THE ROAD MAP TO APPLY EVOLUTIONARY INTELLIGENCE TO ASPHALT PAVEMENT MODELLING

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ABSTRACT

Modelling the service life for asphalt pavements is widely made with base on empirical methods, developed half-century ago, with poor results. The new reality of the XXI century, with high construction costs, environmental restrictions and growing volumes of vehicles in the highways, enforce the shift to a new level of quality and accuracy to predict the service life of the pavements. This paper presents some insights either theoretical or experimental into a making from the ground, of an approach to predict and model the asphalt pavement behaviour using soft computing tools and, at the same time, create a way to accumulate the knowledge in this engineering field. The knowledge about the asphalt pavement life cycle is organized in a hierarchical way in order to be reused in a formal way, leading to an evolutionary process of adaptation and construction (Neves et al. 2007).

INTRODUCTION

Created in the old Roman Empire, the paved roads are at the center of a big revolution in the human history. The pavement allows any person, day or night, with raining or snow, to move between two locations in an effective way, helping to grow all human activities, as the commerce, the industry, the health sciences, just to name a few.

Thousands years after the Via Áppia was paved by the Romans, the most used methods for pavement modelling and design remain at an unbelievable empirical level. The studies based on fatigue tests made in the last half-century, after the introduction of the asphalt as material for highways, do not allow any true progress to understanding and modelling the asphalt pavement behaviour.

This empirism results in an early and high rate of failure in some pavements and, in anothers, over-design; both cases have a poor cost-effectiveness for the used money. The empiric approaches also do not provide any way to scientifically accumulate the knowledge, making hard for the pavement engineering use the experience of one highway in to another as the experience remain empirically accumulated in the persons, and can be easily lost due to forgetting, retirement or death.

The new challenges of the XXI century, with the growing quantity of the vehicles in the streets, growing capacity of load of the trucks, high costs of the materials used in pavements, high cost of the labour and the crescent environment restrictions to mining and the use of materials like stones, enforce the achievement of a new level in prediction of the service life and modelling the asphalt pavement behaviour (Flintsch 2003).

Due the ultra-complex behaviour of the asphalt pavement, quality modelling cannot be achieved with empirical or *semi-religious* approaches. A strong tool, able to handling all the necessary variables and its near infinite combinations need to be used. The soft computing approach to modelling may be in line to provide the necessary power to this task (Yang et al. 2003; Bosurgi and Trifirò 2005).

THE SOURCE DATA

In order to be able to use and reuse the knowledge available is necessary, first, to generate and organize the information about the performance of the pavement.

The initial step, and the first challenge, is in the instrumentation of a section of highway open to live-traffic, with sensors to register in a database and/or knowledge base all variable data believed as important and connected to the durability of the asphalt pavement. As its service life do not decrease in a linear or constant rate, the database need to register the information for one full cycle of the service life of the asphalt pavement, or in another words, to get data all along several years.

The desirable variables to construct the database can be grouped in three areas: (a) environmental, (b) vehicles and (c) structural response of the pavement.

The asphalt pavement is subject of a well known influence of the environment, where the desirable variables are: air temperature, rainfall, wind speed, groundwater level, solar radiation, UV radiation and the pavement temperature.

The pavement is a structure subject to loads by vehicles, and the desirable variables in this arena are: vehicle counting, speed, classification and configuration by axle, and weight by axle.

The asphalt pavement has, in general terms, an asphalt concrete layer and a granular layer. To know how the pavement structure is performing under loads and with the influence of the environment, the desirable data are: asphalt layer vertical strains, asphalt layer pressures, asphalt layer horizontal strains, moisture in the granular layer, granular layer pressures and strains.

The Figure 1 shows the desirable variables in a chart format. Every time a vehicle crosses the instrumented section all sensors are read and the generated data is recorded in the database. The recording is only stopped when the pavement meets the end of the service life.

The criteria to the end of the service life can be anyone, technical, financial, functional or of any other nature. Also a multiple criteria can be used with this method and, in this case, the data need be recorder until the last criteria is meeting. For each criteria the database will be “cuted” in a different point and a new matrix of data is created.

THE CONSTRUCTION OF THE KNOWLEDGE

With the database already built, the next step is to compile the information available to another language, a math language (Figure 2). This is a fundamental step in order to make easy handling of the data to fix the importance of each variable and its interaction to the pavement durability.

