Assessment of Road Pavement Condition, Based on the Combined Concept of Chance, Change and Entropy

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Abstract: - This paper presents a new methodology for the assessment of road pavement condition, based on three powerful concepts, aimed to accommodate the uncertainty caused by the complex interrelationships, material defects, structural deficiencies, human errors, and ambient fluctuations characterizing the pavement systems. These very useful concepts, selected with the aim, to approach, in a new comprehensive manner, the difficult task of assessment of road pavement condition are as follows: the concept of chance, expressed in terms of probabilities and reliability; the concept of change, expressed in terms of dynamics, e.g. of change of the pavement condition in time; the concept of entropy, expressed in terms of differences in pavement system's entropy, occurred in time, as an appropriate quantitative parameter, measuring the degree of uncertainty of a pavement to meet its specific structural, surface and traffic safety requirements.
Key-Words: - pavement condition, chance, probability, change, dynamics, entropy

1 Background

There is a growing awareness of the road maintenance problem in the actual world. Many countries are incurring extremely high costs because of inadequate maintenance of their road network. Lack of effective maintenance is leading to the need for premature rehabilitation of their roads and is causing high costs for vehicle operation, for industry and for agriculture. In most countries the maintenance budget is inadequate and consequently, road administrations have to spend their budgets effectively and in such a way as to achieve the best value for the money. However, constraints of available resources make it necessary to set priorities for budget allocation, and these are needed at all levels in the hierarchy, from national to local level. That's why the accurate assessment of the road condition, in order to establish the maintenance needs and to set such priorities, is very important. Our research [1] has been oriented towards the development of a method for the quantitative evaluation of the road condition, by converting the various measured parameters, such as deflections, roughness, skidding resistance, rutting and distress index, etc., each of them being expressed in specific units, into a unique, integrating parameter, capable of expressing more precisely, the global road condition. This paper presents a new methodology for the assessment of road pavement condition, based on three powerful concepts, aimed to accommodate the uncertainty caused by the complex interrelationships, material defects, structural deficiencies, human errors, and ambient fluctuations characterizing the pavement systems. These very useful concepts, selected with the aim, to approach, in a new comprehensive manner, the difficult task of assessment of road pavement condition are as follows:

- The concept of CHANCE, expressed in terms of probabilities and reliability;
- The concept of CHANGE, expressed in terms of dynamics, e.g. of change of the pavement condition in time;
- the concept of ENTROPY, expressed in terms of differences in pavement system's entropy, occurred in time, as an appropriate quantitative parameter, measuring the degree of uncertainty of a pavement to meet its specific structural, surface and traffic safety requirements.

The advantage of this new approach, in comparison with the existing ones, consists mainly in the elimination of the numerous weighing coefficients, empirically determined and widely used in the old methods. Also, the new method [2] uses simple dynamic graphical representations of the specific road conditions. According the degree of complexity involved in the analyses of the road pavement condition, these dynamic graphical representation, derived from the well known concept of change, can be developed under the form of diagrams (e.g. for the evaluation of the road pavement condition of a large road network),trigrams, tetra grams or even hexagrams (e.g. for the evaluation of the road pavement condition at a local, regional level, where the decisions taken have to be more specific, in terms of the maintenance works necessary to perform, in order to bring the pavements to the technical conditions required by the environmental and traffic conditions). According this new approach, to any of the possible configuration expressing a specific road pavement condition, existing at a given moment during its design life, it is associated an identification number, determined in terms of topological entropy, this number being very useful, first for the identification of the real case encountered in practice and second, for the establishing of the limits of priority classes for the rehabilitation works. Any line in these diagrams, trigrams or hexagrams, represents a specific road pavement condition, such as bearing capacity of the pavement structure, roughness, skidding resistance, rutting, etc., any of these conditions being expressed in terms of entropy, as sole criterion to rank the relative uncertainty of the pavement to meet the specified requirements.

This global approach, has been possible to be undertaken, due to the continuous progress of the scientific knowledge of the road pavement behavior, registered in the last years [2], and with the advent of the last developments in the field of modeling natural systems [3], entropy optimization [4] etc.

