
IRI_{cr3}	Fit for use – limit value	2.5	100%

Table 1. Characteristic variables, suggested values and confidence levels.

Criteria for longitudinal roughness evaluation	Condition	Confidence level
Criterion 1	$IRI_{85} \leq IRI_{cr1}$	85%
Criterion 2	$IRI_{95} \leq IRI_{cr2}$	95%
Criterion 3	$IRI_{100} = IRI_{cr3}$	100%

Table 2. Criteria for longitudinal roughness evaluation

Through the three criteria above, the required interventions can be determined. More precisely, there are three types of evaluation outcomes (Fig. 3), the first corresponding to no required intervention and other two signifying warning procedures of varying severity (1st LEVEL and 2nd LEVEL).

Functional evaluation, as illustrated in Fig. 3, follows the pavement structural evaluation. If the structural evaluation indicated no need for intervention, then functional evaluation is performed immediately. In the circumstances where structural intervention is required, the roughness profile evaluation is to be performed after the implementation of the required intervention.

For sections under investigation that are both structurally adequate and fulfil the roughness evaluation, the PAME procedure is completed. For all other sections, maintenance treatments to improve the ride quality are suggested, with the roughness evaluation following the implementation of these interventions.

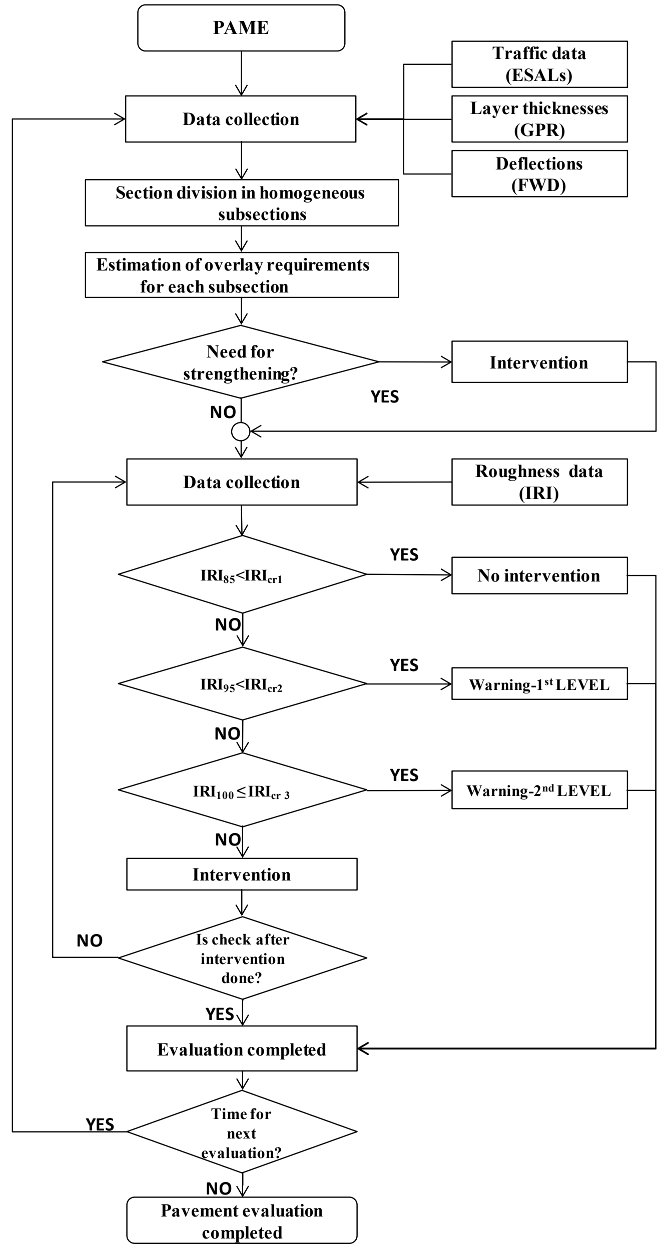

Fig.3. Flowchart of PAvement Monitoring and Evaluation (PAME) procedure.

The proposed procedure is to be periodically repeated for future pavement evaluation in order to support pavement management activities.

III. Implementation

a) Test site

A pilot implementation of the PAME procedure was performed on a highway road section, in order to verify the applicability of the proposed methodology. Both NDT data (i.e. deflection, layer thicknesses and roughness) and traffic information along the heavily trafficked flexible pavement were collected and further analyzed for this purpose. NDT testing using the Laboratory of Highway Engineering of National

Technical University (NTUA) equipment (Fig. 4) was undertaken along the outer traffic lane, as this lane is subjected to the majority of truck traffic and thus exhibits more load-associated distress in comparison with other traffic lanes.