The data need be organized in a form of a matrix, with one line per vehicle.

Now, one has to calculate the relative relevance of each variable and the relative importance of each vehicle for the pavement service life in a consistent way, which is the second challenge in this method. This can be solved using one or more topologies based on Evolutionary Intelligence like evolutive-genetic algorithms, logic-mathematic functions or particle-swarm optimization and, if the translation of the field data to the math is made in a consistent way, a matrix of equations will be generated, which may be solved with traditional approaches. A combination of Evolutionary Intelligence and matrix of equations can also be used to find the best possible classification for the lines (Mendes et al. 2004; Rocha et al. 2005; Rocha et al. 2006).

Once this task have been solved, every line in the matrix of data receives a “pavement damage” index representing the relative importance of the line in relation to the other ones (Figure 3).

It must be pointed out that the importance of the individual variables in the line is useful in order to testify the consistence of the solution of the matrix, but it is not critical information for this method.

The Figure 4 shows the diagram with the tasks to transform the source “brute” data to an information fine to train a neural network system.

The knowledge can be easily accumulated just adding new sets of field data to the initial database. The accumulation allows continuous improvement in the accuracy and usability.

HANDLING THE ERRORS

Regardless the used tools – matrix of equations and/or Evolutionary Intelligence based tools and/or computational topologies – some level of error will remain in the final pavement damage index. The third challenge is to handle this error in an efficient way.

The data obtained in the previous tasks that lead to the pavement damage index, is to be understood as the result of the “true” damage multiplied by an error (Figure 5).

At this stage of the development of the method it is not possible to know if there exist some way to calculate and isolate this error or not. In any case, an excellent solution to handling it was found.

The error can have any size if it is well distributed inside the matrix, or in another words, if the error in the pavement damage index in the line 1 is similar to the error in the line 2, and so on. As the result, the sum of the pavement damage indexes for the full matrix will have the same similar error.

Instead to use the pavement damage index as an absolute value, in this approach it is used in a comparative way, with the individual pavement damage index divided by the sum of the damages; as the error exists in both, the error is divided by itself and eliminated (Figure 6).

Handling the error in this way it helps the calculus of the pavement damage indexes, once it allows the use of some tips, as mix artificial data with true field data, in order to potentiate an easy convergence and a better solution for the matrix. The only rule to be accommodated is: the error need to be well distributed inside the matrix.

TRAINING THE NEURAL NETWORK

The matrix of knowledge made in a consistent way and ready to be used is named "matrix of performance", a source of "intelligence" to train a neural network system.

The only challenge in this step is the computer power to train a so big matrix of data, with dozen of millions of data items.

On the other hand the neural network has to be trained until one is be able to do predictions with a realistic accuracy. This can be easily checked just proposing lines of the matrix of performance as problems to be solved. The neural network will be well trained if found a pavement damage index similar to the one in the matrix of performance for the same lines.

The Figure 7 shows a chart with the matrix of performance and a pavement design proposed as a problem to the trained neural network evaluates the pavement damage.

VALIDITY AND USE OF THE MODEL

The matrix of performance can be used to evaluate the damage to pavements constructed with the same materials used in the instrumented test section used as a data source to the initial database.

The Figure 8 shows how to use the trained neural network to do predictions about the pavement service life. The problem need be proposed in the exact same format used to construct the matrix of performance and with the same information, including data about the environment, vehicles and pavement structural response. The data about the environment can be easily found with meteorological institutes and the vehicles can be counted, for existing highways, or evaluated with traditional procedures, for new highways. For new pavements the structural response can be calculated with finite elements procedures; for existing highways can be calculated with a combination of non-destructive tests (FWD, Benkelman Beam, etc.) and finite elements.

The Figure 9 shows a comparison between the approach here proposed and the equation of fatigue, the current state-of-the-art.

CONCLUSIONS

It is shown in Figure 9 that the (state-of-the-art) technology used in asphalt pavement modelling and design is based on the "equation of fatigue", an empirical-archaic approach that does not meet the requirements of the XXI century needs.

The approach proposed herein is based on soft computing tools leading, to:

- The establishment, for the first time in the pavement engineering, of a viable way to use strictly scientific procedures to model and predict the asphalt pavement behaviour and service-life, taking into consideration all problem variables;
- A change of paradigm with the potential to provide asphalt pavement modelling with unprecedented level of accuracy and reliability, with no subjective or empirical influence;
- The creation of an efficient and suitable form to knowledge gathering, allowing its use and reuse to optimize the accuracy and expand the usability of the model in a continuous way.

