USE OF NEURAL-NEUTRAL LOGICAL SYSTEMS FOR EVALUATING THE TECHNICAL CONDITION OF THE MAINLINE LOCOMOTIVE DIESELS ON THE BASIS OF THE PARAMETERS OF THE ENGINE OIL

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Abstract

The article focuses on the use of Sugeno-type adaptive neuro-fuzzy inference systems (ANFIS) for the assessment of the technical condition of mainline diesel locomotive engines, based on the motor oil tribodiagnostic parameters, without engine disassembly. The main engine units, which include the cylinder-piston group, valve-injector group, plain bearings and fuel dilution of oil, are equipped with subsystems designed to be independent of one another. In addition, a comparative study of trapezoidal and Gaussian membership functions for the input variables is given, and the results obtained are demonstrated to be reliable.

Keywords: Mainline diesel locomotive, diesel engine, tribodiagnostics, motor oil, ANFIS, neural-indeterminate network, membership function, integral assessment.

1. INTRODUCTION

Today, the rising demand for greater volumes of freight and passenger trains requires that diesel mainline locomotives are continuously, reliably and safely in operation. The key determinant of the service life and economic efficiency of these locomotives is the technical condition of a diesel engine, which provides the power supply.

Traditional maintenance and repair systems are largely scheduled on preventative maintenance, which may result in disassembly prior to the end of the component's useful life. This leads to too much time, labour and economic costs, in turn.[1]

In the process of diesel engine operation, its main parts (cylinder-piston group, valve-jet group, sliding bearings, etc.) undergo mechanical friction and thermal effects between parts, which inevitably cause wear. The physicochemical properties of used motor oil reflect wear products and the process of wear of the motor oil's working parts. For this reason, tribodiagnostic techniques in the analysis of motor oil, which do not require the disassembly of the motor, are of current importance.

The connection between oil parameters (viscosity, mechanical impurities, acid number, flash point, etc.) and the wear level of engine components is, however, complex and non-linear, and is often fraught with uncertainties. The traditional statistical and deterministic methods are not sufficiently accurate in such multi-dimensional non-linear systems.

In this context it is necessary to use the most recent technologies of modern artificial intelligence, proved to be very accurate in conditions of uncertainty, such as the adaptive neuro-fuzzy logic systems (ANFIS - Adaptive Neuro-Fuzzy Inference System). The primary goal of this research is to create Sugeno-type neural-fuzzy logic models for technical condition evaluation of mainline diesel locomotive diesel engines using tribodiagnostic parameters of motor oil, and to examine their effectiveness.[2]

The difference between the traditional maintenance system and the proposed system is clearly observed in the given comparative diagram of the maintenance system shown in figure 1, which is implemented by taking an oil sample from the engine.

