INTELLIPave - CONSIDERING ASIDE FAILURE CRITERIA AND UNKNOWN VARIABLES IN EVOLUTIONARY INTELLIGENCE BASED MODELS FOR ASPHALT PAVEMENT

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ABSTRACT
On 2008 was published (Salini et al, 2008) the guidelines to use an artificial intelligence based approach to create high quality models to asphalt pavements, surpassing most of the well know problems and limitations of the current empiric and empiric-mechanistic approaches. This paper describe part of this new approach called INTELLIPave, with focus in show how to totally unknown variables are considered in the model in an implicit way, regardless its nature or complexity, and how the failure criteria is used aside, and no longer inside, of the model.

INTRODUCTION

Model the asphalt pavement are among the biggest challenges of the engineering. The consensus tell about an intrinsic viscous-elasto-plastic non-linear and anisotropic behaviour; very complex, but not sufficient to explain the performance, suggesting the existence of more undiscovered parcels of the behaviour or the inexistence of any kind of pattern. Aside of the intrinsic ones, the asphalt pavement behaviour is subject to the interference of many external factors, as the characteristics of the vehicles (speed, loads, *et cetera*) and the climate (temperatures, rainfall, *et cetera*).

Half of century ago a number of methods were developed for asphalt pavement design, but with almost no efforts to try model the asphalt pavement behaviour in a way allowing to include all or most of the variables. In general terms these methods are very simplistic and based on empiric or empiric-mechanistic approaches, with the performance represented by two or three empiric variables, like the ESAL (Equivalent Single Axle Loads), CBR (California Bearing Ratio) or the maximum strain in the asphalt concrete layer (Figure 01).

In the late 1990s was announced the development of a new method under the name AASHTO 2002 with the goal of solve most of the existing problems to asphalt pavement modeling and giving a new level of technical accuracy for the service life prediction; as its name suggests, this method was supposed to be finished in the year 2002. Many years after, in 2008, this remain as a promise, an utopia prisoner of a limitless net of problems due to its wrong paradigm: try to join in one single method the empiric philosophy, empiric-mechanistic structural evaluation, a puzzle with many punctual studies and the results of the multimillion SHRP/SUPERPAVE program. Despite the time, efforts, labor and money used, until now it was not found a way to make it to work.

The current methods in use – empiric and empiric-mechanistic – were in line with the technical-economic needs of the time when they were created, half century ago, but since that time the reality changed. Today the number of vehicles in the highways increased exponentially, and the vehicles are more and more heavy, shifting of a load capacity of 9 tons in the 1960s to over 80 tons in current days, and the construction and maintenance costs, for both materials and labor, increased many times. On the other hand environmental questions are also pressing the costs, due to restrictions, namely in mining materials like stone. And this conjunction occurs in a scenario where the available public funds for construction and maintenance of the highways are decreasing. These methods also do not provide any way to scientifically accumulate the knowledge, making hard for the pavement engineering use the experience of one highway into another as the experience remain empirically accumulated on the persons, and may be easily lost due to forgetting, retirement or death.

The lack of a scientific and high efficient methods for asphalt pavement modeling, including pavement design and management, are resulting in an deficient prediction of the asphalt pavement behavior, resulting in a premature failure and higher maintenance costs due the underdesign (University of Minnesota, 1999), or initial costs higher than the ideal due the overdesign, in both cases resulting in a poor cost-effectiveness, due to the available funds. The introduction and use of new and high performance materials may have also some impact (Brown S. F., 1978).

On the other hand, advanced techniques of evolutionary intelligence, including multi-valued extended logic programming, evolutionary computation and neural networks, are been used with great success to model problems with complex, disperse or uncertain behavior, allowing to bypass many limitations of the traditional approaches in handling large amounts of data. According to Salini et al (2008), the soft computing tools allow to model the asphalt pavement dilemma in a true and long waited scientific way, avoiding the subjectivity and well know limitations and problems of the empiric and empiric-mechanistic methods, once it handles all the variables without concessions or simplifications, creating a new paradigm for asphalt pavement modeling in line with the technical-economic needs of the XXI century.

This new approach is flexible, technologic intensive and allows for the gathering and accumulation of scientific knowledge. It is applied in three steps to a database containing the details for one full cycle of life time of the asphalt pavement history: (1) first, the data is evaluated in order to determinate the quality of the information available through the use of logic functions subjected to mathematical proof; (2) then, the database is optimized in order to determine the weight of every variable and piece of data, generating a model organized in the form of a matrix with billions of records; (3) finally, the matrix of data is used to train a set of neural networks which, once trained, will be able to do predictions for asphalt pavement design and management.

Among the innovations of this new approach are the spin-off of the failure criteria from the model and the consideration of unknown variables in an implicit way.

