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DEVELOPING THE OPERATIONAL RELIABITY OF MOTOR VEHICLES

KSZTAŁTOWANIE NIEZAWODNOŚCI EKSPLOATACYJNEJ POJAZDÓW MECHANICZNYCH

Abstract

This article presents a process of developing operational reliability based on damage occurring during operation. A programme operating on the basis of the artificial neural network method was used to determine the probability of damage to selected engine elements. The results calculated in this way may serve as feedback information for the design process, enabling continuous improvement in the quality of the product, i.e. the automobile combustion engine. Factors taken into consideration during artificial neural network construction, the number of inputs and outputs resulting from the number of variables, and the learning algorithm were described.

Keywords: *developing reliability*, *operational reliability*, *artificial neural networks*

Streszczenie

W artykule przedstawiono proces kształtowania niezawodności eksploatacyjnej pojazdów w oparciu o występujące w procesie eksploatacji uszkodzenia. Do wyznaczania prawdopodobieństwa uszkodzeń wybranych elementów silnika wykorzystano program oparty na metodzie sztucznych sieci neuronowych. Obliczane przez niego wyniki mogą służyć jako informacja zwrotna dla procesu projektowania, dzięki czemu możliwe jest stałe podnoszenie jakości produktu, jakim jest samochodowy silnik spalinowy. Opisano czynniki uwzględnione na etapie budowy sztucznej sieci neuronowej, tj. liczba wejść i wyjść wynikające z liczby zmiennych oraz algorytm uczenia.

Słowa kluczowe: *kształtowanie niezawodności*, *niezawodność eksploatacyjna*, *sztuczne sieci neuronowe*

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Designations

ANN – Artificial Neural Network
ECU – Engine Control Unit
MIL – Malfunction Indicator Light
SI – Spark Ignition
OBD – On-Board Diagnostics

1. Introduction

One method of advertising cars used by manufacturers to encourage customers to buy their products is to promote their high reliability. The word ‘reliable’ evokes universal trust, so that the buyer is certain that the vehicle will not malfunction frequently during operation. From the perspective of manufacturers, this assessment is most often qualitative, which is not to say, however, that they do not commission studies and analyses on the subject. A manufacturer can collect and accumulate a great deal of information on the malfunctions and defects of vehicles from their introduction on the market to their use. Warranty repairs and servicing by authorised stations and repair workshops are an excellent source of data. Analysis of damage from a design and construction point of view and identification of the characteristics of reliability enables designers to modernise vehicles and to adapt them in terms of forecasted customer demand [1, 2, 7].

The problem of the flow and application of information between the design stage and stage of use is presented below. The novel element in this work is the proposal for damage prediction through the application of neural networks. This has been presented through a hypothetical example, illustrating the possibility of applying neural networks to the assessment of the operational reliability of vehicles.

2. The process of developing reliability during the stages of design, production, and use

The development of vehicle reliability is inextricably linked to the problems of safety, operational sustainability, and environmental protection. Therefore, strict requirements relating to these problems must be taken into account during the design process. Operational databases, among other things, are sources of information for vehicle designers. They make it possible to establish and adjust repairs and preventive strategies (e.g. instruction manuals and periodical inspections). Operational data is the basis for optimisation, modernisation, and all kinds of improvements implemented through technical, technological, economical, or educational activities, as shown in Fig. 1 [2, 7].

Operational information should enable automotive concerns to make decisions regarding modernisations implemented in design solutions, methods of production, and operational guidelines introduced in new car models. Such changes, once implemented, should guarantee improved reliability and safety, ecology, driving comfort and should also account for the vehicle's serviceability and, in particular, its diagnosability. Information on damage and the subjective opinions of users are essential for the designer and manufacturer.

The identification of damage sustained during car operation makes it possible to determine probabilistic reliability characteristics that are used to plan a series of preventive measures to limit failure frequency. Information about damage resulting from production is used to improve the production process and to improve the production quality of spare parts in terms of quantity and variety. The application of modern materials and technologies providing lightness of construction enables, among other things, reduced operational fuel consumption, improved dynamic and traction properties, and the elimination of corrosion-related problems.