2. Principles of modeling natural systems applied to the road pavements

Let's consider S as a given road pavement structure , which usually has a finite number of sets of abstract space states W, characterizing its distinct physical states, defined as follows:

$$W = \{w1, w2, w3,...\} \qquad (2.1.)$$

In accordance with the theory of the modeling of the natural systems (Casti,1989), an observable of S is a rule f associating a real number with each w belonging to S , and this could be written as follows:

$$f : W - R \qquad (2.2.)$$

where R is the multitude of the real numbers.

Let assume that in a particular case, from the simplest point of view concerning its bearing capacity, a road pavement structure S is characterized by a set W of four abstract states: w1, w2, w3 and w4, defined as follows:

w1 - the difference between the specific probability values (the probability level, p1, for which the measured bearing capacity will have to meet the technical specifications required for that pavement, and the minimum probability value, characterizing its complete failure, p0=0), for which the maintenance organization has to do nothing, concerning the improving the existing bearing capacity of the pavement;

w2 - the difference between the specific probability values, defined as for the previous state, for which some maintenance works, such as asphalt surface treatments, has to be performed by the maintenance organization, in order to preserve the existent bearing capacity of the pavement;

w3 - the difference between the specific probabilities, defined as for the previous states, for which rehabilitation works, such as construction of asphalt or concrete overlays, has to be performed by the maintenance organization, in order to improve the existing bearing capacity of the pavement;

w4 - the difference between the specific probabilities, defined as for the previous states, for which, the maintenance organization has to decide and perform the complete reconstruction of the existing pavement, in order to bring it to the technical parameters, required by the specific traffic and environmental conditions;

In this particular case we may define the observable of the system S, f1: W - R , by the rule:

f1(w) = difference between the specific probabilities

or f(wi)=pi-p0

where i=1,2,3,4

If, for example, we consider the specific probability levels: p1=0.96; p2=0.76; p3=0.56 and p4=0.37, the set W of observable f1(w) will be as follows:

f1(w1)=p1-p0=0.96

f1(w2)=p2-p0=0.76

f1(w3)=p3-p0=0.56

f1(w4)=p4-p0=0.37

One may observed, that the system S, can also be described by the observable f2: W - R, with a different rule:

f2(w)=difference between the specific risks of failure of road pavement, or:

f2(wi)=qi-q0

in the particular case considered above, the set W of observable f2(w) being as follows:

f2(w1)=q1-q0=0.04-1.00=-0.96

f2(w2)=q2-q0=0.024-1.00=-0.76

f2(w3)=q3-q0=0.44-1.00=-0.56

f2(w4)=q4-q0=0.63-1.00=-0.37

The system S can also be described by the set W of observable f3 : W - S, by a rule involving the difference between its specific entropies, as follows:

f3(wi)=-pi*log pi - (-p0*log p0)

In our particular case the set W of the observable f3(w), should be:

f3(w1)= -p1*log p1- (-p0*log p0) =0.056537

f3(w2)= -p2*log p2- (-p0*log p0) =0.300905

f3(w3)=- p3*log p3- (-p0*log p0) =0.468440

f3(w4)= -p4*log p4- (-p0*log p0) =0.530729

Let consider again these observables, defined as above:

f1(w1)=0.96 f2(w1)=-0.96 f3(w1)=0.055537

f1(w2)=0.76 f2(w2)=-0.76 f3(w2)=0.300905

f1(w3)=0.56 f2(w3)=-0.56 f3(w3)=0.46488

f1(w4)=0.37 f2(w4)=-0.37 f3(w4)=0.530729

The question is, which of these observables (f1, f2, f3, ..., fn) gives us the possibility to see more of the system S, and note also the linkage relationships between the observables f1, f2 and f3, these relationships being, as follows:

f1(wi)=-f2(wi)

f3(wi)=-f1(wi)*(log f1(wi))/log2

f1(wi)=-f3(wi)/((log f1(wi))/log2)

f2(wi)= f3(wi)/((log f1(wi))/log2)