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AUTHOR BIOGRAPHIES

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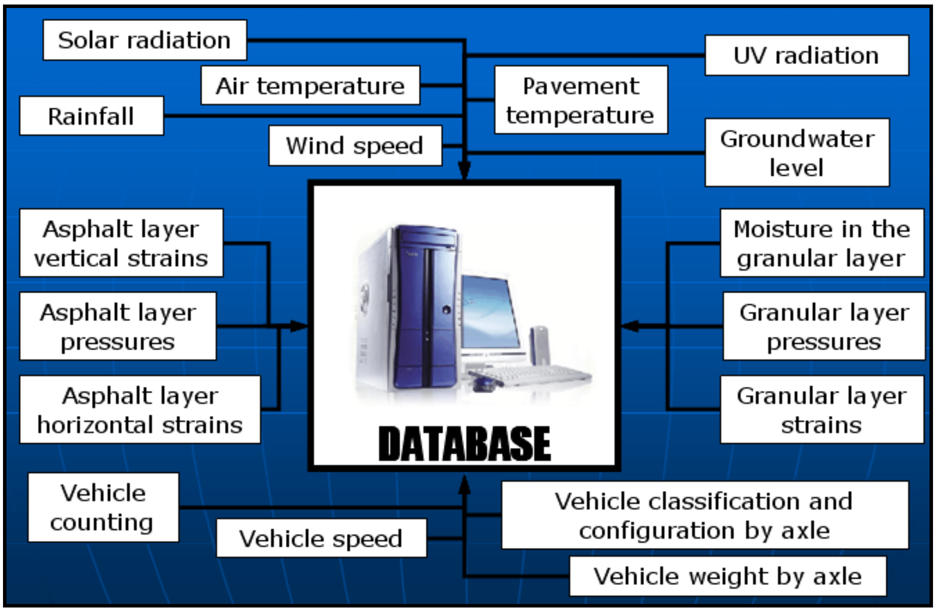


Figure 1: Desirable Variables to a Database Suitable for Asphalt Pavement Modelling Using Artificial Intelligence