THE MODEL AND THE FAILURE CRITERIA

The current paradigm for asphalt pavements looks to explain the pavement performance using a failure criteria before model the behavior. For practical purposes, the failure criteria (like Strains; ε_t) is inside or part of the model (Figure 1). As no explanation for the behavior was found in half of century of tries, no good model was produced. In this new approach this problem is handled in a different way, the failure criteria is placed aside of the model, and no longer inside.

This is a very important paradigm change, because allow create very high quality models without the need for an explicit explanation of the behavior, but an implicit one, where the prediction will follow and reproduce the performance registered in a database. This new paradigm is not valid just for pavements, but also for any model for any kind of purpose.

For practical purposes the failure criteria will just point where the database will be “cutted”, with the axles crossing the pavement below (after) that point eliminated because, according the criteria, the pavement is no longer serviceable.

This give a total flexibility to choose the failure criteria, because it can be evaluated according any kind of parameter, objective or subjective, technical, financial or even exotic or exoteric. The only must is to be able to indicate when the pavement no longer meet the chosen criteria, and cut the database in that point. The Figures 2, 3 and 4 show an example where the cracked area at 20% was chosen as failure criteria.

The pavement can be subject to many different deficiencies like cracking, rutting or roughness, and every one happens in a different time in the same asphalt pavement. This new approach allows the use of multiple criteria to design or manage the pavement, giving the possibility to forecasting different scenarios and to make better decisions.

For every criteria the database is cutted in a different point, the data need to be re-optimized and the neural networks, retrained.

MODELLING UNKNOWN VARIABLES IN AN IMPLICIT WAY

When the failure criteria is placed aside of the model, a new world of possibilities is open. One of the most interesting is in the fact of the used variables in the model assume another purpose: provide orientation about where the model can be used with accuracy, and for that are necessary a number of variables, but not ALL; the orientation need be good, but not perfect. In fact, the model can be constructed even without any variable, but in that case it will works almost at an empiric level.

When one variable is removed from the model is assumed that all the pavements evaluated or designed using the model will be subject of that variable in the exact same way the pavement used as source to the model was. The influence of the variable remains in the model, but in an implicit way, instead explicit. This logic is valid not just to the known variables, but also to all and any unknown variable; in another words, all unknown variables, regardless of its nature, complexity or relevance, are considered in the model in an implicit way.

The Figure 02 shows the model using the cracked area up to 20% as the failure criteria for the pavement service life when are used (symbolically) all known variables. The pavement is serviceable, with a cracked area equal or lower than 20%, up to the axle number 5667000.

The Figure 03 shows the same pavement, but with five variables eliminated. Again, the pavement remains serviceable up to 5667000 axles. One of the eliminated variables was the vehicle speeds, but its importance remains inside the model in an implicit way, because the pavement was subject of different speeds; the model just have no register about that speed. In this case the model can be used with accuracy to do predictions in highways where the expected speeds are in the same range of the speeds happened in the test section source of the data used to build the model.

In the Figure 04 are (symbolically) inserted all known and all unknown variables with influence in the pavement service life. As the failure criteria is aside of the variables, the end of the service life remain in the same position, with all unknown variables included in the model in an implicit way.

CONCLUSIONS

The failure criteria for the asphalt pavements can be successfully used aside of the model, instead inside, avoiding or solving most of the problems found in the empiric and empiric-mechanistic approaches. The split give a new world of possibilities to optimize the prediction system in order to improve the accuracy of the model, handling many or all variables at the same time, and making it flexible to be used any kind of criteria for failure, regardless of its nature, like technical, financial or other. All known and unknown variables can be considered in the model in an explicit or implicit way.

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$$\mathrm{ESAL} = (\text{shift factor}) \cdot (\varepsilon_t)^{-f1} \cdot (E)^{-f2}$$

ESAL = Equivalent single axle loads (standard axle)
ε_t = Maximum strain
E = Modulus
f1, f2 = Adjusting factors
shift factor = Laboratory-to-field adjusting factor

Figure 01 – Empiric-mechanistic Equation for Asphalt Pavement Service Life Prediction

Axles	Climate							Structural response						Vehicles				Cracked area
1	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	0%
2	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	0%
3	C1	C2	[illegible]	[illegible]	[illegible]	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	0%
4	C1	C2	[illegible]	[illegible]	[illegible]	C6	C7	S1	S2	S3	S4	S5	S6	V1	[illegible]	[illegible]	[illegible]	0%
5	C1	C2	[illegible]	[illegible]	[illegible]	C6	[illegible]	[illegible]	S2	S3	S4	S5	S6	V1	[illegible]	[illegible]	[illegible]	0%
...	...	...	...	...	[illegible]	...	[illegible]	[illegible]	...	...	...	...	...	...	[illegible]	[illegible]	[illegible]	...
5666998	C1	C2	C3	C4	[illegible]	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	20%
5666999	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	20%
5667000	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	**20%**
5667001	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	**21%**
5667002	C1	C2	C3	C4	C5	C6	[illegible]	[illegible]	S2	S3	S4	S5	S6	V1	V2	V3	V4	21%
5667003	C1	C2	C3	C4	C5	C6	[illegible]	[illegible]	S2	S3	S4	S5	S6	V1	V2	V3	V4	21%
5667004	C1	C2	C3	C4	C5	C6	C7	S1	S2	S3	S4	S5	S6	V1	V2	V3	V4	21%
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Cutting point of the database to meet the failure criteria