One visible effect of these activities is the improved reliability of vehicle parts subjected to modification in successive production lots. In turn, the implementation, for example, of a powertrain designed from the ground up, starts the process of accumulating operational information and is linked to the necessity of keeping damage statistics and of implementing improvements in those parts and components tending to fail more frequently, until the appropriate level of reliability is attained.

With regard to the introduction of the Euro III exhaust emissions standard in 2000, all cars sold in the territory of the EU are equipped with an OBD, the function of which is to monitor systems responsible for emissions of harmful substances in exhaust fumes. When emissions are exceeded by over 50%, the driver is informed by an appropriate message [8].

However, damage to some components is often so insignificant (and does not cause an increase in emissions over 50%) that it remains unnoticed or is ignored by the user. This can be termed a state of partial unserviceability. Further operation in such a state may not only

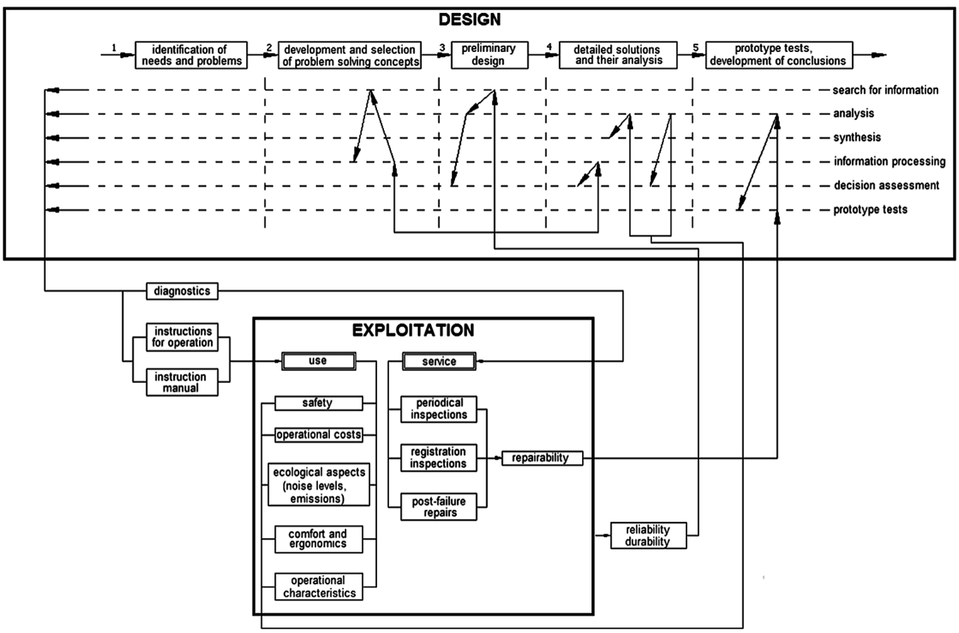

Fig. 1. Informational structure between the design and operation of a motor vehicle

cause an increase in emissions of harmful substances in exhaust fumes but can also be related to more serious damage, causing the engine to be completely unserviceable in the future and leading in turn to significant vehicle repair costs. This is why it is so important to detect and repair any damage as quickly as possible. Diagnostic testers enabling fast detection of damage based on information recorded in the ECU as so-called ‘freeze frames’, in which engine operating parameters at the time of failure are saved, play an important role in this process and facilitate the localisation of the failure [2, 8].

The illustration in Fig. 1 shows the design stages at which, and purposes for which (design function), operational information is used, as well as at which of these stages determinations concerning operation are made (operating instructions, instruction manuals, preventive procedures). It should be noted that operational information from the same group (e.g. reliability and durability indices) may be used several times in order to adjust the project as it is developed in more detail. Some of the most important qualities related to vehicle operation include safety, operating costs (fuel consumption), ecological aspects (noise level, emissions), aesthetics, comfort, and ergonomics. User requirements in this area are paramount in the design and modernisation of vehicles. Periodical inspections, registration inspections, and post-failure repairs are distinguished in the servicing subsystem. Operational data in this area makes it possible to fine-tune rational repair strategies.