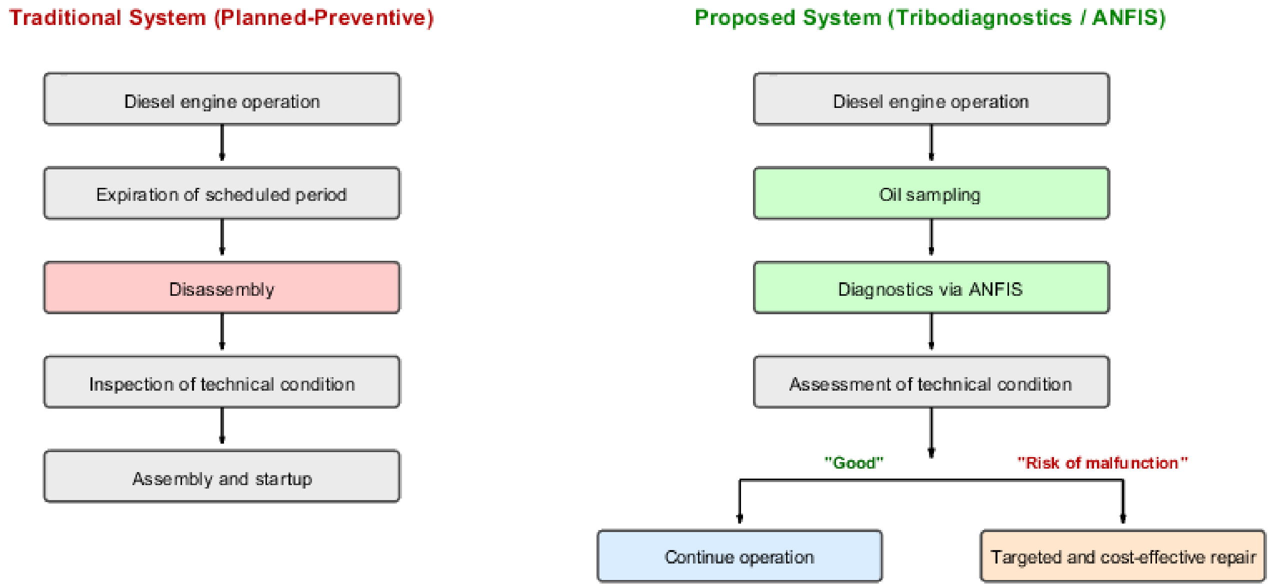

Figure 1. Diagram showing the different maintenance systems.

2. METHODS

2.1. ANFIS architecture and its structure

The architecture of the Adaptive Neuro-Fuzzy Inference System (ANFIS) type 5 layer flexible neural-fuzzy logic network was chosen as the network model to be used for the assessment.The "ANFIS" Adaptive Neuro-Fuzzy Inference System of Sugeno type 5 layer flexible neural-fuzzy logic network was selected as the model of the neural network to be used for the assessment. It is an approach that brings the learning feature of neural networks and the linguistic benefits of fuzzy logic systems together.[3]

The 5-layer architecture of the Sugeno-type adaptive neural-fuzzy logic system used in the study is clearly illustrated in Figure 2.

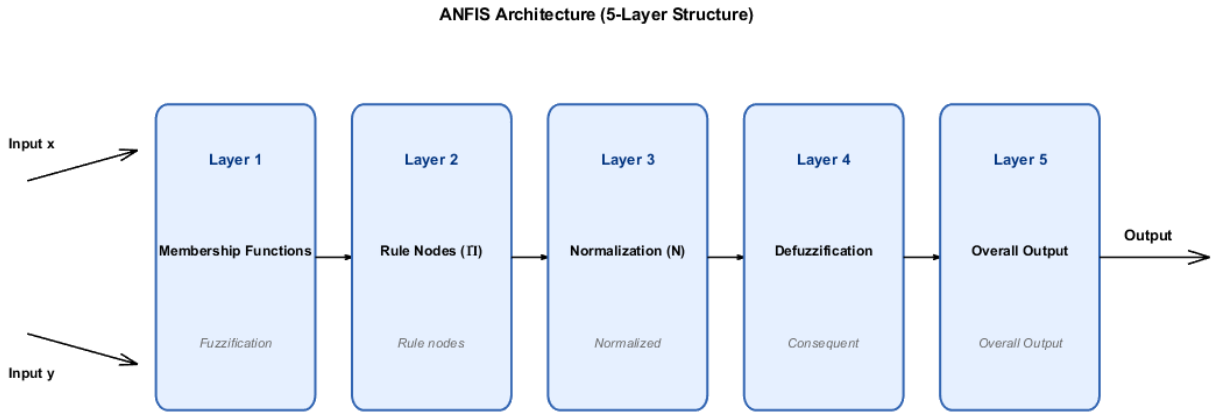

Figure 2. 5-layer ANFIS network architecture of the Sugeno type.

2.2. Diagnostic subsystems and rules database

Four independent diagnostic subsystems have been designed for the main friction pairs and systems of the engine in order to assess the technical condition of the engine completely:

Input parameters used were viscosity, mechanical impurities and acid number, which were assessed using cylinder-piston group (CPG). This subsystem has been built a database of 18 fuzzy rules.

The fuzzy rules were used to create a valve-nozzle group (VNG) model that was based on the mechanical impurities and flash point temperature.

Sliding bearings (SB): A 6-rule system was developed which includes the viscosity and water content parameters.