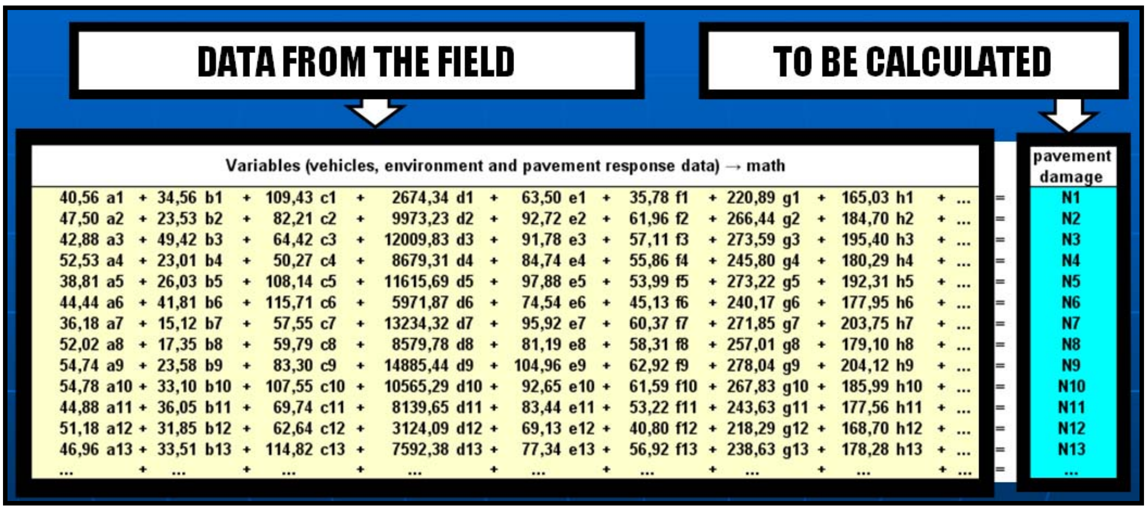
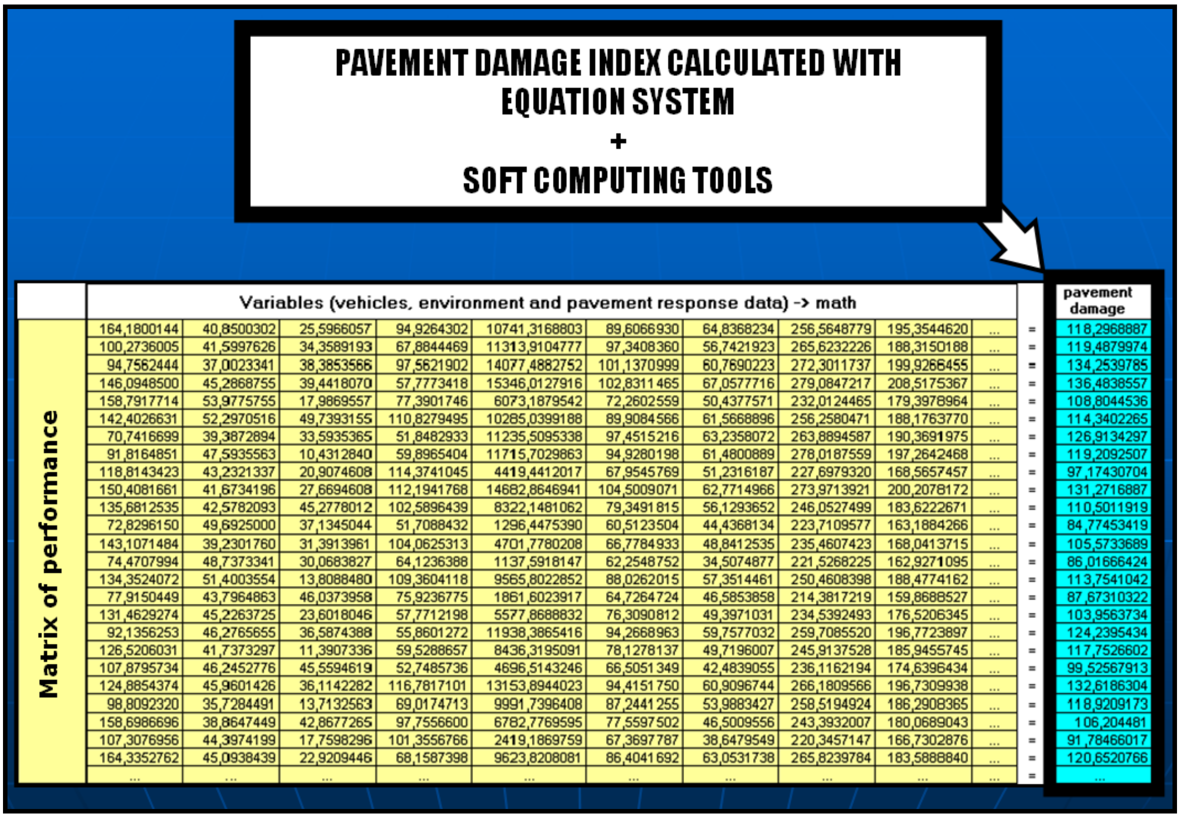