Correctly established schedules of service activities and post-failure repairs constitute the principal elements of developing the operational reliability of a vehicle.

3. Determination of the probability of damage through selected elements of a combustion engine using an artificial neural network

A combustion engine is a complex technical object with a mixed reliability structure. When it reaches the customer, it is assumed to have a certain quality and related reliability. Early detection of damaged engine components and fittings makes it possible to limit an engine’s destructive influence on other units, which leads to the improvement of engine reliability as a whole over the long term.

The purpose of applying the method of ANN [3–6] for damage detection based on various types of symptoms is to restore the engine to a state of full serviceability and to improve reliability during its further operation.

Based on information concerning damage contained in the databases of authorised vehicle service stations, a program using the ANN method can be developed to calculate the probability of damage being sustained by selected engine parts based on symptoms reported by the customer and error messages saved in the on-board computer. It can indicate the location of the malfunction in conditions where knowledge about the failure is incomplete.

At the same time, results obtained by the described method may be used as feedback for designers who program an engine’s reliability during the design stage by implementing specific changes in its construction. This method may be particularly helpful in cases where the error code is not saved in the controller, and the failure is signalled only by subjective symptoms reported by the user or detected during a road test.

The following factors were accepted as malfunction criteria in the presented programme:
- the MIL lamp is lit,
- problems with starting the engine,
- starting the engine is impossible,
- uneven operation in neutral gear,
- uneven operation when load is increased,
- loss of power or stalling,
- limited engine power,
- increased fuel consumption.

Based on the symptoms listed above, the probability of damage being sustained by the following engine parts/subassemblies is calculated (with consideration of the power and exhaust system):
- engine temperature sensor,
- electric fuel pump,
- electronic throttle valve,
- ignition coil,
- spark plugs,
- oxygen sensor.

The ANN (Fig. 2) must be trained with a data set pertaining to one specific power train of a selected manufacturer from a specific production period. In the described case, the analysis concerns the SI combustion engine used in vehicles of a well-known brand that is achieving very good sales results in Poland. Thanks to the large number of vehicles of this brand serviced at authorised service stations, it is possible to collect an appropriately large data set that enables effective learning for the ANN [3]. Based on the electronic data archiving system used by service stations, information on damage symptoms and effective repairs can be obtained. In the described case, a set consisting of 100 data batches was created: *symptoms – damage*. Selected examples of damage are given in Table 1 and 2.

Table 1

Symptoms registered by the user (selected data from the training set)

	Variable / measurement number	1	2	3	4	5	…	100
1	The engine MIL lamp is lit				x			
2	Problems with starting the engine	x						x
3	The engine cannot be started							
4	Uneven operation in idle gear	x	x					
5	Uneven operation when load is increased	x		x	x			x
6	Loss of power or stalling					x		x
7	Limited engine power							
8	Increased fuel consumption						x	

Table 2

Damage to engine elements corresponding to the symptoms from table 1

	Variable / measurement number	1	2	3	4	5	…	100
1	Engine temperature sensor							
2	Electric fuel pump	x				x		
3	Electronic throttle valve		x					
4	Ignition coil				x			
5	Spark plugs			x				x
6	Oxygen sensor						x	

In the described case, the user interface of the program is of particular significance (for the mechanic performing repairs as well), so it was assumed that the user will respond to questions concerning symptoms. It was assumed that one of three answers is given to a question about symptoms: *yes*, *no*, or *partially*, which correspond to the following values of network inputs: 1, 0, 0.5. In turn, the result is given as the probability of damage of each element in the selected group (values in the range of (0; 1)).