Oil dilution (OD): Evaluated with 6 rules of flash point/density[4].

The connections between the main engine nodes independent diagnostic subsystems are illustrated in Fig. 3.

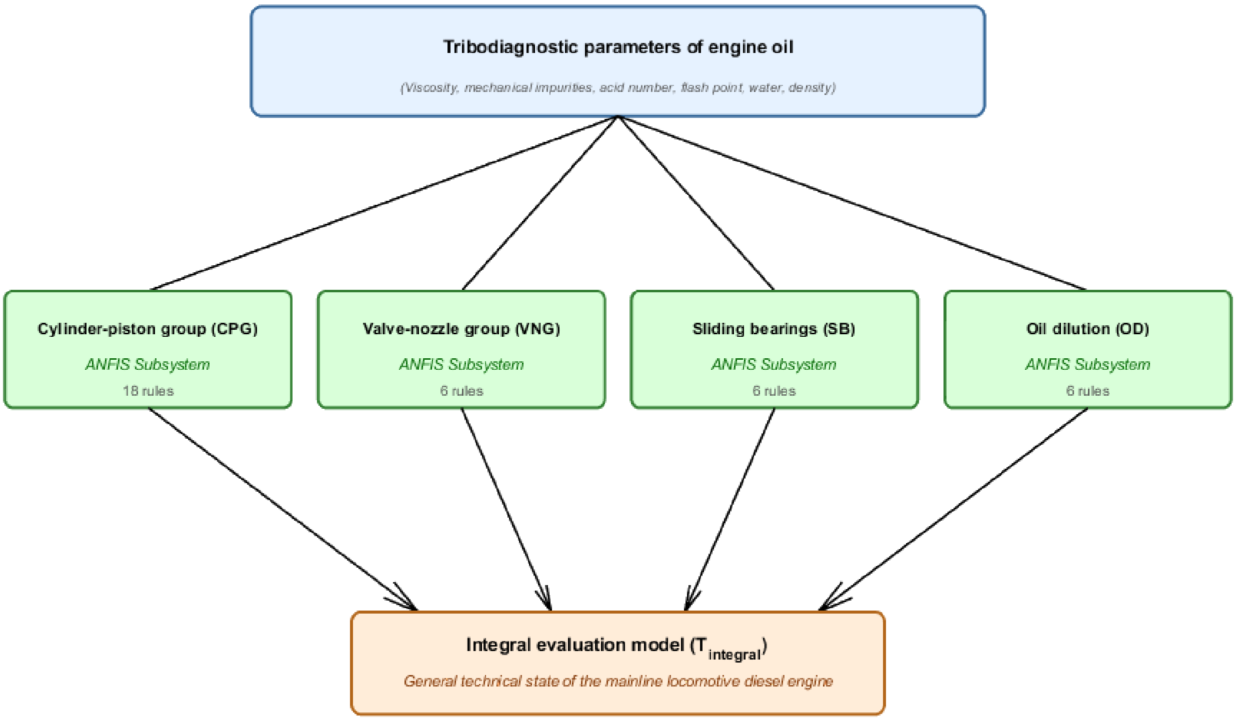

Figure 3. General structural diagram of engine diagnostics subsystems.

2.3. Principles of mathematical and logical modeling

The AND ("and") connective in the fuzzy rule base was realized with the product (algebraic product) t-norm.

For the defuzzification process, the zero-order Sugeno structure and weighted average method were used.

The trapezoidal membership function ("trapmf") and gaussian membership function ("gaussmf") were employed in the analysis of the linguistic values of the input variables.[5]

The graphical presentations of trapezoidal and Gaussian membership functions applied to the evaluation of the linguistic variables in the modeling process are depicted in Figure 4.