Figure 2: Field Data Organized in Form of a Matrix of Numbers



Variables (vehicles, environment and pavement response data) -> math											pavement damage
164,1800144	40,8500302	25,5966057	94,9264302	10741,3168803	89,6066930	64,8368234	256,5648779	195,3544620	...	=	118,2968887
100,2736005	41,5997626	34,3589193	67,8844469	11313,9104777	97,3408360	56,7421923	265,6232226	188,3150188	...	=	119,4879974
94,7562444	37,0023341	38,3853566	97,5621902	14077,4882752	101,1370999	60,7690223	272,3011737	199,9266455	...	=	134,2539785
146,0948500	45,2868755	39,4418070	57,7773418	15346,0127916	102,8311465	67,0577716	279,0847217	208,5175367	...	=	136,4838557
158,7917714	53,9775755	17,9869557	77,3901746	6073,1879542	72,2602559	50,4377571	232,0124465	179,3978964	...	=	108,8044536
142,4026631	52,2970516	49,7393155	110,8279495	10285,0399188	89,9084566	61,5668896	256,2580471	188,1763770	...	=	114,3402265
70,7416699	39,3872894	33,5935365	51,8482933	11235,5095338	97,4515216	63,2358072	263,8894587	190,3691975	...	=	126,9134297
91,8164851	47,5935563	10,4312840	59,8965404	11715,7029863	94,9280198	61,4800889	278,0187559	197,2642468	...	=	119,2092507
118,8143423	43,2321337	20,9074608	114,3741045	4419,4412017	67,9545769	51,2316187	227,6979320	168,5657457	...	=	97,17430704
150,4081661	41,6734196	27,6694608	112,1941768	14682,8646941	104,5009071	62,7714966	273,9713921	200,2078172	...	=	131,2716887
135,6812535	42,5782093	45,2778012	102,5896439	8322,1481062	79,3491815	56,1293652	246,0527499	183,6222671	...	=	110,5011919
72,8296150	49,6925000	37,1345044	51,7088432	1296,4475390	60,5123504	44,4368134	223,7109577	163,1884266	...	=	84,77453419
143,1071484	39,2301760	31,3913961	104,0625313	4701,7780208	66,7784933	48,8412535	235,4607423	168,0413715	...	=	105,5733689
74,4707994	48,7373341	30,0683827	64,1236388	1137,5918147	62,2548752	34,5074877	221,5268225	162,9271095	...	=	86,01666424
134,3524072	51,4003554	13,8088480	109,3604118	9565,8022852	88,0262015	57,3514461	250,4608398	188,4774162	...	=	113,7541042
77,9150449	43,7964863	46,0373958	75,9236775	1861,6023917	64,7264724	46,5853858	214,3817219	159,8688527	...	=	87,67310322
131,4629274	45,2263725	23,6018046	57,7712198	5577,8688832	76,3090812	49,3971031	234,5392493	176,5206345	...	=	103,9563734
92,1356253	46,2765655	36,5874388	55,8601272	11938,3865416	94,2668963	59,7577032	259,7085520	196,7723897	...	=	124,2395434
126,5206031	41,7373297	11,3907336	59,5288657	8436,3195091	78,1278137	49,7196007	245,9137528	185,9455745	...	=	117,7526602
107,8795734	46,2452776	45,5594619	52,7485736	4696,5143246	66,5051349	42,4839055	236,1162194	174,6396434	...	=	99,52567913
124,8854374	45,9601426	36,1142282	116,7817101	13153,8944023	94,4151750	60,9096744	266,1809566	196,7309938	...	=	132,6186304
98,8092320	35,7284491	13,7132563	69,0174713	9991,7396408	87,2441255	53,9883427	258,5194924	186,2908365	...	=	118,9209173
158,6986696	38,8647449	42,8677265	97,7556600	6782,7769595	77,5597502	46,5009556	243,3932007	180,0689043	...	=	106,204481
107,3076956	44,3974199	17,7598296	101,3556766	2419,1869759	67,3697787	38,6479549	220,3457147	166,7302876	...	=	91,78466017
164,3352762	45,0938439	22,9209446	68,1587398	9623,8208081	86,4041692	63,0531738	265,8239784	183,5888840	...	=	120,6520766
...	...	...	...	...	...	...	...	...	...	=	...