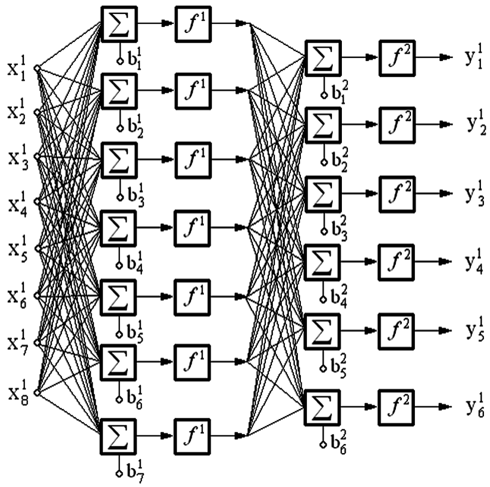

Fig. 2. Structure of the ANN used to calculate the probability of damage of engine parts

A learning set consisting of 100 data batches was used to train the ANN. During the learning process, the network learns real-life cases and approximates this data, thanks to which it can calculate the probability of damage to elements for symptoms that were not previously registered and that may arise during future operation. The minimisation of error in the learning process is a measure of its efficiency and makes it possible to state whether data approximation is proceeding correctly. The learning process is considered complete when the mean square error is not reduced in over a dozen successive learning steps (Fig. 3).

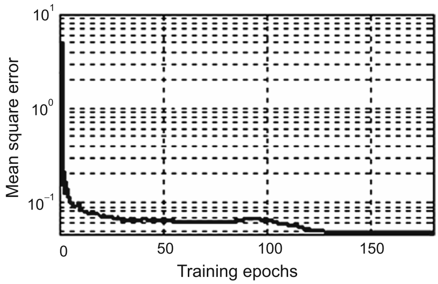

Fig. 3. Graph of the mean square error during the training process

When the learning process is complete, weights have constant values and the network can be simulated by any input parameter values.

4. Evaluation and shaping of operational reliability

Identification of a damaged part based on the diagnostic program using the ANN method makes it possible to locate damage, making it possible to perform quick repairs to restore vehicle serviceability. Data obtained during performed repairs may constitute feedback for possible design changes in the scope of production and operation (Fig. 4).

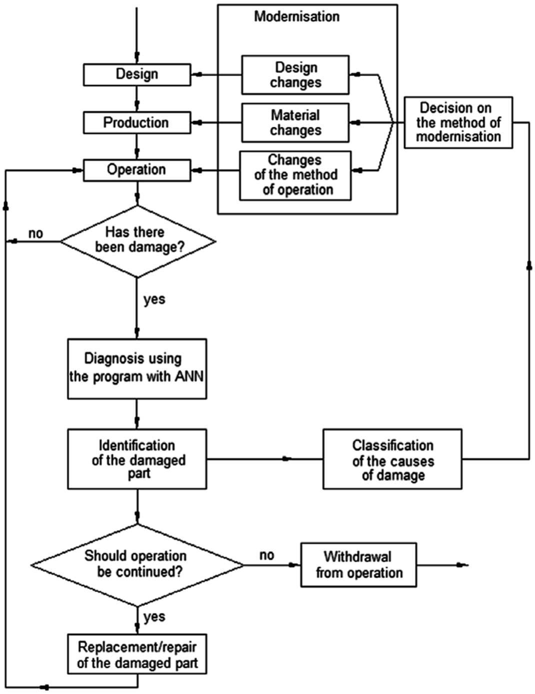

Fig. 4. The role of the diagnostic programme based on ANN in the modernisation of engine design

On one hand, this method enables fast detection and repair of current damage, thanks to which more serious malfunctions during further operation are prevented, and on the other hand, it provides feedback for the processes of design, production, and operation (Fig. 4), which leads to improvement of reliability parameters in successive modernised production series of a given powertrain.

5. Conclusions

Manufacturers aim at producing appropriately reliable vehicles, among other goals. Vehicles should not be subject to frequent failures during the warranty period, or as long as the design and technological solutions fulfil ecological requirements and safety standards. Following the operating period planned by the manufacturer, the vehicle should be withdrawn from operation. One effective method of forcing users to replace a vehicle with a new one is the uneconomical nature of further use caused by more frequent failures, combined with a customer-friendly price policy employed by manufacturers regarding exchanges and sales of new vehicles. Such a policy guarantees a continuity of vehicle sales and production that satisfies the automotive industry.

The implementation of such a policy is possible if operational studies of vehicles and the assessment of their operational reliability is conducted in accordance with the procedures and standards established by specialists concerned with the reliability of technical devices.

In this area, this work constitutes a contribution to the development of the analysed subject matter.

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