One may observe, that although the observable f2 alone, contains less information about the system S, than the observables f1 or f3 , this lack of information can be compensate for if we know the linkage relations, mentioned above. But this is just an example. Generally speaking, in order to "see" the complete system S, we would need an infinite number of observables fi : W - R, so we can conclude finally that the complete system S is described by W and the entire set of observables F = {fi}. For practical reasons, in the particular case of the road pavement system, it's inconvenient to work with such large set of observables, so we have to just throw most of them away and to focus our attention on a proper subset of F, this subset being in fact, an abstraction of S. Thus, the real problem in our particular case is to find a good abstraction, more useful and practical one, and in order to find it we can use different techniques, even mathematical tricks and subterfuges, all these aimed at finding the best abstraction, capable to describe more completely the road pavement condition. So, finally, we may conclude that a specific road pavement condition consists of an abstract state space W, together with a finite set of observables:

fi : W - R, i=1, 2, 3, ...,m

Symbolically, our road pavement, considered as a natural system S, can be written as follows:

S = {W, f1, f2, ...,fm} (2.3.)

the observables {f1, f2, ...,fm}, providing the raw data by which we finally, can see its global condition.

The set of relationships linking these observables forms the equation of state for a specific road pavement, and formally it can be written as follows:

Qi(f1, f2,...,fm) = 0 i=1, 2, ...,m (2.4.)

In our study we shall follow, intuitively this general and abstract approach, each of the observables f1, f2, ...,fm, aiming to describe a particular road pavement condition, in terms of relative uncertainty (entropy).

3 The concept of chance

Both definitions of the concept of chance, e.g. the definition based on subjective probability and that one based on relative frequency, are more useful in road pavement engineering. The relative frequency, defines the probability of an outcome event E, P(E), as the ratio between the number n of the outcomes favorable to the event E and the total number N of possible outcomes, and it is used when one has to deal with processes which are repeated a very large number of times. This definition can be written as follows:

P(E)=n/N (3.1)

In the particular case of global evaluation of the condition of a road pavement structure, when the concept of repeated processes become meaningless, we are using the so called subjective probability, defined as the ability of the pavement to be successful or to fail in meeting the specific technical requirements established by the road administration, according to the environmental and traffic conditions affecting that pavement. According the existing literature [5], this definition can be written as follows:

P(Success & Failure) = 1 (3.2)

The probability of success of a pavement structure is called reliability, R, and its probability of failure p(f),is also called probability of risk, and with these symbols, the relation 3.2. Defining the subjective probability becomes:

R + p(f) = 1 (3.3)

Generally speaking, the adequacy of a road pavement to meet its technical conditions may be determined, by comparing its actual level of performance with that specified one. The specified level of performance will be a function resultant of many uncertain components of the pavement structure under consideration, such as traffic loading, location of the underground water table, climate and temperature, etc.. In the same time, the actual level of performance of the pavement structure will be also a resultant function which will depend on the variability of material parameters, testing errors, construction and supervision procedures, ambient conditions, etc. The ratio between the mean value of the safety margin, sf, and its standard deviation, sd, is called reliability index [5]. Practically, the reliability index distribution is unknown, and this may reduce considerably its adequacy to express or to predict the performance of a road pavement, but despite this aspect [6], it may be used as a basis for evaluation of the performance of many civil engineering structures, as well as in conjunction with the relative entropy concept in order to rank the performance of road pavements.