Figure 3: The Pavement Damage Index Calculated

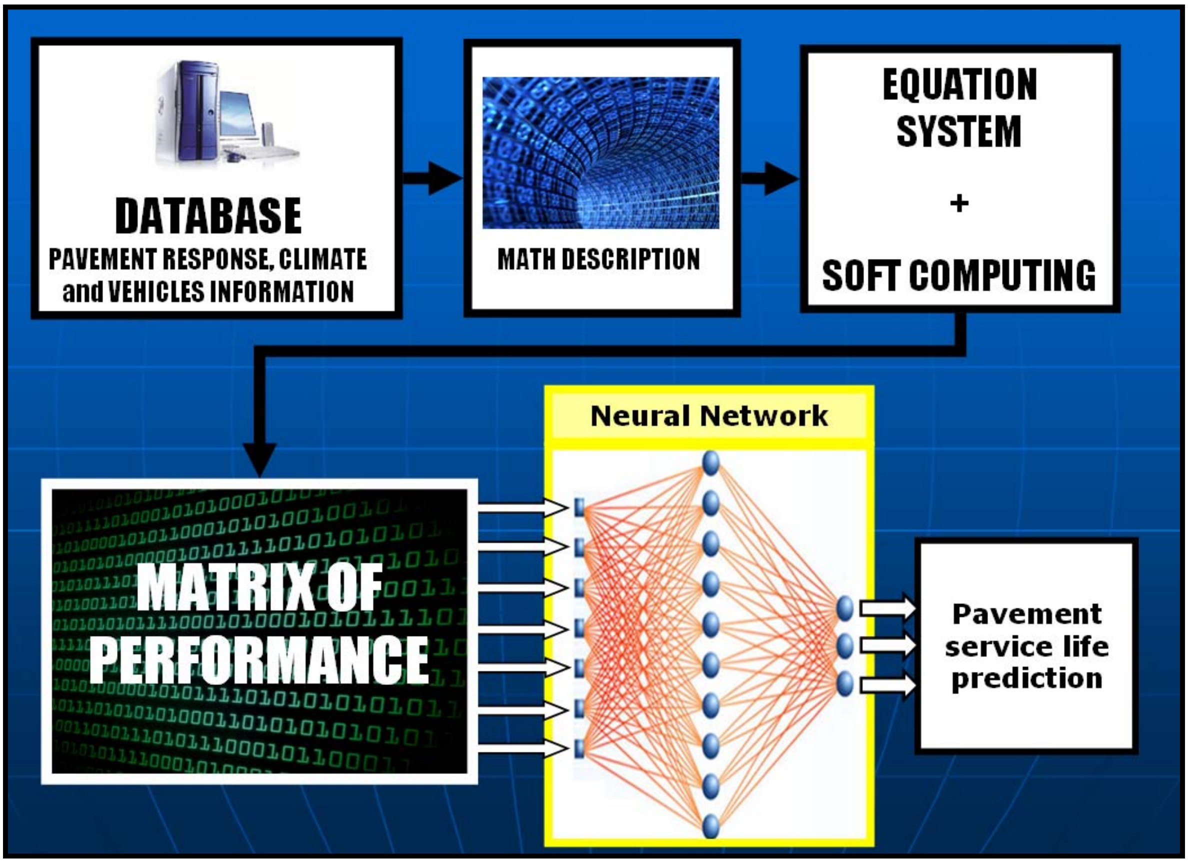


Figure 4: The Database With the History of the Pavement is “Handled”
to Become a Matrix of Performance to Train the Neural Network System

$$\left(\text{Calculated Pavement Damage Index}\right) = \begin{pmatrix}\text{True Pavement} \\ \text{Damage Index}\end{pmatrix} \cdot \text{Error}$$

Figure 5: The Found Pavement Damage Index has an Unknown Error

$$\frac{\text{Pavement Damage Index} \cdot \cancel{\text{Error}}}{\left(\sum(\text{Pavement Damage Index})\right) \cdot \cancel{\text{Error}}}$$