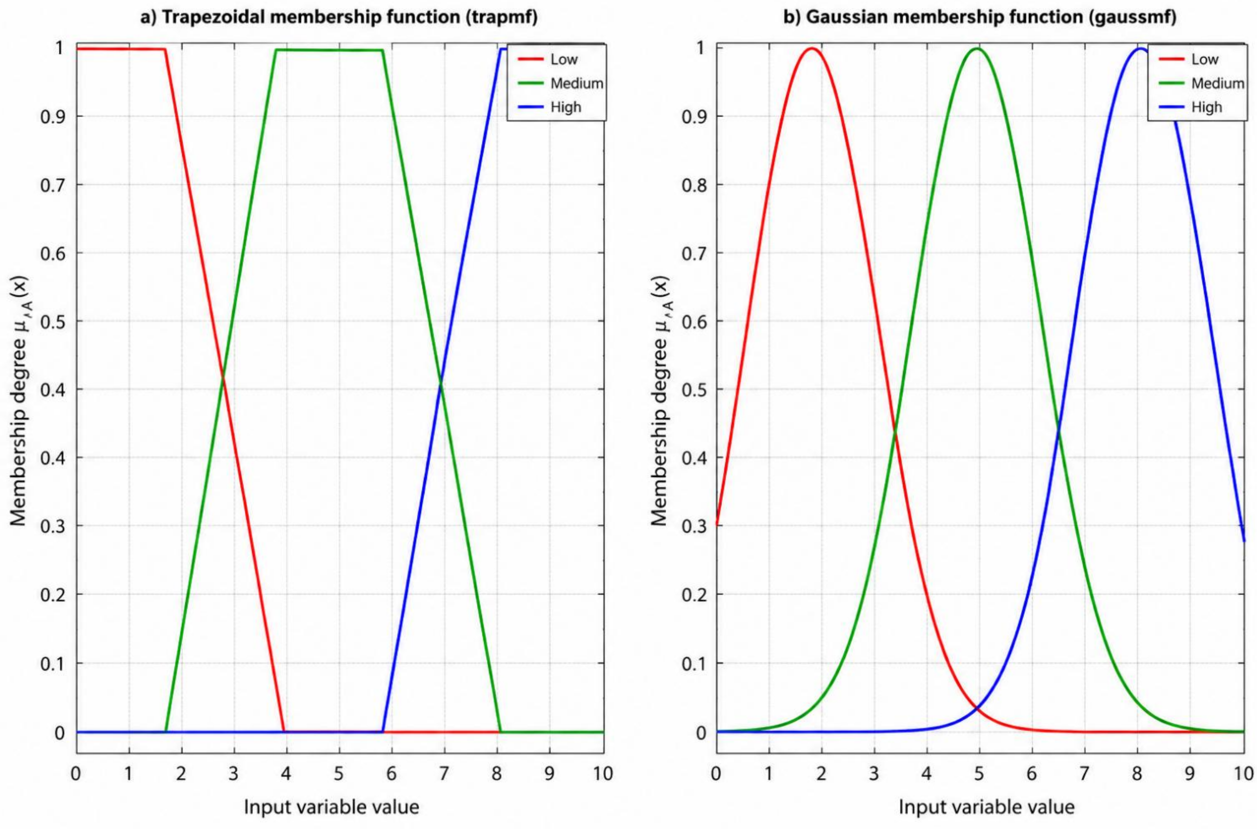

Figure 4. Graphs of the trapezoidal (trapmf) and Gaussian (gaussmf) membership functions

3. RESULTS AND DISCUSSION

3.1. Surface modeling and analysis

The Fuzzy Logic Toolbox MATLAB environment was used to test the Sugeno-type ANFIS models, which provided continuous evaluation values of the main friction pairs and systems of mainline diesel locomotives. The output surfaces (“Surface Viewer”) produced according to the ranges of variation of the input variables showed the following characteristics:

The cylinder-piston group (CPG) showed that the viscosity change of the oil, mechanical contamination and acid number were nonlinear and could be clearly separated using 18 different fuzzy rules to establish lower and upper limits for wear.[6]

Valve-nozzle group (VNG): This allowed for the evaluation of the combined effect of the thermal and mechanical factors when the ratio of mechanical impurities and flash point changed.

It was determined that the values of viscosity (SB) and water content (OD), flash point and density indicators in these subsystems are entirely representative of actual operating conditions.