4 The combined concepts of chance and change applied to the road pavements.

From the ancient times, the human mind has been preoccupied with the chance aspect of events, and a great amount of human effort has been directed for preventing, combating or restricting the danger, represented by chance. Our modern science is based upon the principle of causality and is considered to be an axiomatic truth, but very often these axioms of causality are being shaken to their foundations, and with the progress of modern physics, we finally understood that what we call natural laws are merely statistical truth, every natural process being affected by chance, so that, under natural circumstances, a course of events absolutely conforming to specific laws is almost un exception [7]. In the struggle of the human mind to handle the events of chance, the matter of interest has been from the very beginning, the specific configurations formed by chance events in the moment of observation, and then the global interpretation of these configurations. This concept may be extended to the particular case of road pavements, subjected to the specific traffic and climate conditions, where different types of events of distress, caused by the variability of the pavement materials, may occur simultaneously, determining a specific pattern of the pavement condition. Such a pattern is, in fact, a specific configuration of the effects of these various distress events, whose development and evolution in time are very often governed by the laws of chance. This configuration of distress events, governed by chance, and forming a specific pattern at a given moment is a dynamic pattern, permanently changing his structure with time. From the time of Confucius and with the ancient Greeks, the man contemplated the thesis expressing this idea of change and the modern mathematical manifestations of this concept, stating that “all things are in flux ", are resumed under the general notion of the dynamic system [3]. If we consider the road pavement condition as being a dynamic process, providing a great variety of behavioral patterns, the complex problem of determining the road pavement condition at a given moment during its design life will consists in identifying its specific pattern, related to that moment of observation, based on the results obtained by performing the measurement of the various parameters, each of these parameters, expressing a specific aspect of the global pavement condition. After the identification of the appropriate pattern from the multitude of the possible existing patterns, the next step may consist in selecting a convenient strategy from the multitude of strategies which can be priory developed as parts of the pavement management system adopted. Also, even the specific laws of different types of distresses are less known, by applying the principles of the optimization of entropy [4] one may assign an appropriate probability distribution, according the range of information available [6] , e.g.the Uniform distribution when we don't know anything about the real distribution, ; the exponential law, when we know at least the expected value of the distribution; the Normal distribution when we know the expected value and the range of the standard deviation, etc. As it has recently been demonstrated, [4] the most standard probability distributions, such as the uniform, geometric, exponential, gamma, normal, beta and Cauchy distributions, can be obtained by maximizing the classical, Shannon entropy measure. The use of this principle may be of particular importance for the processing and interpretation of the LTTP data available at this stage, even the real probability distributions of the evolution of the different parameters involved it is not well known. According to the principles of modeling natural systems described earlier, if we assume that our road pavement system S, is described by a set of abstract states X, defined as follows:

$$W = \{w1,w2,...,wn) \quad (4.1)$$

then the dynamic on W is defined as a rule, specifying how a given state w transforms to another state Tt(w) at a time t, this rule being written:

$$Tt(x) : W – W \quad (4.2)$$

where, Tt is called "the transformation", and both the state set W and the time set Tt can be either continuous or discrete variables. This rule describes " a flow" or "a change" of state of the dynamic system W. Knowing or assuming ,in terms of entropy, the dynamic rule of state-transition and the initial state w0 W, than we should easily find answers to the questions, related with our system, such as follows:

-what kind of pattern will emerge in the long term limit?

-how fast these limiting patterns are approached during the design life of a specific road pavement?

-which are the types of the initial states (patterns) giving rise to different classes of limiting patterns?

Ultimately, all these questions are coming down to the fundamental question of whether or not certain types of limited behavior are possible under this dynamic rule. As an example of such a state-transition process, let's consider the sequence of states which may occur in a road pavement structure, in time, every of these states (e.g. x1= structural condition; x2= surface condition; x3=safety condition), developing in time according a specific pattern (law), so that the transition - matrix of the pavement condition from the initial state to the states 1, 2, 3, can be written as follows:

		P (next state)		
		1	2	3
P (initial state)	1	p11	p12	p13
	2	p21	p22	p23
	3	p31	p31	p33

The elements of this matrix, pij, designate the probability that the initial condition i will become state j in the next transition.

5 The concept of entropy. Entropy optimization principles. Different measures of entropy.

Any new road is supposed to be constructed to specification requirements with at least a 95% confidence level, and may be considered as a complex macroscopic physical system, characterized by a high degree of order, such a road being, in fact, without any significant defaults. After its completion and opening to traffic, coming under the combined incidence of the repeated actions of the wheel loads, of climatic and other environmental factors, etc., the road will suffer a certain decrease of its initial degree of order. As we know, in order to measure the uncertainty of a physical system, a special notion, [8,9] has been developed. This notion, derived indirectly by application of the second principle of Thermodynamics into Informatics, is called entropy. Let us consider the physical system (S), and its global condition W, at a given moment, characterized by a finite number of state conditions: w1, w2... wn, the probabilities related to these conditions being: p1, p2, p3... pn. For convenience, these data may be arranged as follows:

(wi): w1 w2 w3 ... wn

(pi): p1 p2 p3 ... pn

In this case the value of the entropy of this system, H(S), shall be determined with the relation:

$$H(S) = - \quad pi*\log pi \qquad (5.1)$$

According literature [10], in order to establish a quantitative unit measure for the entropy we may consider the most simple physical system, X, that of tossing a coin, which presents only two equally probable conditions, p1 = p2 = 1/2. By applying relation 6 to this particular case, one obtains :

$$H(X) = - [(1/2*\log 1/2) + (1/2*\log 1/2)] = 1$$

The entropy unit obtained in this way has been called a bit, (binary digit). The evaluation of the entropy of a physical system, by using the relation (6), may be simplified by introducing a special function (fi), defined with the relation (5.2):

$$(f) = -p*\log p \qquad (5.2)$$

and in this case, the relation becomes :

$$H(S) = \quad fi \qquad (5.3)$$

the function fi being tabulated, [10] for various values of probability, between 0 and 1.
If we consider more complex systems, composed from a finite number of independent sub-systems, the entropy of the entire system will be determined by summing the partial entropies, using a relation similar to the relation (9), developed for the case of a complex system (Z), composed of two independent sub-systems (X) and (Y):

$$H(Z) = H(X,Y) = H(X) + H(Y) \qquad (5.4)$$

Usually, the sub-systems forming a complex physical system are dependent upon each other and in such a case the relation (9) developed for independent sub-systems is no longer applicable. In such a case, conditional entropy applies. Thus, the entropy of the entire complex system (Q), composed of three interdependent sub-systems: X, Y, and Z shall be determined by using the relation (5.5):

$$H(Q) = H(X,Y,Z) = H(X) + H(YIX) + H(ZIX,Y) \qquad (5.5)$$

where the conditional entropy of each sub-system is calculated in the hypothesis that the conditions of all previous sub-systems are known. Now, considering the road pavement condition as a complex system composed, e.g., of five main sub-systems, characterized by the various parameters such as roughness, distress, bearing capacity, skidding and comfort, the maximum value of the road entropy, Hmax, calculated in the hypothesis that all these sub-systems are independent, shall be as follows:

$$Hmax = 5*hmax = 5*0.5307 \text{ bit} = 2.6535 \text{ bit}$$

and for practical convenience, this value may also be expressed in milibit units, so:

$$Hmax = 2653.5 \text{ mbit.}$$

Let consider an examples of the evaluation of the specific road pavement condition, in terms of relative uncertainty, e.g., in terms of specific entropy. Given the following deviations, hi, of elevations from a straight line, at points of 3.00 meter intervals, along the traveled lanes of five roads, we should try to rank the roughness of the pavements, in terms of uncertainty (entropy):

Deviation			Road :		
hi(mm)	a	b	c	d	e
h1	12	13	11	9	15
h2	18	15	15	12	14
h3	16	12	19	10	18
h4	16	13	21	9	21
h5	13	15	8	10	20
h6	12	19	10	7	19
h7	19	16	12	11	7
h8	10	10	20	12	10
h9	16	11	18	10	9
h10	10	14	13	8	7

Calculations of the conventional statistics (average, standard deviation, Coefficient of variation) and of the classical and maximum entropies [8]. The following synthetic data are extracted from this worksheet:

Road:	a	b	c	d	e
Sum(mm)	142	138	153	98	140
Avg.(mm)	25.818	25.090	27.818	17.818	25.454
STD.(mm)	3.059	2.481	4.051	1.536	5.157
Dif.Ent.(byte)	0.338	0.023	0.052	0.018	0.102

Analyzing these data, one may conclude that, from the all five roads considered, the flattest is the road “d", its entropy being very near the maximum entropy; the roughest is the road "a", for which the difference between its real entropy and its desired entropy [9] is maximal. A similar approach, based on entropy, may be used in ranking road pavements according their structural or safety conditions. In most general cases, where the global road condition is considered as a complex system composed from independent and interdependent sub-systems, the entropy value characterizing the whole road shall be calculated by using a relation similar to the relation (5.5.) above.