$$\therefore$$

$$\frac{\text{Pavement Damage Index}}{\sum(\text{Pavement Damage Index})}$$

Figure 6: The Error is Divided by Itself and Eliminated

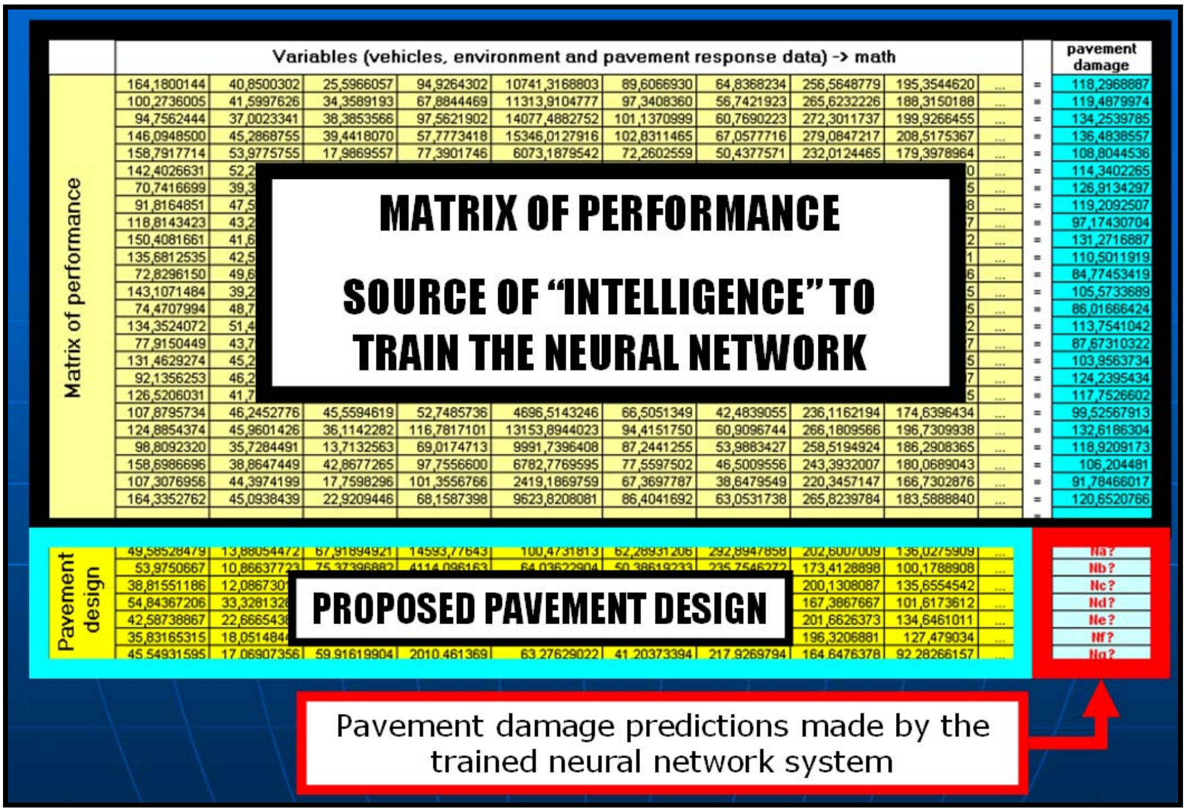


Figure 7: The Neural Network Will be Able to Do Predictions for Problems Proposed in the Exact Same Way Was Described the Initial Database Used to Generated the Matrix of Performance