The 3D surface plots created in the MATLAB environment (Fig. 5) show the technical condition assessment results as a nonlinear response to changes in the input variables.[7]

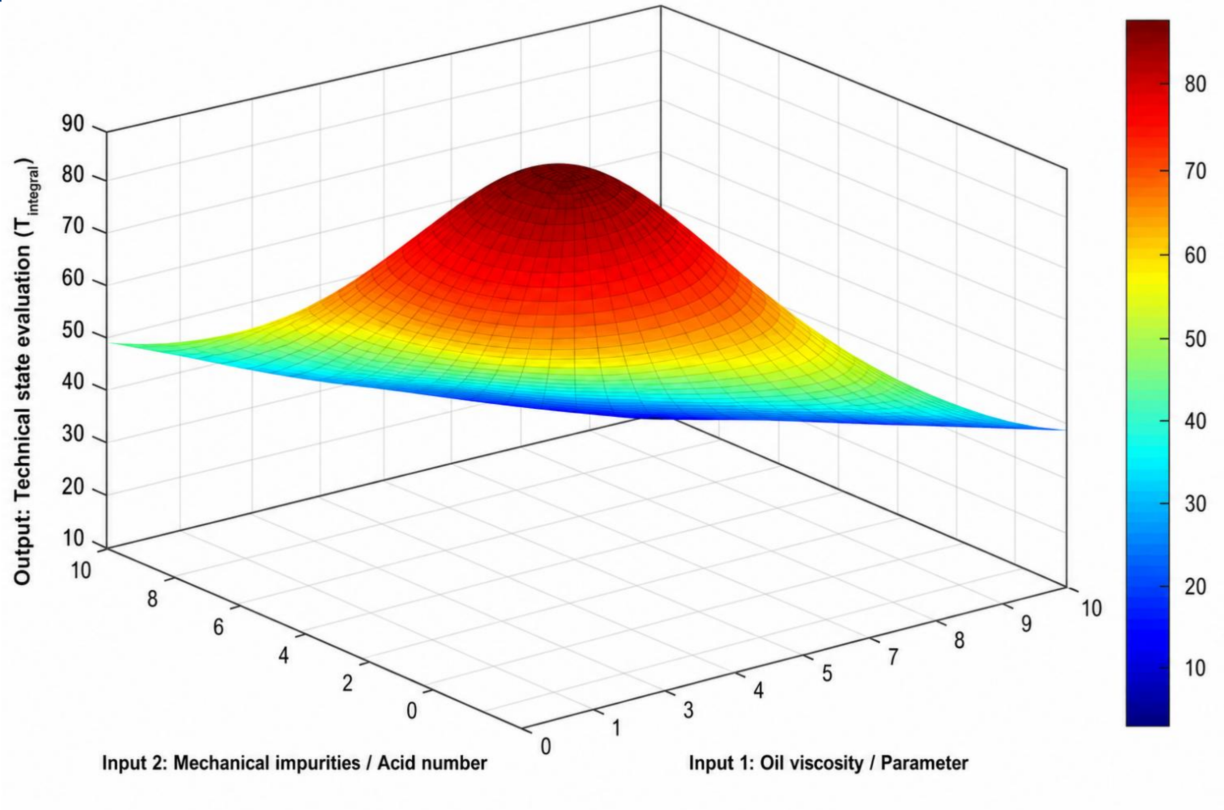

Figure 5. 3D output surfaces generated in the MATLAB Surface Viewer.

3.2. Comparative analysis of membership functions

The influence of trapezoidal (“trapmf”) and Gaussian (“gaussmf”) membership functions for the variables of input were comparatively investigated for evaluating accuracy and stability of the models. These calculations are shown in the table below.

Diagnostic subsystem	Trapezoidal function (trapmf)	Gaussian function (gaussmf)	Distinction (Δ)
Sliding bearings (SB)	2,00	2,00	0,00
Cylinder-piston group (CPG)	1,85	1,86	0,01
Valve-nozzle group (VIG)	2,10	2,12	0,02
Oil dilution (OD)	1,95	1,94	0,01

The comparative analysis result is clearly displayed in the diagram in figure 6, which shows that the difference in the results obtained by both functions is very small.