Data used to build the model

Failure criteria: cracked area up to 20%

Eliminated data

C1 = Solar radiation
C2 = Air temperature
C3 = Rainfall
C4 = Wind speed
C5 = UV Radiation
C6 = Groundwater level
C7 = Pavement temperature

S1 = Asphalt layer vertical strains
S2 = Asphalt layer pressures
S3 = Asphalt layer horizontal strains
S4 = Moisture in the granular layer
S5 = Granular layer pressures
S6 = Granular layer strains

V1 = Tire type
V2 = Vehicle speed
V3 = Vehicle weight by axle
V4 = Vehicle class

Figure 02 – Pavement History – (Symbolically Representation for) All Known Variables

Axles	Climate					Structural response				Vehicles			Cracked area
1	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	0%
2	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	0%
3	C1	C	[illegible]	[illegible]	C5	S1	S2	S3	S6	V1	V3	V4	0%
4	C1	C	[illegible]	[illegible]	C5	S1	S2	S3	S6	V1	V3	[illegible]	0%
5	C1	C	[illegible]	[illegible]	C5	[illegible]	[illegible]	S3	S6	V1	V3	[illegible]	0%
...	...	...	...	[illegible]	...	[illegible]	[illegible]	...	...	...	...	[illegible]	...
5666998	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V	20%
5666999	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	20%
5667000	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	**20%**
5667001	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	**21%**
5667002	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	21%
5667003	C1	C2	C3	C4	C5	[illegible]	[illegible]	S3	S6	V1	V3	V4	21%
5667004	C1	C2	C3	C4	C5	S1	S2	S3	S6	V1	V3	V4	21%
...	...	...	...	...	...	...	...	...	...	...	...	...	...

Cutting point of the database to meet the failure criteria

Data used to build the model

Failure criteria: cracked area up to 20%

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S2 = Asphalt layer pressures
S3 = Asphalt layer horizontal strains
~~S4 = Moisture in the granular layer~~
~~S5 = Granular layer pressures~~
S6 = Granular layer strains

V1 = Tire type
~~V2 = Vehicle speed~~
V3 = Vehicle weight by axle
V4 = Vehicle class

Figure 03 - Pavement History – Eliminate Variables do not Change the Position Where the Pavement Stops to Meet the Failure Criteria

Axles	Climate										Structural response									Vehicles							Cracked area
1	C1	C2	C3	C4	C5	C6	C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	0%
2	C1	C2	C3	C4	C5	C6	C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	0%
3	C1	C2					C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	0%
4	C1	C2					C7	C8		Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2					Vn	0%
5	C1	C2					C7	C8				2	S3	S4	S5	S6	S7	...	Sn	V1	V2					Vn	0%
...	...	...	...	...	...		...	...				...	...	...		...	...	...	...	...	...					...	...
5666998	C1	C2	C3	C4	C5	C6	C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5		Vn	20%
5666999	C1	C2	C3	C4	C5	C6		C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	20%
5667000	C1	C2	C3	C4	C5	C6	C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	**20%**
5667001	C1	C2	C3	C4	C5	C6	C7	C8		Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	**21%**
5667002	C1	C2	C3	C4	C5	C6	C7	C8				2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	21%
5667003	C1	C2	C3	C4	C5	C6	C7	C8				2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	21%
5667004	C1	C2	C3	C4	C5	C6	C7	C8	...	Cn	S1	S2	S3	S4	S5	S6	S7	...	Sn	V1	V2	V3	V4	V5	...	Vn	21%
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Cutting point of the database to meet the failure criteria

Data used to build the model

Failure criteria: cracked area up to 20%

Eliminated data

C1 = Solar radiation
C2 = Air temperature
C3 = Rainfall
C4 = Wind speed
C5 = UV Radiation
C6 = Groundwater level
C7 = Pavement temperature
C8 = Unknown variable
Cn = Unknown variable "n"

S1 = Asphalt layer vertical strains
S2 = Asphalt layer pressures
S3 = Asphalt layer horizontal strains
S4 = Moisture in the granular layer
S5 = Granular layer pressures
S6 = Granular layer strains
S7 = Unknown variable
Sn = Unknown variable "n"

V1 = Tire type
V2 = Vehicle speed
V3 = Vehicle weight by axle
V4 = Vehicle class
V5 = Unknown variable
Vn = Unknown variable "n"

Figure 04 - Pavement History – With the Consideration of All Known and Unknown Variables the End of the Service Life Remain in the Same Position