6 The use of the combined concepts of chance, change and entropy for evaluation of road pavement condition and ranking the maintenance and rehabilitation works

In order to develop an adequate methodology for the evaluation of the partial and global condition of an existing road pavement, at a given moment of its life, let us consider the simplest pattern, involving its structural condition, noted as, "xxx" and its surface condition, noted as "yyy". This general pattern can be represented graphically as a diagram, as follows:

xxx
*
yyy

Further on, in order to simplify things, we assume that each of these pavement conditions is divided into different classes of behavior, each class being characterized by a specific probability matrix, as follows:

Parameter conditions	Symbol	Probability to meet technical specified for the road pavement: pmin	Pmax.
aaa) Structural condition:			
x	xxx	0.76	0.99
x1	x1x	0.56	0.75
x2	x2x	0.37	0.55
x3	x3x	0.01	0.36
bbb) Surface condition:			
y	yyy	0.76	0.99
y1	y1y	0.56	0.75
y2	y2y	0.37	0.55
y3	y3y	0.01	0.36

From these classes of behavior, we can develop the matrix of the all possible situations, which may occur in practice, as follows:

	x	**x1**	**x2**	**x3**
y	x,y	x1,y	x2,y	x3,y
y1	x,y1	x1,y1	x2,y1	x3,y1
y2	x,y2	x1,y2	x2,y2	x3,y2
y3	x,y3	x1,y3	x2,y3	x3,y3

The graphical representations of these sixteen possible diagram patterns are shown below:

	xxx	x1x	x2x	x3x
	xxx	x1x	x2x	x3x
yyy	*	*	*	*
	yyy	yyy	yyy	yyy
	xxx	x1x	x2x	x3x
y1y	*	*	*	*
	y1y	y1y	y1y	y1y
	xxx	x1x	x2x	x3x
y2y	*	*	*	*
	y2y	y2y	y2y	y2y
	xxx	x1x	x2x	x3x
y3y	*	*	*	*
	y3y	y3y	y3y	y3y

Any of these patterns has its specific probability matrix, as for example the pattern no.1, as follows:

A) Calculation of entripy measures for patternl

Pattn.1 Simbol:	Probability P% min	max
Xxx	0,76	0,99
*		
yyy	0,76	0,99

- Superior entropy limits:

	P%	Non P% risc
Xxx	0,76	0,24
*		
yyy	0,76	0,24

x	y	nx	Ny
0,76	0,76	0,24	0,24

Possible events	Prob. Pi%	Entropy: Shannon H(pi)	Entropy: Kapour Hg	Entropy:
x,y	0,5776	0,457376	0,457376	16,81362
x,ny	0,1824	0,447759		16,91544
nx,y	0,1824	0,447759		45,53229
nx,ny	0,0576	0,237184	0,237184	46,38273
Sum	1	1,590080	0,694561	125,6440
Shanon:		0,457376		
Kapour		0,694561		
Casti		16,81362	125,6440	

- Inferior entropy

	P%	Non P% risc
Xxx	0,99	0,01
*		
yyy	0,99	0,01

x	y	nx	Ny
0,99	),99	0,01	0,01

Possible events	Prob. Pi%	Entropy: Shannon H(pi)	Entropy: Kapour Hg	Emtropy: Casti
x,y	0,9801	0,028422	13,28889	0,028422
x,ny	0,0099	0,065917	13,40607	
nx,y	0,0099	0,065917	383,7499	
nx,ny	0,0001	0,001328	659,2288	0,001328
Sum	1	0,161586	1069,673	0,029750
Shanon:		0,028422		
Kapour		0,029750		
Casti		13,28889	1069,673	

General results	Entropy H (Pmax)	Entropy H (pmin)
Shannon	0,028422	0,457376
Kapour	0,029750	0,694561
Casti (i)	13,28889	16,81362
Casti (ii)	1069,673	125,6440

B) Example related with pattern

Pattn.1 Simbol:	Probability P% min	max	pi
Xxx	0,76	0,99	0,83
*			
yyy	0,76	0,99	0,79

Real case entropy limits:

	P%	Non risc	P%
xxx	0,83	0,17	
*			
yyy	0,79	0,21	

x	y	nx	ny
0,83	0,79	0,17	0,21

Possible events	Prob. Pi%	Entropy: Shannon H(pi)	Entropy: Kapour Hg	Entropy: Casti
x,y	0,6557	0,399250	0,399250	15,55383
x,ny	0,1743	0,439297		15,65021
nx,y	0,1343	0,388995		60,69056
nx,ny	0,0357	0,171643	0,171643	62,45805
Sum	1	1,399187	0,570893	154,3526