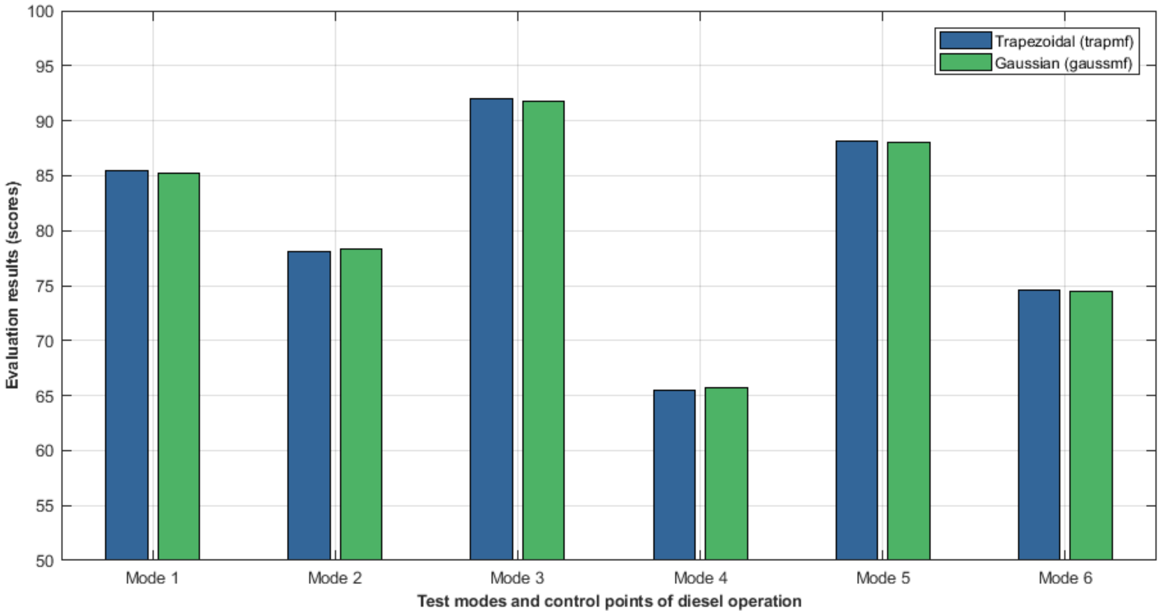

Figure 6. Comparative diagram of the results of membership functions.

3.3. Discussion

The detailed analysis of the results showed that both types of membership functions gave the same result (2.00 points) in the sliding bearing model. For the rest of the subsystems, the gap between the two values calculated with the two functions (trapezoidal and gaussian) was no more than 0.01-0.02 points. The following scientific and technical determination explain this situation:

Trapezoidal functions are very efficient in setting clear limits in regulatory technical documentation and exactly defining linguistic gaps, which are applied near the limits of technical standards.

Gaussian functions are smooth, continuously differentiable functions, which is crucial for the future training of the network using experimental data (“backpropagation”) as these functions guarantee stable convergence, and they create transitions that don't contain sharp jumps.

An integral assessment model ($T_{integral}$) derived from a local scores combination, was developed and used successfully to predict the overall technical condition of mainline diesel locomotives with high precision and reliability, using the expert assessment method. This helps to maximise running costs.[8-10]

4. CONCLUSIONS

The architecture of the adaptive neuro-fuzzy inference system of the Sugeno type with four independent diagnostic subsystems of the main friction pairs has been successfully developed to assess the technical condition of the mainline locomotive diesel engines based on the motor oil tribodiagnostic parameters without dismounting the engine. The membership functions were then compared to determine the difference in output for trapezoidal and Gaussian function membership functions, and it was found that the difference for the membership functions used is negligible (between 0.01 and 0.02 points), proving good stability in the models and the capacity to deliver reliable results in different operating conditions. The proposed neural-fuzzy logic model could help to improve the reliability of the diesel engine, try to predict the trouble in advance, and significantly lower maintenance costs by adopting a "condition-based maintenance" approach instead of a scheduled-preventive maintenance approach. In addition, the model database developed will be a basic platform to process sensor data in real-time and to develop automated diagnostic systems in the future.

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