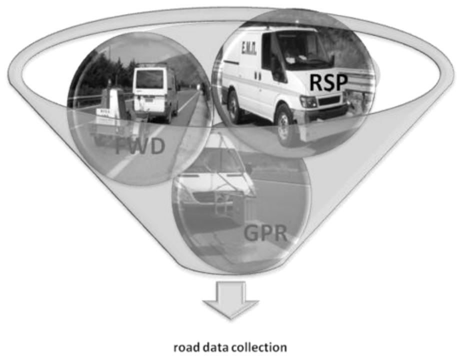

Fig.4. NDT systems used for data collection.

FWD (Dynatest, 2001) measurements were performed at a 200m spacing in the right wheel path of the lane, while the GPR (RoadScanners, 2001) records were continuous along the entire length of the lane. During the FWD testing, the in-situ pavement temperatures and air temperatures were recorded for analysis purposes. Finally, roughness data was recorded using a Road Surface Profiler (RSP) (Dynatest, 2007).

IV. Data Analysis and Results

Structural evaluation of the highway pavements condition followed the segmentation of the road section into homogeneous subsections, based on approximately uniform pavement structure and bearing capacity. The final segmentation is based on the division of the main section into subsections according to the normalized deflection values (D_0 index), asphalt layer thickness and traffic using a suitable statistical technique (i.e. Cum Sum method).

Fig. 5 illustrates the division of the road section based on the asphalt concrete layer thicknesses into (eight) subsections, based on the statistical values (si) derived from the implementation of the Cum Sum method.

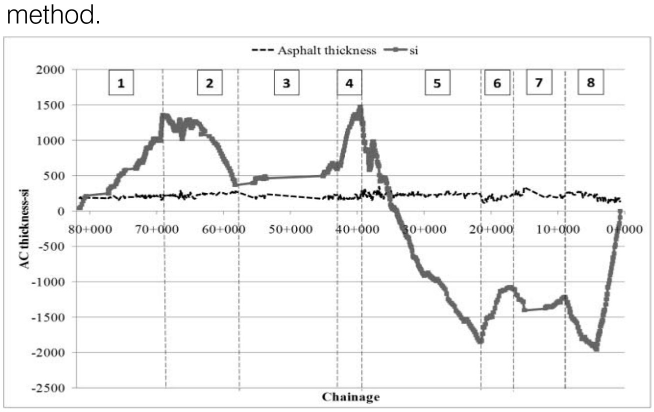

Fig.5. Segmentation of road section based on AC layer thickness.

The implementation of the Cum Sum method according to the D_0 index and the traffic leads to the final segmentation of the road section into nine uniform subsections (SS_1-SS_9), illustrated in Fig. 6.

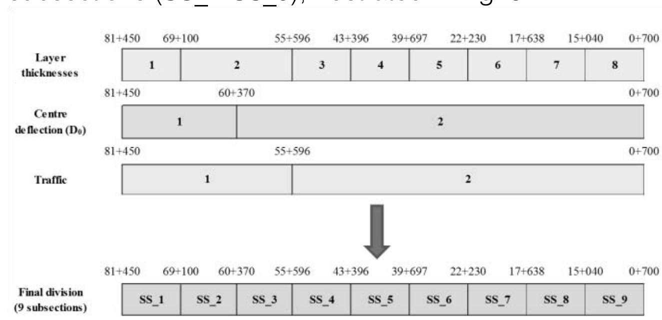

Fig.6. Final road segmentation based on AC layer thicknesses, D_0 index and traffic.

After defining the homogeneous subsections, a structural evaluation analysis is conducted, in order to assess the in situ pavement layer properties (i.e. backcalculated moduli). This information is subsequently utilized to determine the bearing capacity and calculate the overlay requirements for a 20-year design period.

Structural analysis results (Fig. 7) indicate that seven out of nine subsections appear to be structurally adequate, with the two remaining (SS_2 and SS_8) sections in need of structurally reinforcement.

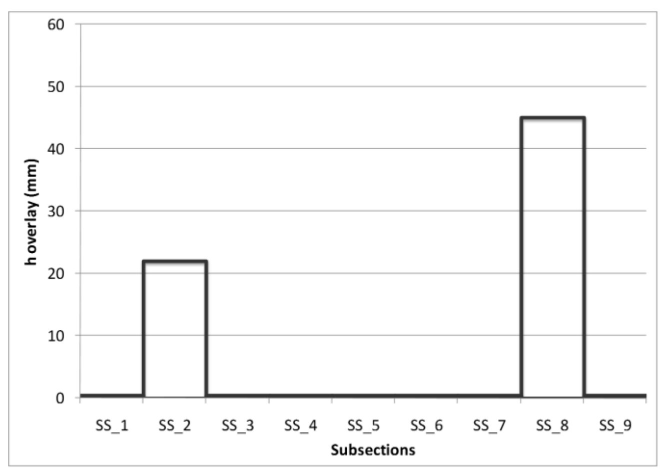

Fig.7. Overlay requirements per subsection (SS).