Entropy	Pi	Entropy H (Pmax)	Entropy H (pmin)
Shannon	0,399250	0,028422	0,457376
Kapour	0,570893	13,28889	0,694561
Casti (i)	15,55383	13,28889	16,81362
Casti (ii)	154,3526	1069,673	125,6440

From the multitude measures of entropy developed and used in different fields of research, the following have been selected and computed in our study ,with the aim to find out which one is more suitable and advantageous for the specific case of evaluation of the road pavement condition:

a) the classical entropy [8], described as above and determined with the relation:

$$H(pi) = - \ pi*\ln(pi)$$

b) the generalized measure of entropy [4], determined with the relation:

$$- \ pi*\ln(pi) \ - \ (1-pi)*\ln(1-pi)$$

c) the topological entropy (Casti,1988)

Topological entropy is more important for the identification of different patterns of road pavement condition. The topological entropy is defined as a measure of the likelihood of particular configuration [10]. In order to define more precisely a sole road pavement condition, expressed by a specific configuration, it is often necessary to connect up the topological and the measure spatial/temporal entropies, according with the complexity of the system. If we have N, a sequence of numbers defining a specific road pavement condition configuration, with k parameters describing its global condition, the topological entropy, Ht, reflecting this specific configuration, will be calculated with the relation;

$$Ht = 1/N*\log_k (N)$$

the total number of possible sequences n, will be :

$$n = K^i$$

where i is the number of possible cases of any individual condition.

7 Conclusions and further recommendations

This paper presents the results of a research study conducted with the aim of investigating, in a detailed manner, the possibility to develop a new methodology for the evaluation of road pavement condition.

The study was not intended to present the routine methodology for the extraction the stochastic information from laboratory or from routine pavement investigations, assuming that such techniques are well known, and their results ,expressed in terms of tendencies ,standard deviations or coefficients of correlation, obtained by tractable probabilistic analysis, may be used as raw data for the new proposed methodology.

With the purpose of simplifying the calculations and for conducting the study in a more systematic manner, the multitude of the parameters, influencing the global road pavement condition, have been grouped into the following main classes:

- parameters of structural condition (mainly, bearing capacity)
- parameters of surface condition (mainly: roughness, rutting, distress)
- parameters of safety condition (mainly, skidding resistance)
- parameters of comfort condition (mainly, the relation traffic/geometric design; landscape, environment)

For the first time the comfort condition as described above, was intended to be introduced as an essential part of the global pavement condition, in the future developments of the Pavement Management Systems.

Further on, each of the four main conditions mentioned above has been divided into three to four sub conditions, defined each one, according its specific probability matrix. For a more suggestive graphical representations of these patterns , the following symbols have been used for the different lines forming a specific pattern: xxx or ---- (continuous line) , representing a sub condition which ,generally meets the technical requirements, so that there is no need to undertake any important maintenance or rehabilitation action; x1x or -- -- (yielding line) , having in its middle space a cipher (1,2 or 3), representing the gravity of the condition and consequently the maintenance or rehabilitation measure which are recommended to be undertaken, in order to bring the pavement to its specified requirements, e.g. ,as follows:

1- need for routine maintenance measures

2- need for overlay or special maintenance actions

3- need for reconstruction or radical maintenance measures.

The specific study of the diagram patterns,, have been conducted with the aim to find out, from the different measures of entropy, used nowadays in different research fields, the classical measures of entropy may be used successfully, for the evaluation of an individual parameter (e.g. roughness, etc), in order to rank the different roads on the sole criterion of entropy, which is more powerful than other criteria such as standard deviation, coefficient of variation or reliability.

During the documentation study on the subject of entropy related with the assessment of pavement condition, , it was very interesting to find out that in a research study ,concerning road pavement performance , conducted by the University of Alabama, in which 31 experts rated the performance of 1086 road sections, on a scale of 0 to 100, the probability value for which they recommended major rehabilitation ,P=0.379 was very near the probability P=0.37, for which one may get the maximum value of entropy [12]. Finally, taking into consideration the results of these research and the advantages offered by the various entropy measures in characterizing partially or globally the road pavement condition, we strongly recommend further developments , at a greater scale ,in terms of time, teams for work and complexity of patterns considered, and coordinate study to be undertaken into the future in the frame of research LTPP program, and also the use of the results of this study in the analysis of the existing LTPP data.

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