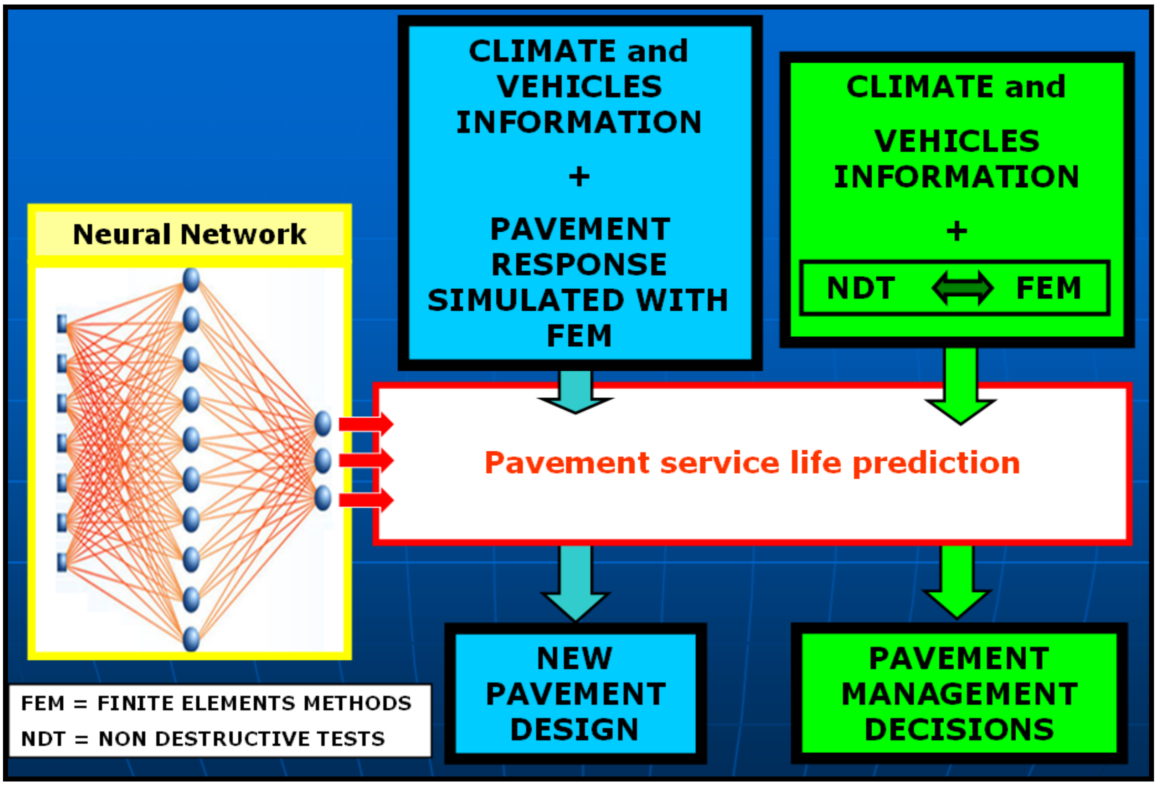


Figure 8: The Trained Neural Network System Will do Predictions About the Service Life for Both, Design New Pavements and Take Decisions in a Pavement Management System

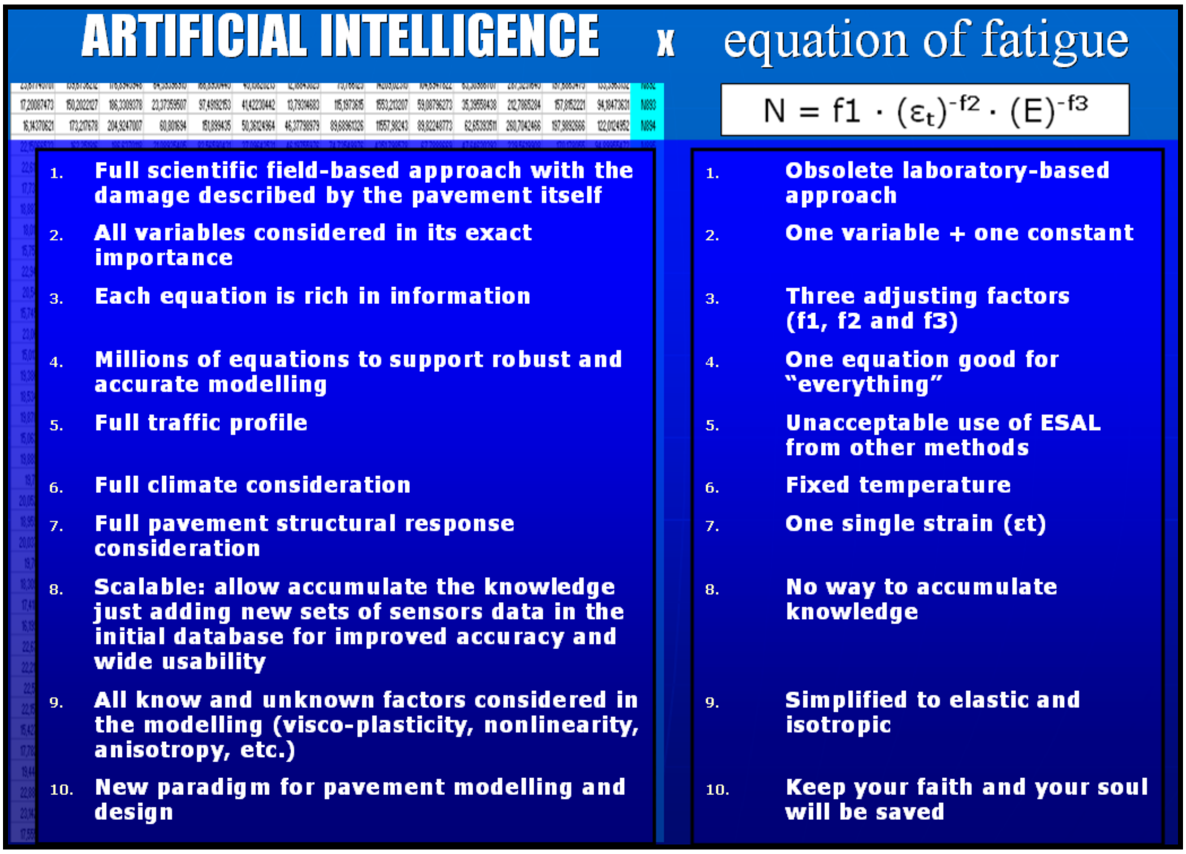


Figure 9: Comparison Between the Modelling Using Neural Network Trained With the Matrix of Performance Against the Current "Technology" of The Equation of Fatigue