After the structural evaluation, a longitudinal profile evaluation of the pavement surface along each subsection is conducted, only after the required, if necessary, intervention measures are implemented. The functional evaluation is based on statistical analysis of the measured IRI. Within the scope of the current application, for single IRI index values, a 10 meter long representative longitudinal road segment was adopted. By analyzing the distribution of the relative frequencies of the measured IRI values for the subsections SS_1-

SS_9, the probability density function type log-normal distribution showed the best approximation, according to Kolmogorov-Smirnov test results (Fig. 8). The theoretical distribution function that best fits the distribution of the obtained IRI data is then used to calculate the characteristic variable values at the recommended confidence levels in order to evaluate the recommended criteria (Table 3).

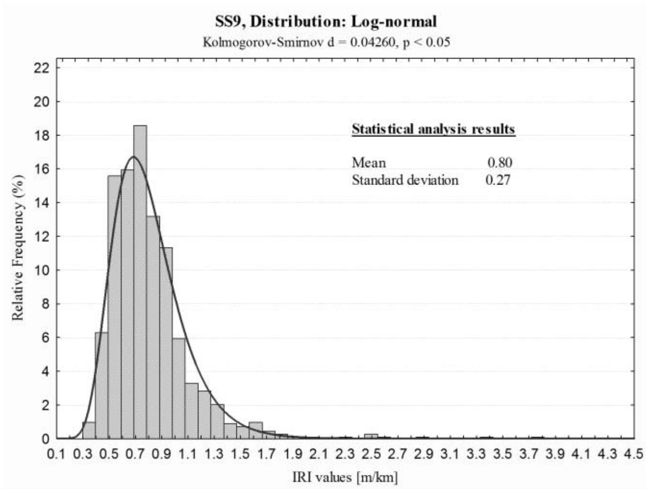

Fig.8. Best fit probability distribution function.

Motorway Subsections	Confidence levels and characteristic variable values								
	85%			95%			100%		
	IRI_{85}	IRI_{cr1}	Eval.	IRI_{95}	IRI_{cr2}	Eval.	IRI_{100}	IRI_{cr3}	Eval.
SS1	1.0	1.1	✓	1.1	1.8	✓	2.5	2.5	✓
SS2	0.8	1.1	✓	0.9	1.8	✓	2.5	2.5	✓
SS3	0.7	1.1	✓	0.7	1.8	✓	2.5	2.5	✓
SS4	1.0	1.1	✓	1.2	1.8	✓	2.5	2.5	✓
SS5	0.9	1.1	✓	1.0	1.8	✓	2.5	2.5	✓
SS6	0.9	1.1	✓	1.0	1.8	✓	2.5	2.5	✓
SS7	0.9	1.1	✓	1.1	1.8	✓	2.5	2.5	✓
SS8	0.9	1.1	✓	1.0	1.8	✓	2.5	2.5	✓
SS9	1.1	1.1	✓	1.2	1.8	✓	2.5	2.5	✓

Table 3. Longitudinal roughness evaluation results

The results of the subsection's functional evaluation indicate that the pavement condition is adequate and pavement intervention is not required. Based on the above, the proposed PAME procedure is concluded.

V. Conclusions

The PAME procedure developed in the present work is a useful procedure to assist in pavement management activities on a project level basis, through the determination of optimum section strategies and priority interventions, especially in incidences where data availability/requirements are limited. The main requirement for the PAME method is the collection of NDT thickness, deflection and roughness data, which is to be properly analyzed and evaluated based on weighted criteria, following a strict pavement monitoring program.

Apart from rural roads or highways such as the one considered in the present work, the PAME procedure could be used for urban roadways or other road classifications. The criteria, particularly the functional criteria, will change depending on the road type, as the desired IRI performance level would be different dependent on road classification. In any case the proposed procedure is fairly straightforward in its implementation and the data feeding the evaluation is objective, in contrast with many pavement condition collection methods, that can be very subjective, and dependent on personnel collecting or analyzing the data.

The PAME procedure can provide the road owners/operators with a simple and practical tool to support pavement management activities. The procedure ensures pavement agencies a cost effective use of their constrained resources. Moreover, the proposed methodology has the ability to be customized according to the road owners' requirements and the corresponding intervention strategies.

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